



ENVIRONMENTAL IMPACT STATEMENT

Nautilus Minerals Niugini Limited

Solwara 1 Project

Volume A
Main Report

Text

September 2008

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VOLUME A: MAIN REPORT TEXT

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A	Risk Register
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Environmental Impact Statement
Solwara 1 Project

1. INTRODUCTION

1.1 Background

Nautilus Minerals Niugini Limited (Nautilus) is advancing a proposal to develop the Solwara 1 Project ('the Project'). The development involves world-first mining of high-grade polymetallic Seafloor Massive Sulphide (SMS) deposits that are located at approximately 1,600 m water depth on the floor of the Bismarck Sea, New Ireland Province, Papua New Guinea (PNG), about 50 km north of Rabaul (Figure 1.1). SMS deposits are associated with hydrothermal vent systems and are considered modern-day analogues of Volcanogenic Massive Sulphide (VMS) deposits that have historically been major sources of the world's copper, zinc, gold and silver.

The Project comprises two phases and it is proposed to develop Phase 1 in advance of Phase 2. The two Project phases can be summarised as follows:

- **Phase 1.** The initial phase of the Project involves recovering copper-, gold-, zinc- and silver-rich SMS ore deposits from the ocean floor using a Seafloor Mining Tool (SMT) deployed from a Mining Support Vessel (MSV). Ore mined by the SMT will be pumped to the MSV via a riser and lifting system (RALS). Once at the surface, the ore will be dewatered and barged to a temporary holding facility at the Port of Rabaul and then shipped overseas to a processing facility and smelter.
- **Phase 2.** The second phase involves treating the recovered materials locally in PNG and a feasibility study will commence when Phase 1 has demonstrated the extraction and recovery process and the Project has successfully achieved commercial production. The dewatered ore mined from the seafloor will be barged to the concentrator (the preferred location within PNG is yet to be finalised) for processing and the concentrate then shipped to an overseas smelter.

Phase 1 and Phase 2 of the Project will be addressed in separate environmental impact statements (EISs). This EIS addresses Phase 1 only and therefore Phase 2 will not be discussed further.

Nautilus, the Project Operator, has prepared this EIS as the statutory basis for the environmental assessment of the Project. This will enable a ministerial decision on whether the Project should proceed and, if so, under what conditions. Coffey Natural Systems Pty Ltd (Coffey) was commissioned to assist Nautilus in the preparation of this EIS.

The EIS is founded on a series of supporting studies (see Section 1.6.4). Hard copies of the EIS can be obtained on request from:

Mr Mel Togolo
PNG Country Manager, Nautilus Minerals Niugini Limited
Level 1, Deloitte Tower, Douglas Street
Port Moresby, NCD, Papua New Guinea

The EIS sets out a development proposal intended to enable engineering, cost, environmental, commercial and social implications to be assessed by:

- The Project proponent (see Section 1.3) in their decision to sanction the Project to proceed.
- The public in formulating their responses to the EIS.
- The relevant government agencies of the Independent State of Papua New Guinea in evaluating the Project's public interest credentials and in formulating conditions under which it might proceed.

The development proposal will continue to evolve as engineering work proceeds through the detailed design phase. Nautilus does not expect these changes to materially affect the conservative findings of this EIS but will assess these variations as a matter of course and report any potentially significant change to the relevant government agencies.

1.2 Project History

Initial discovery of seafloor hydrothermal vent activity in the Bismarck Sea occurred in 1985 when the US research vessel *RV Moana Wave* photographed sulphide deposits on the northern portion of a geological feature known as Manus Ridge. The vent field, now known as Solwara 2, lies approximately 200 km west-northwest of Solwara 1.

Subsequent to the discovery of Solwara 2, eleven additional hydrothermal vent systems have been discovered in the Bismarck Sea during numerous international scientific research cruises. Solwara 1, located in the Eastern Manus Basin, was discovered in 1996 by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) during their PACMANUS III cruise.

Several sulphide samples were collected from Solwara 1 during a number of scientific cruises in the late 1990s. Analysis of samples indicated very high grades of copper, gold and silver and, based on these findings, Nautilus applied for an exploration licence over Solwara 1. On 28 November 1997, Nautilus was granted Exploration Licence (EL) 1196, allowing exploration to commence at Solwara 1.

Initial commercial exploration at Solwara 1 occurred in early 2005, when Placer Dome Oceania Limited, as part of a Farm-In Agreement with Nautilus, completed a deep tow, side scan sonar and lister dredge sampling program. Bulk sampling and ship-based drilling followed in early 2006. During this campaign, simultaneous biological and physical environmental characterisation of Solwara 1 commenced.

In mid 2006, Nautilus recovered all exploration rights from Placer Dome Oceania Limited and undertook further exploration and scientific work. A scientific cruise with Woods Hole Oceanographic Institute in August 2006, and a six-month exploration and environmental investigation campaign in 2007 allowed further geological characterisation of the mineral resource and EIS characterisation studies to take place.

Results from the geological investigations of the sulphide deposits at Solwara 1 have confirmed the presence of copper and gold in grades high enough to allow commercial development to proceed. Nautilus has committed to developing the Project, subject to obtaining the required approvals, and engineering design has proceeded in parallel with the preparation of this EIS.

1.3 Solwara 1 Project Proponent

The development of the Solwara 1 Project is being proposed by Nautilus, its consultants and contractors. Nautilus is a wholly owned subsidiary of Nautilus Minerals Inc., a publicly traded company listed on the Toronto (TSX) and the London (AIM) stock exchanges.

Among Nautilus' cornerstone shareholders are three of the world's largest resource companies, namely Anglo American (5.7%), Teck Cominco (7.2%), and Epion Holdings (22.4%).

Within PNG, Nautilus holds exploration licences in the Bismarck and Solomon Seas totalling 51 granted exploration licences, covering 107,917 km², and 37 exploration licence applications, covering 88,906 km². Outside PNG, Nautilus holds granted prospecting licences in Tonga and the Solomon Islands and has applications pending in Tonga, Fiji and New Zealand.

1.4 Purpose of the Development

The proposed development will mine SMS deposits from the seafloor at Solwara 1 and focus on the recovery of copper and gold using methods that are environmentally responsible, socially acceptable, technologically achievable and economically viable. The Project will implement the PNG resource development policy in a manner consistent with current legislation that enables the Project to proceed whilst appropriately regulating its development and impacts. The Project is consistent with the Fourth National Goal and Directive Principle of the Constitution of PNG, which states:

We declare our Fourth Goal to be for Papua New Guinea's natural resources and environment to be conserved and used for the collective benefit of us all, and be replenished for the benefit of future generations.

Seafloor mining presents a potential new source of income and growth for PNG from a resource that has yet to be utilised. The Project will bring benefits in the form of:

- Training and employment opportunities for PNG citizens.
- Opportunities for local businesses to provide goods and services to the Project.
- Monetary benefits such as taxes, royalties, fees and compensation payments.
- Ongoing generation of human and financial capital in PNG, which will underpin further economic and social development in PNG.
- Improvements in the nation's balance of trade, infrastructure development and commercial, employment and educational opportunities.

In particular, these benefits would be maintained for the nominal Project life and beyond. Stakeholder consultation has indicated that the Project has good support in the region.

Seafloor mining also presents a possible source of resource development and industry diversification for PNG. Nautilus has exploration interests throughout the Bismarck and Solomon seas and will seek to continue seafloor mining in PNG if this Project is successful.

1.5 Environmental Settings and Issues

There are a number of aspects of the Project that set it apart from other mining projects worldwide.

First of all, it is relatively small scale; there is no need for large-scale site preparation or construction of complex facilities, and no direct landowner issues. Instead, its footprint is principally that of a single mining vessel (with attendant support vessels) and precision mining machinery operating on a target area of just 0.112 km² of seafloor. The Project proposes the first-ever attempt to commercially develop SMS deposits, including small areas of active mineralised chimney habitats and their associated colonies of hydrothermal vent fauna. Understanding the impacts of mining on these biological communities is the fundamental environmental issue for the Project.

In an effort to enhance scientific knowledge while meeting the needs of this EIS, Nautilus has engaged international scientific experts to design and conduct environmental studies at Solwara 1 and the surrounding area. In addition, Nautilus has provided the oceanographic and deep sea sampling platforms required to conduct this work.

The facilities required for the environmental research comprise the same basic platform of vessel and remotely operated vehicle (ROV) seafloor sampling equipment utilised for mineral exploration of the seafloor. Consequently, the proposed mine site at Solwara 1 and a reference site 2 km to the southeast have become the most intensively studied hydrothermal areas in the region. In particular, sampling by ROV enables visual and manipulative precision in sampling (e.g., of sediments and animals, even down to selected species and individuals) that is impossible by remote grab sampling from surface, however sophisticated the equipment.

The application of complex ship-borne technology is not limited to exploration and baseline studies. Once in operation, the mining process provides a larger but similar vessel and ROV platform for continuing environmental monitoring work, allowing validation of predictions and effects of mitigation measures. These are developed in detail in the ensuing sections of this EIS. The fact that mining cannot exhaust the underlying geothermal energy that drives the formation of the chimneys and sulphide deposits is unique to this Project and this, combined with the precision abilities of the ROVs, offers opportunities to enhance recovery. These too are explored in this EIS.

In comparison with typical EISs for land-based projects in PNG, the offshore location of the Project has necessarily shifted the consultative focus from landowner issues (as there are no direct impacts) to the more international scientific input described above. Nevertheless, consultation with governments, regional communities in New Ireland and East New Britain and other offshore resource users has been followed throughout the impact assessment process to ensure awareness of the fundamentals of the Project, particularly those that differentiate it from other projects, and to provide the forum for raising and receiving responses to concerns.

All of the factors mentioned in this section have defined the conduct of the baseline studies and consultation plans and Nautilus' approach to the EIS.

1.6 This Report

1.6.1 Approach to EIS

The approach to this EIS necessarily reflects the Project characteristics, and the proposed studies and assessments were described in the Environmental Inception Report (Enesar, 2007), which was approved by DEC in May 2007. Detailed and well-planned studies are required in order to understand the pre-development environment to allow an assessment of expected impacts and to propose effective mitigation and management measures.

To accomplish this, Nautilus has engaged with international experts and non government organizations (NGOs) which, via workshops and consultation, have provided input into identifying the main areas of concern, and the studies needed to address those issues. Nautilus has dedicated vessel and ROV time specifically for the use of deep sea hydrothermal vent specialists in completing the baseline surveys, some of which have extended into a broader acquisition of knowledge and publishable scientific research.

The reports of these studies are included as supporting documents in the appendices (Volume B of this EIS), with summaries given in Chapter 7. While the impacts to the seafloor and its hydrothermal chimneys have been identified as the main defining issue for this Project, Chapter 7 also includes all other descriptions of existing environment, including meteorology, air quality, oceanography, water and sediment quality, mid-water and surface-water biology, resource use and occurrence of large marine mammals and turtles.

The offshore components of the Project have no impacts to landowners. Nevertheless, social awareness and general acceptance of the Project will be important for successful operation. Nautilus has maintained regular contact with regional stakeholders and government agencies from New Ireland, East New Britain and Port Moresby to keep them informed of Project development progress and to understand any concerns. Meetings have been held regularly over the past two years to maintain this contact and consultation is described in Chapter 4. The general demographic characteristics of the Project area are described in Chapter 8, together with the issues raised at these meetings and how they have been addressed. Most have related to distribution of benefits and access to fisheries resources.

The process of impact assessment was approached first through an internal risk assessment of issues at each engineering step of the process. The results of this provided the initial assessment of potential hazards, impacts, mitigation strategies and severity of residual effects. This was further developed at the April 2008 workshop held in San Diego, USA, where input was provided by an international team of scientists on appropriate mitigation measures aimed at protecting biodiversity of the Solwara 1 area. These measures have been adopted and proposed by Nautilus. Chapter 9, Offshore Environmental Impacts and Mitigation Measures, is structured in three parts: a) the main issues, b) proposed mitigation measures and c) the residual effects after mitigation measures have been implemented. This mirrors each of the sections in Chapter 7 and covers all operational aspects of the Project. Residual risks are assessed in terms of the scale and duration of impact. The equivalent for social issues is provided in Chapter 10.

The final chapters of the EIS cover accidental and natural hazards, such as volcanic eruptions, earthquakes and tsunamis (Chapter 11), greenhouse gas and climate change (Chapter 12), and environmental management, monitoring and reporting (Chapter 13). Much of the environmental management and monitoring programs emerged from the San Diego workshop, where impacts were considered as 'impact hypotheses', testable in the binary sense that a predicted condition would or would not occur. This has set the framework for the monitoring tasks and, while details of locations of sites and frequencies are yet to be provided, Chapter 13 comprises a comprehensive set of conditions for pre-operational baseline and ongoing operational (and post-operational) monitoring tasks.

A detailed list of the EIS structure is provided in Section 1.6.4.

1.6.2 Statutory Context

For new mineral development projects in PNG, the proponent is required to meet the applicable PNG laws and regulations. In November 2000, the PNG Government approved the *Environment*

Act 2000, which was implemented with its associated regulations in January 2004. The Project is a Level 3 activity under the *Environment Act 2000* (Sub-Category 17), for which an Environmental Impact Statement (EIS) is required to be submitted to the Department of Environment and Conservation (DEC).

This report constitutes the EIS for the Phase 1 of the Project. The EIS process is described in Section 3.1.

1.6.3 EIS Scope

This EIS seeks approval to construct and commission both the onshore and offshore components for Phase 1 of the Solwara 1 Project.

1.6.4 Report Structure

The EIS is presented in three volumes:

- A stand-alone executive summary, prepared in English and Pidgin that provides a summary of the proposal.
- A main report (this report, Volume A), intended to be a stand-alone document that can generally be understood without reference to the technical reports upon which it is based.
- A volume (Volume B) comprising the technical reports generated by the various investigations supporting the EIS. These reports are appendices to the main EIS report.

The EIS does not disclose information that is confidential for cultural or commercial reasons, but Nautilus may provide the latter in confidence to DEC upon request.

The main report comprises 16 chapters, as well as a table of contents that outlines figures, tables and plates in the relevant chapters. The references include bibliographic details for each source cited in the main report.

The format of the main report is:

- Chapter 1 – (this chapter) provides background and purpose of the development and structure of the EIS.
- Chapter 2 – details the viability of the Project, including the proponent's credentials, feasibility investigations and compatibility with PNG Government objectives.
- Chapter 3 – provides an overview of PNG legislative requirements, legal administration, international agreements and other guidelines applicable to the Project.
- Chapter 4 – describes the consultation program that has been undertaken and is ongoing for the Project.
- Chapter 5 – describes the proposed Project including both onshore and offshore elements and alternatives considered.
- Chapter 6 – the proposed timetable for implementation of the Project.
- Chapter 7 – describes the existing environment within and around the Project area.
- Chapter 8 – describes the socioeconomic situation in the Project area.

- Chapter 9 – documents potential environmental issues, the approach and nature of various investigations, mitigation and management measures and assessment of residual impacts.
- Chapter 10 – documents the potential socioeconomic impacts, the approach and nature of various investigations, mitigation and management measures and assessment of residual impacts.
- Chapter 11 – details potential natural hazards, accidents and corresponding safeguards.
- Chapter 12 – details Project greenhouse gas emissions.
- Chapter 13 – provides a summary of Nautilus' proposed environmental management policy and an outline of the proposed monitoring and reporting activities.
- Chapter 14 – details the individuals who contributed to the preparation of the EIS.
- Chapter 15 – bibliographic details of each reference used in the main report.
- Chapter 16 – glossary.

The supporting studies that are appendices to the main EIS report are set out in Table 1.1.

Table 1.1 Solwara 1 Project EIS – Supporting Studies

Appendix Number	Supporting Study Title	Author
1	Baseline Environmental Study Eastern Manus Basin, Papua New Guinea – Module 1 Preliminary Scoping Study	CSIRO Division of Exploration and Mining
2	Baseline Environmental Study Eastern Manus Basin, Papua New Guinea – Module 2 Detailed Scoping Study	CSIRO Division of Exploration and Mining
3	Oceanography at Solwara 1	Coffey Natural Systems
4	Characterization and comparison of macrofauna at inactive and active sulphide mounds at Solwara 1 and South Su (Manus Basin)	Duke University Marine Laboratory
5	Macroinfauna of Active and Inactive Hydrothermal Sediments From Solwara 1 and South Su, Manus Basin, Papua New Guinea	Integrative Oceanography Division – Scripps Institution of Oceanography
6	Quality Including Trace Elements of Sediments from the SuSu Knolls, Manus Basin, Bismarck Sea, Papua New Guinea	Department of Geology, University of Toronto
7	Water and Sediment Characterisation and Toxicity Assessment for the Solwara 1 Project	CSIRO Land and Water Science
8	Juvenile Amphipod Whole Sediment Test Report	CSIRO Land and Water Science
9	Elutriate Testing Report Solwara 1 Project, Incorporating Phase 1: Effect of Holding Time; Phase 2: Effect of Temperature	Charles Darwin University
10	Biomass, Biodiversity and Bioaccumulation Desktop Study	Hydrobiology Pty Ltd
11	Modelling the Dispersion and Settlement of Sediment Removal Operation Prior to Mining at the Solwara 1 Mining Lease, Papua New Guinea	Asia-Pacific ASA

Table 1.1 Solwara 1 Project EIS – Supporting Studies (cont'd)

Appendix Number	Supporting Study Title	Author
12	Modelling the Dispersion of the Returned Water Discharge Plume from the Solwara 1 Seabed Mining Project Manus Basin, Papua New Guinea	Asia-Pacific ASA
13	Prediction of underwater noise associated with a proposed deep-sea mining operation in the Bismarck Sea	Curtin University of Technology – Centre for Marine Science and Technology
14	The Potential for Natural Disasters being Triggered by Mineral Extraction at the Solwara 1 Seafloor Hydrothermal Vent Site	Rabaul Volcanological Observatory
15	Stakeholder Consultation	Coffey Natural Systems

1.7 Areas Defined

This EIS discusses the issues and impacts associated with the Project in a range of spatial contexts that are set out below and outlined below.

- Solwara 1, North Su and South Su - the areas defined as Solwara 1, North Su and South Su are shown in Figure 1.2.
- Barge corridor and crew transfer routes – barge and crew transfer routes that will be used during operations are shown in Figure 1.3.
- Port of Rabaul - project facilities to be used during operations at the Port of Rabaul are shown in Figure 1.3.

2. VIABILITY OF THE PROJECT

2.1 Proponent's Credentials

Nautilus Minerals Niugini Limited (Nautilus) is a wholly owned subsidiary of Nautilus Minerals Inc., a publicly listed company on the Toronto (TSX:NUS) and London (AIM: NUS) stock exchanges with interests in the commercial exploitation of seafloor SMS deposits.

The Project first received international attention in 1997 when the PNG Government granted the world's first exploration licence (EL 1196) for Manus Basin SMS deposits to Nautilus. After limited exploration activities in the following years, Nautilus (then known as Nautilus Minerals Corporation Limited) negotiated a Farm-In Agreement with Placer Dome Oceania Limited (PDOL) (wholly owned by Placer Dome Inc. [PDI]) in 2004, in which PDOL committed to earning a percentage of the Nautilus projects via specific expenditure. Successful exploration programs were subsequently completed by PDOL in early 2005 and 2006.

Barrick Gold Corporation (Barrick) acquired PDI in early 2006 and, in July 2006, Barrick entered into an agreement with Nautilus whereby Barrick's interest in the Project was converted into an equity stake in Nautilus. Following Barrick's equity stake, three companies, Epion Holding Limited, Taurus Investments SA (a wholly owned subsidiary of Anglo American PLC (Anglo)) and Teck Cominco Limited invested in Nautilus and became major shareholders of the company.

In February 2007, Nautilus completed a listing on the London Alternative Investment Market (AIM) and raised US\$100 million in a brokered institutional equity placement. It also raised US\$75 million in a brokered private placement on the Toronto Stock Exchange.

Within PNG, Nautilus holds exploration licences in the Bismarck and Solomon Seas totalling 51 granted exploration licences, covering 107,917 km², and 37 exploration licence applications, covering 88,906 km². Outside PNG, Nautilus holds granted prospecting licences in Tonga and the Solomon Islands and has applications pending in Tonga, Fiji and New Zealand.

The Independent State of Papua New Guinea has a statutory right to acquire up to 30% equity in the Project. Should this occur, the State is required to reimburse Nautilus the equivalent percentage of funds expended by Nautilus to date, and contribute to further exploration and development costs on a pro rata basis.

2.2 Feasibility Investigations

While the Project is the first proposed commercial development of SMS deposits anywhere in the world, much of the remote subsea technology required is available or adaptable from that commonly used in offshore oil and gas, telecommunication and dredging industries. Technology commonly used by these industries, such as ROVs, electric motors, hydraulic systems, subsea pumps, and umbilical power cables, is expected to be directly transferable to the Project. Nautilus has developed alliances with key offshore equipment and service providers, which have conducted engineering tests and assisted in the development of suitable seafloor mining equipment.

The Solwara 1 deposit comprises high-grade sulphide mineralisation that has been sampled and tested to indicate that marketable concentrates of copper and gold can be produced using standard froth flotation techniques. The financial viability of the Project is underpinned by the high mineral grades of Solwara 1. A National Instrument 43-101-compliant (CSA, 2005) estimate of the

seafloor massive sulphide resource at Solwara 1 has been completed (Golder Associates, 2008). The basis for the estimate is provided in Section 5.4 and shows that at Solwara 1:

- The Indicated Mineral Resource is 870 kt of ore containing 6.8% copper and 4.8 g/t of gold.
- The Inferred Mineral Resource is 1,300 kt of ore containing 7.5% copper and 7.2 g/t of gold.

Accessing the high grade ores directly from the seafloor surface involves substantially less use of heavy machinery in the stripping and storage of overburden and waste rock and some reductions in gaseous emissions and solid wastes per tonne of product compared with conventional mining. On the other hand, the environmental characteristics and potential impacts to the seafloor areas of the massive sulphide deposits are less well known. Consequently, long-lead time, environmental monitoring studies have been conducted since December 2005 to provide the basis for understanding the existing environment at Solwara 1. Specifically, the aim of these (and subsequent) studies was to:

- Establish existing conditions and an understanding of the existing environment.
- Determine potential environmental issues.
- Provide a basis for determining avoidance, management and mitigation measures (and their effective implementation).
- Provide a basis for environmental impact assessment. Details of the EIS studies are provided in Section 7.2.

Socioeconomic studies have been undertaken to:

- Establish existing conditions.
- Identify potential commercial, educational, health and employment opportunities.
- Provide a basis for a socioeconomic impact assessment.
- Determine management priorities.

While environmental studies commenced at the end of 2005, Nautilus has been actively exploring the Manus Basin since 1997. Studies have included geophysical surveys, bulk sampling, conceptual mining studies, water quality investigations, oceanographic investigations, seafloor mapping and biological surveys. A significant amount of information on the mineral resource and existing environmental conditions has been collected. Major studies and surveys carried out so far are summarised below.

2.2.1 Geophysics

- Geophysical survey (Williamson and Associates, 2005 as cited in Enesar, 2007). This geophysical survey used geophysics, sonar, induced polarisation, resistivity, self potential, magnetics and gravity measurements in order to map the seafloor.
- Video survey (College of William and Mary, James Cook University and University of Toronto on behalf of Placer Dome and Nautilus, 2006 as cited in Enesar, 2007). This survey of the seafloor provided detailed video images of chimney locations and other geological and biological features at Solwara 1.
- Bathymetric survey (Century Subsea and Williamson and Associates, 2005 to 2006 as cited in Enesar, 2007). This side scan sonar survey resulted in the generation of a detailed bathymetric map of Solwara 1 site.

- Electromagnetic survey by Nautilus during the Wave Mercury 07 Campaign. The survey delineated a conductivity anomaly that correlates extremely well with 2007 drill hole data and has been used to aid the interpretation of the geology.

2.2.2 Engineering

- Pre-feasibility study (PFS) (Worley Parsons, 2005). This study concluded that much of the technology required for the Project was already available from the offshore oil, gas and telecommunications industries. The study further assessed the Project on a financial basis and found that the mining venture could be economically competitive with terrestrial mines.
- Subsea cutting test (Cellula Robotics, 2006). These tests investigated the performance of an excavator deployed to the ocean floor at depths 1,500 to 1,700 m. The purpose of the trial was to determine the excavator and cutterhead performance under hydrostatic pressure and depth.
- Dewatering system study (Technip Offshore, 2006a). This study investigated potential dewatering systems for Solwara 1.
- Mining system design concept study (Cellula Robotics, 2006). This compared and described various mining concepts for Solwara 1.
- Seafloor Mining Tool design (SMD, 2008). This design resulted in a detailed engineering design for the Seafloor Mining Tool.
- Riser and Lift System design (Technip Offshore, 2008b). Design of the riser and lift system and dewatering process aboard the Mining Support Vessel.
- Mining services design (Clough, 2008). A detailed design of the mining process.

2.2.3 Geotechnical Investigations

- Detailed testwork program (Golder Associates & Nautilus Minerals, 2008). A program of geotechnical testwork on drill core in a laboratory established onboard the vessel *Wave Mercury* during the Wave Mercury 07 Campaign allowed geotechnical and density characteristics of the ore to be established.
- Compression testing (Strata Testing Services, 2007). These tests were conducted on 17 samples and resulted in a characterisation of undrained triaxial compression of Solwara 1 ore.
- Abrasivity testing (University of Melbourne, 2007). Forty core samples were tested for abrasiveness and showed that seafloor materials at Solwara 1 can be mined.

2.2.4 Resource Investigation

- Drilling program (SRK, 2006). Trial cutting tests and bulk sampling also provided an opportunity for a number of environmental investigations of water quality, oceanography and biology.
- Polymetallic sulphide property test (Placer Dome, 2006). Detailed mineralogical analyses were carried out on the polymetallic sulphide material mined from the Manus Basin.
- Drilling program (Golder Associates, 2008). A program of diamond core drilling of 111 holes from the vessel *Wave Mercury* using ROVs lowered onto the seafloor. Nautilus engaged Golder Associates to provide a range of services including establishment of an onboard geotechnical logging and testing program.

- Resource estimate (Golder Associates, 2008). A National Instrument 43-101-compliant (CSA, 2005) estimate was completed in 2008.

2.2.5 Oceanography

- Oceanographic study (Coffey Natural Systems, 2008) [Appendix 3] Full ocean water column current metering was undertaken during January 2006 and from October 2006 to March 2008. Additionally, oceanographic profiles of conductivity, temperature, salinity and transmissivity were conducted at Solwara 1.
- Regional oceanographic characterisation (Cresswell, G., 2007). This provides a compilation of the locations of all available oceanographic and meteorological data for the Manus Basin. Data was found as far back as 1985.
- Metocean data summary (Triton, 2006). This study examined and summarised commercial sources of meteorological and oceanographic data.
- Design Criteria Study (RPS Metocean, 2008). This report summarises the analysis carried out and the data prepared to determine specific meteorological and oceanographic design criteria for the components of the mining system.

2.2.6 Water and Sediment Quality

- Water quality monitoring (Enesar, 2006a). Water sampling was undertaken during the drilling program. The parameters measured included physico-chemical variables, inorganic species and total organic carbon.
- Water sampling program (CSIRO, 2007) [Appendix 7]. A water sampling program at Solwara 1 was carried out by CSIRO Land and Water Science in 2007. Laboratory analysis provided a characterisation of physico-chemical parameters.
- Sediment geochemistry (University of Toronto, 2007) [Appendix 6]. A sampling program was undertaken in 2007 that collected sediment cores from Solwara 1 and South Su. The cores were analysed in association with cores taken from previous studies to determine baseline sediment geochemistry and composition of seafloor sediments.

2.2.7 Biology

- Global sulphide mound ecosystems research (Cindy L. van Dover, 2005 – ongoing as cited in Enesar 2007). A series of studies has compared different sulphide chimney sites in terms of their associated biology and vent activity.
- Manus Basin baseline environmental study (CSIRO, 2005-2007) [Appendices 1 and 2]. CSIRO was engaged to complete three modules of study as follows:
 - Module 1 identified and compiled information already available from the Bismarck Sea, including published materials and cruise reports and unpublished data.
 - Module 2 followed on from Module 1 and included a detailed review of databases, culminating in a gap analysis report with recommendations for a baseline environmental study.
 - Module 3 involved the compilation of environmental baseline data on species diversity and endemism, habitat distribution of microfauna and macrofauna associated with sulphide chimney systems in the Manus Basin.

- Macrofauna research project (The College of William and Mary, 2006 as cited in Enesar 2007). This study included biological observations of megafauna (animals >2 cm) from sample collections from Solwara 1, using digital photography and real-time video analysis.
- Macrofauna research project (James Cook University, 2006 as cited in Enesar, 2007). Investigations of the macrofauna (animals 250 µm to 2 cm) of the sediments and sedimentary characteristics of the Solwara 1 deposit area were carried out from samples collected using ROV-operated box cores.
- Microfauna research project (University of Toronto, 2006 as cited in Enesar, 2007). Investigations of the microfauna (animals 63 µm to 250 µm) of the Solwara 1 deposit area from sediment samples collected using ROV-operated push cores.
- Benthic habitat assessment (Scripps Institution of Oceanography, 2007) [Appendix 5]. Visual assessment from video transects, and sediment samples for faunal characterisation adjacent to areas of venting at Solwara 1.
- Biomass, biodiversity and bioaccumulation study (Hydrobiology, 2008) [Appendix 10]. A desktop study assessed the potential for contaminants to accumulate via the food chain into top-order species such as surface schooling mackerel and tuna. The study also predicted the effect of mining activities on deep-sea species that rely on bioluminescence.
- Endemicity investigations (Duke University, 2007) [Appendix 4]. This study sampled macrofauna at active and inactive sites at Solwara 1 and South Su. The study identified species present at these two locations and determined the taxonomic and genetic similarities – via deoxyribonucleic acid (DNA) analysis – with species of vent communities at local, regional and global scales.
- Video survey (Placer Dome & Nautilus Minerals, 2006). A systematic survey of Solwara 1 and South Su was undertaken with still and video cameras mounted on an ROV. This footage, combined with images captured during other work at both sites, has resulted in the capture of over 3,000 hours of footage.

These studies have assisted Nautilus to define the Solwara 1 deposit, and to understand the geological, biological and environmental characteristics of the resource.

2.3 Compatibility with PNG Government Strategies

The proposed development will mine SMS deposits at Solwara 1 for copper and gold using methods that are environmentally responsible, socially acceptable, technologically achievable and economically viable. As such, the Project is consistent with the Fourth National Goal and Directive Principle of the Constitution of PNG, which states:

We declare our Fourth Goal to be for Papua New Guinea's natural resources and environment to be conserved and used for the collective benefit of us all, and be replenished for the benefit of future generations.

Seafloor mining presents a potential new source of wealth and growth for PNG. The Project will bring benefits in the form of royalties, and improvements in the nation's balance of trade, employment opportunities and potential for new industrial development that will have positive social and economic effects within PNG. In particular, these benefits would be maintained for the nominal Project life and probably beyond.

Seafloor mining also presents a possible source of industry diversification for PNG. Nautilus has exploration licences throughout the Bismarck and Solomon seas and intends to evaluate the potential of these licences and, where appropriate, apply for and mine any additional economic resources that it discovers.

Project compatibility with PNG Government legislation and policy is discussed further in Chapter 3.

3. POLICY, LEGAL AND ADMINISTRATIVE FRAMEWORK

This chapter describes the PNG legislation and agreements relevant to the Project. Additionally, it discusses international standards and principles that the Project has adopted.

The Independent State of Papua New Guinea promotes the development of its mineral resources through various policies to manage investment and impacts. This is supported by a legislative and policy framework, which ensures that approved developments assess, reduce and manage any residual social and environmental impacts such that they are as low as practicable.

It is a government priority and constitutional requirement to ensure the people of PNG benefit from the development of their resources, but within a sustainable, environmentally responsible and socially acceptable manner. The Mining Act provides that mineral resources belong to the state and that licences are required to explore, recover or sell these resources.

3.1 PNG Legislation and Agreements

The principal pieces of PNG legislation regulating the environmental and socioeconomic aspects of the Solwara 1 Project are the *Mining Act 1992* and the *Environment Act 2000*.

3.1.1 Mining Act 1992

The Mining Act is presently the principal policy and regulatory document governing the mining industry in PNG. The Mining Act vests ownership of all minerals in or below the surface of land (or under the sea) with the national government, and governs the exploration, development, processing and transport of minerals.

This is the first proposal for deep-sea mining of seafloor massive sulphide deposits and, as such, represents a new activity in environments where potential impacts have not previously been assessed. While the project is located beyond PNG's internal waters¹, the Mining Act allows exploration activities and mining of minerals to be undertaken on the seafloor within PNG territorial waters. The Solwara 1 deposit falls into this category.

3.1.2 Environment Act 2000

Environmental Impact Statement

The Department of Environment and Conservation (DEC) administers the *Environment Act 2000*, the legal framework for regulating the environmental effects of the Solwara 1 Project.

On 5 October 2006, Nautilus submitted a Notification of Preparatory Work on Level 2 and Level 3 Activities to the DEC under the provisions of the *Environment Act 2000* for the first phase of the Solwara 1 Project.

Phase one of the Solwara 1 Project is a Level 3 activity under the *Environment Act 2000* (Category 18.1), for which an environmental impact statement (EIS) is required. Accordingly, on

¹ A nation's internal waters are defined as all waters and waterways on the landward side of the baseline (usually defined as the lowest astronomical tide line) from which a nation's territorial waters are defined. It includes waterways such as rivers and lakes, and sometimes the water within small bays.

17 October 2006, DEC issued a Notice To Undertake Environmental Impact Assessment under Section 50 in the following manner:

- Submit an Environmental Inception Report (EIR) under Section 52. The objectives of the EIR were to:
 - Identify the potential environmental and social issues of developing the Project.
 - Describe the scope of the EIS to address these issues.
 - Initiate the formal process of stakeholder consultation.
 - Enable DEC to review the proposed EIS scope and redress any shortcomings.

Nautilus submitted the EIR for the offshore component of the Solwara 1 Project on 1 February 2007. DEC approved the EIR on 28 May 2007.

- Submit an EIS under Section 53 (this document).

The DEC (2004) publication *Guideline for Conduct of Environmental Impact Assessment and Preparation of Environmental Impact Statement* describes EIS requirements. It requires the EIS to assess potential environmental and social impacts of the Solwara 1 Project and to describe how the proponent intends to avoid, manage or mitigate these impacts.

Approval Process

Figure 3.1 shows the EIS approval process stipulated by Section 51 of the *Environment Act 2000*. The EIS is submitted to the Director who has 30 days to inform the proponent how long the assessment period will be. The Director, while assessing the EIS, may refer the EIS to a number of bodies, such as an environment consultative group or a public enquiry committee. If a provincial environment committee has been established, the Director must refer the EIS to the committee for its comments.

After this preliminary assessment period, the Director will make the EIS available for public review and, during this time, the proponent may be required to make public presentations or submit a program of public review.

Following the public review, the Director must make a decision to accept or reject the EIS. If the EIS is rejected, the decision can be appealed under Section 68 of the *Environment Act 2000*. If the EIS is accepted, the Director must refer the decision to the Environment Council together with an assessment report and any public submissions. The Environment Council then has 90 days to decide whether it is satisfied with the EIS. If the Council is not satisfied with the EIS, it is returned to the proponent for revision and resubmission. If the Council is satisfied with the EIS, it advises the Minister to approve the proposed activity in principle. The proponent can then apply for a permit to carry out its project.

Environmental Permit and Management

An EIS (e.g., this document) must accompany a permit application for a Level 3 activity. Sections 65 and 66 of the *Environment Act 2000* provide criteria for granting and setting conditions of permits respectively. Under Section 66, these conditions may include installation of monitoring equipment (s.66(1)(c)), preparation and carrying out an environmental management program (s.66(1)(d)), audits (s.66(1)(g)), emergency response (s.66(1)(h)), baseline studies (s.66(1)(k)) and rehabilitation (s.66(1)(l)). Part VII of the *Environment Act 2000* provides for permits for the use of water resources in PNG, including dams, diversions, discharges of wastes and/or contaminants and the taking of water resources via water use and investigation permits.

The Environmental (Water Quality Guidelines) Regulation 2002 (Independent State of Papua New Guinea, 2002) prescribes water quality guidelines to be met beyond a mixing zone by discharges to the natural water environment.

Chapter 13 describes the proposed environmental management framework for the Project.

3.2 Other Legislation and Regulations

3.2.1 Existing

The PNG legislation has been reviewed to identify those acts and regulations that are applicable to preparing the EIS and implementing the Project. Table 3.1 provides a summary of legislation that may apply.

Table 3.1 Other environmental legislation and regulations

Statutory Instrument	Implications for Solwara 1 Project
Environmental Legislation	
<i>The Fauna (Protection and Control Amendment) Act 1974</i> (Chapter 154)	Propose/implement measures to prevent workforce poaching.
<i>The International Trade (Fauna and Flora) Act 1979</i> (Chapter 391)	Propose/implement measures to prevent workforce poaching.
<i>Dumping of Wastes at Sea Act 1979</i> (see Section 3.2.2 below)	Requirement for a permit for dumping of substances other than those substances and articles derived from the normal operation of a vessel.
<i>Prevention of Pollution at Sea Act 1979</i> (Chapter 371) (see Section 3.2.2 below)	Standard offshore operating requirements for contractors.
Environment Regulations	
Environment (Council's Procedures) Regulation 2002	Procedures of the Environment Council (who will provide advice to the Minister on this EIS).
Environment (Prescribed Activities) Regulation 2002	The Project is Level 3 activity (Sub-Category 17) requiring an EIS (this document).
Environment (Water Quality Criteria) Regulation 2002	Permit required to set a mixing zone, at whose boundary prescribed water quality criteria are to be met.
Environment (Fees and Charges) Regulation 2002	Fees for an EIS. Procedures for permit fees and charges for water use, discharges to water and disturbed area runoff. Fees and charges to be set by DEC.

In addition, a range of acts and regulations covering commercial, professional and health issues of relevance to the Project are provided in Table 3.2.

Table 3.2 General legislation and regulations

<ul style="list-style-type: none"> • <i>Mining (Safety) Act 1977</i> • Mining (Safety) Regulations 1935 • <i>Industrial Safety, Health and Welfare Act 1961</i> (Chapter 175) (<i>Mining (Safety Act 1977</i> takes precedence) • Industrial Safety, Health and Welfare Regulation 1965 (Chapter 175A) • Industrial Safety (Explosive-Powered Tools) Order 1973 (Chapter 175D) 	<ul style="list-style-type: none"> • <i>Telecommunications Act 1996</i> • <i>Trade Licensing Act 1969</i> (Chapter 96) • <i>Accountants Act 1996</i> • <i>Business Names Act 1963</i> (Chapter 145) • Business Name Regulation 1964 (Chapter 145) • <i>Investment Promotion Act 1992</i> • Investment Promotion Regulation 1992 • <i>Medical Registration Act 1980</i> (Chapter 398)
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Table 3.2 General legislation and regulations (cont'd)

<ul style="list-style-type: none"> • <i>Explosives Act 1953</i> (Chapter 308) • <i>Building Act 1971</i> (Chapter 301) • Building Regulations 1994 • <i>Licensing of Heavy Vehicles Act 1977</i> (Chapter 367) • <i>National Institute of Standards and Technology Act 1993</i> • <i>Road Maintenance Act 1971</i> (Chapter 246) • <i>Customs Act 1951</i> (Chapter 101) • Customs Regulation 1951 (Chapter 101A) • Customs (Prohibited Imports) Regulation 1973 (Chapter 101C) • Public Health (Drinking Water) Regulation 1984 (Chapter 226) • Public Health (Sanitation and General) Regulation 1973 (Chapter 226G) • Public Health (Septic Tanks) Regulation 1973 (Chapter 226H) 	<ul style="list-style-type: none"> • Medical Registration By-Laws 1984 (Chapter 398) • <i>Professional Engineers (Registration) Act 1986</i> • Central Banking (Foreign Exchange and Gold) Regulation 2000 • <i>Customs Duty (Rebate) Act 1982</i> (Chapter 390) • <i>Excise Act 1956</i> (Chapter 105) • <i>Goods and Services Tax Act 2003</i> • <i>Stamp Duties Act 1952</i> (Chapter 117) • Stamp Duties Regulation 1953 (Chapter 117) • <i>Radio Spectrum Act 1996</i> • Radio Spectrum Regulation 1996 • Motor Traffic Regulation 1967 (Chapter 243) • <i>Inflammable Liquid Act 1953</i> (Chapter 311) • Inflammable Liquid Regulation 1968 (Chapter 311) • <i>Employment Act 1978</i> (Chapter 373) • <i>Employment of Non-Citizens Act 1978</i> (Chapter 374)
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3.2.2 Proposed

Two new bills have been proposed that address marine pollution. They are intended to repeal a number of existing acts and regulations (Table 3.3). While the bills do not yet form part of PNG legislation, requirements and regulations contained in them have been considered in this EIS.

Table 3.3 Proposed marine pollution bills

Bill	Description
Marine Pollution (Sea Dumping) Bill	Designed to repeal the <i>Dumping of Wastes at Sea Act 1979</i> .
Marine Pollution (Ships & Installations) Bill	Designed to repeal the <i>Prevention of Pollution at Sea Act 1979</i> and Prevention of Pollution at Sea Regulation

3.2.3 Guidelines

Ambient Water Quality

In PNG, discharges to water are regulated under the *Environment Act 2000*, whereby application is required for an Environment (Waste Discharge) Permit.

When granted, the permit will contain a number of conditions, one of which is the need to comply with prescribed water quality guidelines at the downstream limit of a site-specific mixing zone² that is applied at the time the permit is granted. These legally enforceable water quality guidelines

² A mixing zone is the body of water into which waste is discharged and where the prescribed water quality guidelines are not required to be met. The downstream end of the mixing zone is normally the first location downstream of the proposed discharge point where local people use the river and is called the compliance point. A similar concept applies to the marine environment where discharge to the environment occurs.

(for fresh and marine receiving waters) are contained in Schedule 1 of the Environment (Water Quality Guidelines) Regulation 2002 (Independent State of Papua New Guinea, 2002).

Drinking Water Quality

Schedule 2 of the Public Health (Drinking Water) Regulation 1984 (Independent State of Papua New Guinea, 1984) describes enforceable standards for drinking water quality. These standards were adopted from World Health Organisation (WHO) International Standards for Drinking Water, 1971.

Sewage Effluent

Specific guidelines for the discharge of sewage effluent do not exist, although sewage treatment plant effluent water quality criteria may be specified in an Environment (Waste Discharge) Permit, which is required under the *Environment Act 2000*. In the absence of PNG guidelines, International Finance Corporation (IFC) guidelines (see section 3.5.2) have been adopted. In addition, any sewage discharges would need to comply with Schedule 1 of the Environment (Water Quality Guidelines) Regulation 2002 (Independent State of Papua New Guinea, 2002).

Air Quality

PNG regulations do not specify air quality criteria and appropriate standards. In the absence of PNG guidelines, Australian guidelines (see Section 3.5.1) for ambient air quality and effects on terrestrial vegetation, and IFC guidelines (see Section 3.5.2) have been adopted.

Noise Quality

PNG regulations do not specify noise level criteria and appropriate standards from Australian (see Section 3.5.1) and IFC (see Section 3.5.2) guidelines have been adopted.

3.3 International Environmental Agreements

Table 3.4 summarises the international treaties, conventions and protocols relevant to the Project and to which the Independent State of Papua New Guinea is a signatory.

Table 3.4 Applicable international agreements to which PNG is a signatory

Title	Objective	Solwara 1 Project Issue
United Nations Convention on the Law of the Sea (UNCLOS) (1994)	Multilateral agreement on the law of the sea that allows countries to exploit their own resources under an internationally agreed framework that establishes guidelines for businesses, the environment and the management of marine natural resources	Marine biodiversity analysis and management
Convention for the Protection of the Natural Resources and Environment of the South Pacific Region (SPREP) (1990)	Protection, development and management of the South Pacific marine and coastal environment	Biodiversity studies and management
Vienna Convention for the Protection of the Ozone Layer (the Vienna Convention) (1993)	Protection of the ozone layer	Compliance with standards and protocols

Table 3.4 Applicable international agreements to which PNG is a signatory (cont'd)

Title	Objective	Solwara 1 Project Issue
Kyoto Protocol to United Nations Framework Convention on Climate Change (1997)	Has as its objective the reduction of negative changes to the earth's climate, with a particular focus on greenhouse gases. Places onus on industrialised countries (Annex 1 countries) to reduce emissions. Developing countries like PNG are exempt from the reduction requirement.	Greenhouse gas emissions to be reported to the Greenhouse Gas/Ozone Unit, Department of Environment and Conservation
Convention on Biological Diversity (1993)	Preserving and sustaining biological diversity	Biodiversity studies and management
International Convention for the Prevention of Pollution from Ships 1973 (as modified by the London Protocol of 1978) (MARPOL) (1994)	The ICPPS requires member states to minimise the risk of marine pollution from ships, in particular oil tankers	Vessel operations
Convention to Ban the Importation into Forum Island Countries of Hazardous Wastes and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes Within the South Pacific (Waigani Convention) (2001)	Proscription of international trade in hazardous waste and notification procedures, monitoring mechanisms and cooperative authorities	Materials selection

The ratification of UNCLOS by the PNG Government in 1997 established the nation's Exclusive Economic Zone (EEZ), extending the state's sovereign rights to 200 nautical miles offshore. The ratification of UNCLOS by PNG has enabled deep-sea mining to be approved and regulated by the state beyond PNG's territorial waters, and out to the limits of its EEZ.

3.4 Socioeconomic Impact Assessment Requirements

Consideration of social and economic impacts is an integral part of the assessment of the Solwara 1 Project under the Environment Act.

Section 51 of the Environment Act requires that the likely social impacts of the proposed activity be set out in the EIS in accordance with issues identified in the approved environmental inception report. Two DEC guidelines apply:

- Guideline for the Conduct of Environmental Impact Assessment and Preparation of Environmental Impact Statement, Section 6 (DEC, 2004).
- Social Impact Assessment Guideline, pages 1 to 8.

DEC (2004) guides that a social impact statement should form part of the EIS. It should include, but not be limited to, demographic information, information on existing infrastructure, public health issues and social services availability, and present economic status of the Project area.

This EIS addresses the socioeconomic impact assessment requirements outlined above by way of a social impact assessment. The scope and findings of this study are detailed in Chapter 8 and Chapter 10.

Given the setting of the onshore components of the Project, i.e., on fully developed and alienated land (see Chapter 5), an archaeological and cultural heritage survey was not necessary.

3.5 International Standards and Principles

3.5.1 Australian Guidelines

Air Quality

The Project has adopted the following guidelines:

- The National Environmental Protection Measure for ambient air quality (EPHC/NEPC, 1998), which addresses particulate matter, SO₂ and NO₂.
- The Approved Methods and Guidance for Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2001), which provides guidance relating to particulate matter and the nuisance of fugitive emissions (dust deposition).

Noise

The Project has adopted the Australian Standard AS 1055 'Description and Measurement of Environmental Noise' and the New South Wales Industrial Noise Policy (AS, 1997; NSW EPA, 2000).

No PNG legislation exists to address the impacts of in-water noise as it affects marine animals, particularly cetaceans. Therefore the Australian Government Environment Protection and Biodiversity Conservation Act Policy Statement 2.1 – Interaction Between Offshore Seismic Exploration and Whales (DEWR, 2007) has been adopted.

3.5.2 Equator Principles

Projects in the developing world are frequently assessed within the context of the Equator Principles (EPFI, 2006), which were developed in 2003 as an international banking industry framework to determine the environmental and social risks of project financing, and are commonly referred to as 'World Bank guidelines'. They provide a framework for a financial institution to assess the environmental and social impacts, management and risks of the projects that they fund, the underlying premise being that financial institutions will provide loans directly only to projects that have met International Finance Corporation (IFC)³ requirements with respect to environmental and social aspects.

Nautilus will endeavour to comply with Equator Principles where appropriate and concomitantly comply with all relevant IFC performance standards. IFC guidelines that Nautilus consider applicable to the Project are provided in Table 3.5.

The IFC has developed eight performance standards and complementary guidance notes that set out the requirements a project must meet (IFC, 2006a).

In addition to the performance standards, the IFC has developed environmental, health and safety (EHS) guidelines that serve as a technical reference to support the implementation of the IFC performance standards. The EHS performance standards, most of which were released in April 2007, replace those documents previously used as technical references in the World Bank Pollution Prevention and Abatement Handbook. IFC performance standards in relation to mining are currently in draft form.

³ The IFC is the private lending arm of the World Bank Group and the largest multilateral source of loan and equity financing for private sector projects in developing nations.

Table 3.5 Applicable IFC guidelines

Guideline	Description
IFC's Policy and Performance Standards on Social and Environment Sustainability (IFC, 2006a).	Standards developed to manage social and environmental risks and impacts in the private sector of countries eligible for financing.
IFC's Guidance Notes: Performance Standards on Social and Environment Sustainability (IFC, 2006b).	A technical reference that supports the implementation of the IFC Performance Standards.
Environmental, Health and Safety General Guidelines (IFC, 2007a).	A technical reference that provides guidance on common environmental, health and safety issues potentially applicable to all industry sectors.
Environmental, Health, and Safety Guidelines for Mining (IFC, 2007b).	A technical reference in draft form that provides guidance on environmental, health and safety issues potentially applicable to mining projects.
Environmental, Health, and Safety Guidelines for Offshore Oil and Gas Development (IFC, 2007c).	A technical reference that provides guidance on environmental, health and safety issues potentially applicable to offshore oil and gas projects.
Environmental, Health, and Safety Guidelines for Shipping (IFC, 2007d).	A technical reference that provides guidance on environmental, health and safety issues potentially applicable to the operation and maintenance of ships used for the transport of bulk cargo and goods.

4. STAKEHOLDER CONSULTATION

This chapter describes the consultation program that has been undertaken to date and the Project's ongoing program. The sections of the chapter provide an overview of the Project's consultation and disclosure program (Section 4.1), outlines the regulatory requirements related to public consultation (Section 4.2), lists the Project's stakeholders (Section 4.3), describes the public consultation and disclosure program that was implemented for the Project (Section 4.4), documents stakeholder consultation and outcomes (Section 4.5 and Section 4.6) and describes processes for continuing stakeholder consultation into the future (Section 4.7).

4.1 Overview

A key component of EIS investigations and approval process is an effective, ongoing communications program involving Nautilus, national, provincial and local governments, local communities, non-governmental organisations (NGOs) and various other stakeholders, including the international scientific community.

The Project's consultation and disclosure program has involved extensive interactions with stakeholder groups using multiple approaches designed to suit each group. Information about the Project has been presented to communities in New Ireland and East New Britain Provinces and also other provinces. Mining Warden's Hearings were carried out for a total of nine provinces. There has been ongoing regular consultation with the Independent State of Papua New Guinea (the State) government departments. An overview of the areas visited as part of the stakeholder consultation program is presented in Figure 4.1.

Consultation with NGOs and the international scientific community has included formal meetings, presentations and workshops, both within PNG and overseas.

4.2 Independent State of Papua New Guinea Consultation Requirements

Public consultation is a requirement of the State's environmental impact assessment process under the *Environment Act 2000*. Guideline notes from the State's Department of Environment and Conservation (DEC, 2004) state that an EIS's Executive Summary should provide 'details of the consultation program undertaken by the applicant, including the degree of public interest'.

In addition, as part of the EIS approval process under the *Environment Act 2000* (Section 51), the Director of DEC will make the EIS available for public review after a preliminary assessment period. During this time, the proponent may be required to make public presentations or submit a program of public review.

4.3 Stakeholders

A comprehensive list of stakeholders has been developed and grouped into broad categories reflecting differing interests in relation to the Project. These categories are shown Table 4.1. During the course of the consultation process, all stakeholders listed have been engaged.

Table 4.1 Project stakeholders

Category	Individual Groups	Types of Engagement
Independent State of Papua New Guinea	Prime Minister's Department	Face-to-face meetings, workshops
	Mineral Resources Authority	Face-to-face meetings, workshop
	Department of Environment and Conservation	Face-to-face meetings, workshops
	Department of Mineral Policy and Geo Hazard	Face-to-face meetings, workshop
	Department of Commerce and Industry	Face-to-face meetings, workshop
	National Fisheries Authority	Face to face meetings
	Department of Finance and Treasury	Face-to-face meetings, workshops
	Department of National Planning and Monitoring	Workshops
	Department of Foreign Affairs and Immigration	Face-to-face meetings
	Department of Trade and Industry	Face-to-face meetings, workshop
	Department of Labour and Industrial Relations	Workshops
	Department of Provincial and Local Level Government	Workshops
	National Maritime Safety Authority	Face-to-face meetings
	Internal Revenue Commission	Face-to-face meetings, workshops
	State Solicitors Office	Workshop
Provincial governments	New Ireland	Face-to-face meetings, workshop, wardens hearing
	East New Britain	Face-to-face meetings, workshop, wardens hearing
	West New Britain	Face-to-face meetings, workshop, wardens hearing
	Milne Bay	Face-to-face meetings, workshop, wardens hearing
	Manus	Face-to-face meetings, workshop, wardens hearing
	Madang	Face-to-face meetings, workshop, wardens hearing
	Morobe	Face-to-face meetings, workshop, wardens hearing
	East Sepik	Face-to-face meetings, workshop, wardens hearing
Communities near Solwara 1	Southwest coast of New Ireland, Central New Ireland and Kavieng districts	Face to face meetings
	In East New Britain Province districts visited included Kokopo, Rabaul and Gazelle	Face to face meetings

Table 4.1 Project stakeholders (cont'd)

Category	Individual Groups	Types of Engagement
NGOs	The Nature Conservancy, Pacific Island Countries Program	Face-to-face meetings, workshop
	Conservation International	Face-to-face meetings, workshop
	Barefoot	Workshop
	Wildlife Conservation Society	Workshop
	Centre for Environmental Law and Community Rights	Workshop
	Papua New Guinea Institute of Biodiversity	Workshop, face-to-face meetings
	East New Britain Social Action Committee	Workshop
	Mahonia Na Dari	Workshop
	New Ireland Environment, Monitoring and Awareness Committee	Workshop
	Ailan Awareness	Workshop
	Individual and community rights Advocacy Forum	Workshop
	World Wildlife Fund	Face-to-face meetings
	Catholic Church in New Ireland	Face-to-face meetings, workshop
	United Church in New Ireland	Face-to-face meetings, workshop
Sea Turtle Restoration Project	Written correspondence	
Industry groups	The fishing industry (PNG Fisheries Association)	Face-to-face meetings
	The tourism industry, in particular SCUBA diving operators	Workshop
	Chamber of Mines and Petroleum	Workshop, Face-to-face meetings
	Rabaul Chamber of Commerce and Industry	Face-to-face meetings
	New Ireland Chamber of Commerce and Industry	Face-to-face meetings
Academic and research organisations	University of Papua New Guinea, Port Moresby	Face-to-face meetings, seminar
	Divine Word University	Face-to face meeting
	University of Southampton	Workshop
	National Oceanographic Centre (NOC, UK)	Workshop
	Woods Hole Oceanographic Institution	Workshops, scientific collaboration
	Duke University	Workshops, scientific collaboration
	Scripps Institution of Oceanography	Workshops, scientific collaboration
	University of Toronto	Workshop, scientific collaboration
	CSIRO	Workshops
College of William and Mary	Scientific collaboration	

4.4 Public Consultation and Disclosure Program

4.4.1 Goals

The goals of the Project's public consultation and disclosure program are to:

- Build an understanding among stakeholders to reduce the potential for stakeholder disaffection resulting from a misunderstanding of the Project and to provide a structure for stakeholder inclusion in the environmental impact assessment process.
- Ensure that relevant government departments and communities adjacent to Solwara 1 are properly informed about the Project and that there is a structure for these stakeholders to provide input to the environmental assessment process.
- Ensure consideration is given to the valid concerns and interests of stakeholders.
- Incorporate concerns into mitigation plans as practicable.
- Ensure that the applicable regulatory requirements related to public consultation and disclosure are met.
- Provide the groundwork for:
 - Final presentation of the EIS and its supporting studies.
 - Input, where required, into the Project Development Forum, as part of the mining licence application process.
 - Ongoing consultation throughout the life of the project, i.e., construction, operations and decommissioning phases.

4.4.2 Consultation Methods

The Project's public consultation and disclosure program uses both formal (e.g., presentations, meetings, surveys and workshops) and informal (e.g., visits to villages in New Ireland and East New Britain provinces and briefing for Manus Provincial Government), leaflet and brochure distribution, face-to-face and telephone conversations, emails or facsimiles, radio interviews and talk-back shows, EM TV, newspapers) methods to disseminate information to, and to solicit comments from, stakeholders regarding the project.

The methods used in the consultation and disclosure program are listed below:

- Face-to-face discussions, telephone conversations, emails and facsimiles with key individuals (at all levels of stakeholder involvement) to disseminate information about the Project and to receive questions, comments, opinions and concerns.
- Information briefings and formal workshops with national, provincial and local governments, community organisations (communities) and NGOs to provide information about the Project, to discuss specific issues, and to solicit questions, comments, opinions and concerns.
- Presentation of information about the Project to community members, which included Project Awareness presentations to villages in New Ireland and East New Britain. Figure 4.1 shows the locations of the villages visited during the Project Awareness program to date. Prior

warning of Project Awareness program visits enabled communities from surrounding areas to attend the presentations. The Project Awareness program sessions held in May 2007 were through face-to-face meetings in the villages in New Ireland and through Power point presentations in East New Britain districts to describe the Project and its components.

The EIS will be made available for public review after its submission to the Director of DEC. Nautilus has consulted with DEC on the nature of the consultation to be undertaken, the exhibit locations for the EIS and the media in which the public review will be advertised. Presentations of key findings and recommendations of the EIS will be made to stakeholder groups via a 'roadshow', most likely in Kavieng, Rabaul and other community centres in New Ireland and East New Britain.

This will provide an opportunity for DEC and the Project not only to outline the EIS but also to respond to questions and concerns raised in previous consultation sessions. The roadshow satisfies the requirement under Section 51 of the Environment Act to make public presentations or submit a program of public review after the submission of the EIS.

4.4.3 Consultation Program

A summary of the public consultation undertaken for the Project is provided in Table 4.2.

Table 4.2 Public consultation

Date	Location	Number of Attendees	Organisations Represented
Churches			
6 August 2007	Kimadan, New Ireland	<69	Uniting Church
9 November 2007	Kavieng, New Ireland	<47	Catholic Church
Awareness Program			
16 to 19 May 2007	West coast New Ireland (Namatanai and other villages)	2,000	General community
3 July 2008	University of Papua New Guinea	About 200	Students, PNG Government, NGOs
Community Meetings and Engagement Workshops			
22 March 2007	West coast, New Ireland	25	Various community
18 August 2007	Bagabag Island, Madang Province	50 to 60	General community
Various	Rabaul, East New Britain (including Rabaul, Kokopo and Gazelle Districts)	About 250	General community and students
13 December 2007	Rabaul, East New Britain	27	East New Britain-based NGOs, Duke of York see community members (Appendix 15)
20 February 2008	Kavieng, New Ireland	26	Various stakeholders (see Appendix 15)

Table 4.2 Public consultation (cont'd)

Date	Location	Number of Attendees	Organisations Represented
<i>Mining Warden's Hearings</i>			
20 March 2007	Kimbe, West New Britain	6	WNB Admin and community
22 March 2007	Kavieng, New Ireland	15	NIP Admin and community
24 April 2007	Lorengau, Manus	11	Manus Admin and community
23 May 2007	Alotau, Milne Bay	not recorded	MBA and community
29 May 2007	Kimbe, West New Britain	10	Provincial government officers
19 June 2007	Madang, Madang	9	Provincial government officers and community
25 July 2007	Kavieng, New Ireland	8	Kavieng Admin and community
22 October 2007	Wewak, East Sepik	60	Provincial government officers and community
6 November 2007	Lorengau, Manus	70	Provincial government officers and community
17 January 2008	Lae, Morobe	12	Provincial government and community
23 January 2008	Alotau, Milne Bay	11	MBA and community
<i>New Ireland Provincial Workshop</i>			
8 to 15 October 2007	Kavieng, New Ireland	Approximately 200	Provincial government and community
<i>Scientific Workshops</i>			
13 to 14 March 2007	Port Moresby, PNG	30	Various. See Appendix 15
16 March 2007	Rabaul, PNG	7	Duke University, Scripps Institute of Oceanography University of Toronto
17 to 18 April 2008	San Diego, USA	13	Duke University, Scripps Institute of Oceanography, Bangor University, Woods Hole Oceanographic Institution
6, 12 and 24 June 2008	Internet conferences	5	Duke University
1 to 2 July 2008	Brisbane, Australia	5	Duke University

Lists of participants at each workshop, recorded on the day, are given in Appendix 15.

Summaries of selected meetings are provided below.

Church and Community Meetings and Awareness Programs

A number of well-attended meetings (Table 4.2) were held on Bagabag Island (Madang Province), in Kavieng, various villages and settlements on the west coast of New Ireland Province, and the Gazelle Peninsula (East New Britain Province). Project information and Nautilus activities were presented to attendees, who had the opportunity to respond.

The majority of attendees were generally positive while not expressing full support. Most issues and concerns raised were based on and influenced by existing perceptions of land-based operations, in particular that a similar scale of disturbance to the environment would occur on the seafloor.

The main issues arising from the meetings were (see Table 4.3):

- Missing out financial and social benefits.
- Adverse impacts of fish and marine line.
- Impacts on tides and currents.
- Impacts on water quality, particularly at the surface and close to shore.
- Damage to fringing coral reefs.
- Impacts to traditional fishing practices i.e., shark calling.
- Potential for Project activities to cause tsunamis or volcanic eruptions.

Rabaul Engagement Workshop

A workshop held on 13 December 2007 in Kokopo was attended by 27 individuals representing provincial NGOs, provincial government officials and representatives of community groups, including those from the Duke of York Islands (Appendix 15). The purpose was to present the Project to these groups and to understand their major concerns associated with the Project. The main issues arising from the workshop were distribution of benefits and protection of the environment (Table 4.3).

Kavieng Engagement Workshop

A workshop held in Kavieng on 20 February 2008 provided an opportunity for various groups within New Ireland Province to learn about the Project and allow their concerns to be heard. A total of 26 representatives from various provincial governments, community, industry and NGO groups attended the workshop (Appendix 15). The issues that came out of the workshop included environmental protection of the marine environment, in particular reefs and fisheries. Additionally, the distribution of benefits was an issue that was high on the agenda (Table 4.3).

Mining Warden's Hearings

A total of 11 Mining Warden's Hearings were held over the period 20 March 2007 to 23 January 2008. Locations of the hearings are shown in Table 4.2 and were presided over by a Mineral Resource Authority warden, who acted as an impartial arbitrator between attendees (local community, provincial administrators and other stakeholders) and Nautilus, who presented the Solwara 1 Project to attendees and answered questions.

Support for the Project was generally strong and the main issues raised during the meetings were focused on the environment, distribution of benefits, ownership of the resource and the potential for involvement in the Project (Table 4.3).

New Ireland Provincial Workshop

This workshop was organized by the New Ireland Provincial Government. A total of about 200 individuals from NGO groups, local businesses, and public servants attended. Nautilus was invited to give a presentation about its activities in PNG. The general concerns raised were in relation to the environment.

Deep Sea Science Seminar at the University of Papua New Guinea

As part of the mobilisation of Duke University scientists for the NorSky 08 Campaign, a seminar was given by the scientists at the University of Papua New Guinea in Port Moresby on 3 July 2008. The presentation was attended by approximately 200 students and some NGO representatives (e.g. Sea Turtle Restoration Project and Mineral Policy Institute). An overview of deep sea science and the work to be conducted during the Norsky 08 Campaign was given. Pictures and video of the seafloor taken during previous Nautilus offshore campaigns were included in the presentation.

Representatives from PNG Government attended the presentation and participated during the ensuing discussions with students and NGOs.

Port Moresby Scientific Workshop

A multi-stakeholder workshop was held in Port Moresby over two days in March 2007. The workshop was attended by local and international scientists and researchers, NGOs, environmentalists, anthropologists, consultants, and representatives from the PNG Department of Mining and Department of Environment and Conservation. The purpose was to allow for early identification of issues, input into EIS study design in the initial phases of the Project, and to provide transparency of proponent purpose.

The main issues arising from the Port Moresby Workshop were (Table 4.3):

- Endemism.
- Impacts of mining (loss of habitat, water and sediment quality).
- Protection of biodiversity.
- Active versus inactive areas (definitions).
- Natural variation in chimney activity, i.e., switching on/off of active chimneys and hydrothermal vents.
- Recovery: gene pools and gene flow.
- Resilience of systems.
- Precaution in dealing with uncertainty.
- Control areas and set aside areas for conservation and recovery.
- Monitoring.

The main outcome of the workshop was the incorporation of these issues in the design of the studies and research tasks that were completed during the Wave Mercury 07 Campaign over the period 22 March to 28 April 2007.

Rabaul Scientific Workshop

On 16 March 2007 a scientific workshop was held in Rabaul and was attended by international scientists who were about to undertake investigations during the Wave Mercury 07 Campaign. Duke University Marine Laboratory, Scripps Institution of Oceanography Integrative Oceanography Division and the University of Toronto Department of Geology were represented at the workshop.

Outcomes from the Port Moresby Workshop were revisited, to ensure that commitments from that workshop would be fulfilled during the Wave Mercury 07 Campaign.

San Diego Scientific Workshop

A follow-up workshop was held in San Diego, USA on 17 and 18 April 2008, principally with the international research scientists, in order to discuss the findings of the research studies that were completed on the Wave Mercury 07 Campaign and, in the light of these, recommend:-

- Appropriate mitigation measures (principally for the protection of biodiversity of the area and facilitation of recolonisation of mined areas).
- Further baseline studies required prior to commencement of mining to fill in gaps in understanding.
- Ongoing monitoring components for the duration of mining and beyond.

These recommendations have been accepted by Nautilus and are reflected in the mitigation plans described in Section 9.6.2 (where they relate to seabed ecology) and baseline and monitoring study plans as described in Chapter 13.

Internet Conferences and Brisbane Scientific Workshops

A number of internet conferences were held on 6, 12 and 24 June 2008 and a scientific workshop was held in Brisbane on 1 and 2 July 2008. These meetings were conducted in preparation of a scientific cruise at Solwara 1 to undertake monitoring and commence baseline work which came out of the San Diego Workshop (see Section 13.3.2 for details). The meetings were attended by scientists from Duke University Marine Laboratory, who would be undertaking studies aboard the scientific cruise.

Major findings and recommendations from the San Diego Workshop were revisited to ensure commitments would be met.

Publishing Rights

In some cases the collaborating scientists (i.e., their institutes) have contributed time and resources to extend the EIS-specific studies to more general scientific research. The scientists involved in these studies are free to publish findings in the scientific literature. Consequently, Solwara 1 and South Su are now the most intensively studied hydrothermal areas in the region.

4.5 Documentation of Stakeholder Consultation

The information obtained from all forms of public consultation is documented in meeting notes, consultation logs and as part of various EIS studies. These records are maintained by the Project.

Consultation logs established to keep track of consultations undertaken for the Project include logs of meetings with government departments, NGOs and industry groups (e.g., fisheries).

4.6 Consultation Outcomes

The Nautilus team and senior members of different levels of government attended the majority of meetings. As much as possible, Nautilus answered all issues and concerns raised at the meetings. A Frequently Asked Questions (FAQs) sheet has been developed for the main concerns raised and will be made available to the public on the Nautilus website after the EIS is submitted to DEC. The FAQs illustrates how issues have been addressed by project design, mitigation measures, and the development and implementation of systems and processes. The majority of issues raised during the stakeholder program were centred on the environment and social impacts. Table 4.3 is a summary of issues raised during public consultation sessions and other interactions with stakeholders, and illustrates how issues have been, and are proposed to be, addressed by project design, mitigation measures, and the development and implementation of systems and processes.

Table 4.3 Project response to issues raised during consultation sessions

Stakeholder Issue/Concern	Project Response
<i>Environmental Impacts</i>	
Several concerns regarding the possibility of Project activities setting off a natural disaster.	A risk assessment addressing the potential for operations to set off a natural disaster has been undertaken. A disaster and emergency plan will be completed and submitted to DEC prior to operations.
Concern regarding impacts to the biological life.	Completion of baseline and monitoring study plans as described in Chapter 13. The establishment of temporary refuge areas at Solwara 1 and a control site at South Su (see Section 5.1.1 and Section 7.1 for further information regarding South Su), against which Project impacts can be measured. Inclusion of mitigation plans as described in Chapter 9 of the EIS.
Impacts to local fishing and 'shark calling'.	Investigations into the local fishery and potential impacts are included in the EIS (see Chapter 10).
<i>Ownership and Benefits</i>	
Concern that the 'benefits' would not reach the people or provincial governments directly impacted by the project.	Commitment by the Project to employ PNG nationals to the maximum extent practicable. All things being equal, hiring preference will be given to appropriately skilled individuals from communities in New Ireland first, then East New Britain and then to other suitably skilled and qualified PNG nationals. Currently, approximately 25% of current workforce is comprised of PNG nationals.
Fewer jobs for PNG nationals due to the project area being remote.	Investigation into the potential for capacity building of PNG nationals.

Table 4.3 Project response to issues raised during consultation sessions (cont'd)

Stakeholder Issue/Concern	Project Response
<i>Ongoing Community Awareness/Consultation</i>	
Local nationals won't be involved.	An ongoing community awareness program, which included bringing videos showing subsea operations (drilling and cartoons of mining for now), to help explain the project to villagers. More workshops were organised to allow people to ensure information is disseminated appropriately and properly to the local people.
<i>PNG Government Capacity</i>	
Does the government have the capacity to regulate this project?	Yes. Under PNG legislation, the government has the statutory right and obligation to ensure the Project is permitted and operated in alignment with PNG law.

4.7 Continuing Consultation

Consultation with stakeholders will continue during the remainder of the EIS and approvals process associated with the Project and will include:

- An EIS information briefing roadshow by Project representatives with assistance from DEC officers (see Section 4.4.2 above), soon after the submission of the Draft EIS.
- A program for consultation and disclosure prior to and during operations will be included in the Environmental Management Plan (see Chapter 13).

Queries and concerns raised during the EIS roadshow will be documented and reviewed by the Project team in conjunction with other submissions made to DEC during the EIS assessment and public review period. Responses to the queries and concerns will be provided to DEC, including information on any design modifications or mitigating measures the project may institute in response to voiced issues, concerns, and comments. Any new or modified mitigation measures or changes to systems and processes will be captured in the Environmental Management Plan.

Consultation will continue prior to and during operations of the Project. This will include the regular preparation and distribution of printed materials, the placement of information on websites, formal and informal discussions with stakeholders, the development and implementation of mechanisms for the receipt and handling of stakeholder concerns and comments, and the communication of relevant project milestones via various media announcements.

Procedures for recording and responding to issues raised during such consultations will be detailed in the Environmental Management Plan. A grievance procedure will also be established that will set out, for people affected by the project, how to bring their grievances forward so that they may be considered in a culturally appropriate and expeditious manner.

Environmental Impact Statement
Solwara 1 Project

5. DESCRIPTION OF THE PROPOSED DEVELOPMENT

The optimised development proposal presented in this chapter relates to Phase 1 of the Project (see Section 1.1), and involves the recovery of ore from the seafloor and whole-of-ore export to an overseas processing facility, based on an assessment of technical, financial, environmental and social factors relevant to commercial feasibility and public acceptability. The proposal optimises Project parameters (such as mining rate, ore handling and waste management) according to criteria of safety, environmental protection and profitability, in a manner that maximises the positive and minimises the negative impacts of mine development.

Further optimisation will occur as the Project proceeds through detailed design but, in general, Project parameters relevant to environmental and social planning and impact assessment can now be assessed.

5.1 Project Area Definition

Activities associated with Phase 1 will occur in distinct operational zones, as described below and shown in Figures 1.2 and 1.3.

5.1.1 Solwara 1 and South Su

Project mining activities will be confined to the Solwara 1 mound (see Section 5.7). A 500-m exclusion zone will be put in place around the Mining Support Vessel (MSV) to minimise the risk of collisions with non-Project vessels, in accordance with accepted international shipping and oil and gas facility procedures¹. The exclusion zone will fall within the future mining lease (ML) boundary, which in and of itself will be a no-go area for non-Project vessels and persons, as is the custom for MLs on land. Figure 5.1 shows the proposed extent of the future ML boundary.

Additionally, some environmental monitoring activities will be conducted at South Su, as described in Section 13.4.2.

Figure 1.2 shows the areas defined as Solwara 1 and South Su, including the 500-m exclusion zone extending around the boundary of where the MSV will be operating. Additionally, North Su – situated between Solwara 1 and South Su – is shown and delineated in Figure 1.2.

5.1.2 Barge Corridor and Crew Transfers

Dewatered ore will be barged from the MSV to the Port of Rabaul for temporary storage. MSV crew changes will generally be serviced out of Kokopo.

Barge and crew transfer routes are shown in Figure 1.3 and described in Sections 5.7.2 and 5.9.2 respectively.

5.1.3 Port of Rabaul

Ore will be temporarily stored within the existing PNG Ports Corporation Ltd facilities at the Port of Rabaul, prior to being shipped to an overseas processing plant. Figure 1.3 shows the location of the storage facility and storage activities are described further in Section 5.2.2.

¹ Various acts (e.g., the *Australian Offshore Petroleum Act 2006* and *United Kingdom Petroleum Act 1987*) suggest a minimum 500-m exclusion zone around permanent offshore oil and gas facilities to avoid ship collision.

5.2 Project Components

5.2.1 Offshore

The general arrangement of offshore Project activities is shown in Figure 5.2. The main components of the offshore activities are:

- Mine area (Section 5.7). Five zones will be mined at Solwara 1. Mining will commence in a zone of relatively flat seafloor topography. Prior to mining occurring in new areas, pre-stripping of unconsolidated surface sediment will be required. Approximately 130,000 t of unconsolidated sediment will be moved across the five zones. Additionally, approximately 115,000 t of competent waste material within the mining zones, which is below the mine cut-off grade, will be side cast during mining operations.
- Seafloor Mining Tool (SMT) (Section 5.6.1). Initially, the SMT will 'walk' along the seafloor and extract ore with a cutter-suction head to disaggregate the ore to the size required for transfer to surface. The SMT will be remotely controlled from the surface and aided in mining activities by two remotely operated vehicles (ROVs). Once the more rugged seafloor areas have been mined, the SMT will be fitted with tracks.
- Riser and Lifting System (RALS) (Section 5.6.2). Mined ore will be pumped to the surface via a riser pipe attached to the SMT. One pump attached to the bottom of the RALS will pump both water and ore to the surface. The pump will be hydraulically powered by return water from the surface. A flexible riser transfer pipe (RTP) connects the SMT to the base of the RALS.
- Mining Support Vessel (MSV) (Section 5.6.3). A dynamically positioned 153-m-long MSV will be used as the base for the associated surface mining activities. A control room on the MSV will allow remote operation of the SMTs and ROVs. The MSV will include all facilities for dewatering the ore prior to its transfer to shuttle barges for transport to temporary storage at the Port of Rabaul. Water separated during the dewatering process will be pumped back to the seafloor and will be used to drive the RALS pump.
- Remotely operated vehicles (ROVs) (Section 5.6.4). Two work-class ROVs will be used to assist in mining operations on the seafloor at Solwara 1, including the removal of non-mineralised unconsolidated sediments. Additionally, the ROVs will be used to undertake environmental monitoring and management activities as discussed in Chapter 13.
- Shuttle barges (Section 5.7.2). Shuttle barges, either self-propelled or towed by tugs, will be used to transfer dewatered ore from the MSV to the Port of Rabaul.
- Support vessel (Section 5.8.1). Consumables such as fuel, lubricants, spare parts, food and water will be regularly transported to the MSV on a support vessel. Crew transfers will also occur at regular intervals using the support vessel.

5.2.2 Onshore

Onshore facilities will be located at the Port of Rabaul and will mostly utilise existing facilities (Figure 5.3). The main components (Section 5.7.2) are:

- Shuttle barge wharf. The barges will manoeuvre alongside the existing Berth 1 at the port where ore will be transferred to shore.

- Ore transfer. Ore will be transferred from the shuttle barges to a mobile conveyor with a crane and grab system. The conveyor will transport the ore to the temporary storage facility.
- Temporary storage facility. Ore will be stored in stockpiles in a new-build covered storage facility until enough material has accumulated for transfer to bulk carriers for shipping to an overseas processing facility.
- Ship loading. A dedicated ship loader will be installed to transfer ore from temporary storage to bulk carriers.

5.3 Rationale for the Location of Project Components

Resource projects are restricted in the manner of their development in the following ways:

- Physically, by the location of the orebody and the environmental and geotechnical conditions found at that location.
- Environmentally, by the environmental setting of the Project.
- Socially, by the expectations and concerns of stakeholders.
- Economically, by the need to extract and treat the ore profitably.

5.3.1 Mining Method

The mineral resource at Solwara 1 is a Seafloor Massive Sulphide (SMS) deposit (see Section 7.3). The deposit sits proud of the surrounding seafloor and generally is covered by a thin drape of unconsolidated sediment. There is also minor waste rock (below cut-off grades) at the five mining zones, i.e., there is no significant overlying layer of overburden. Therefore, after removal of the unconsolidated sediment and waste rock, the deposit will be mined in a method similar to offshore dredging of hard rock.

Removal of the unconsolidated sediment and mining methods are discussed below in Section 5.7.

5.3.2 Location of Onshore Facilities

Terrestrial mineral resource development can only occur where a commercial deposit is found and this is also true for the Solwara 1 deposit. However, unlike most terrestrial projects, due to the freedom allowed by the shipping of ore, a number of locations for siting the onshore components of the Project were able to be considered.

The Port of Rabaul was selected as the preferred site based on the following attributes:

- The Port of Rabaul is approximately 50 km south of Solwara 1 and therefore allows for minimal shipping distance.
- The port, located within Simpson Harbour, is well protected and provides safe sea conditions year round i.e., it is an all-weather port.
- The Port of Rabaul is an established international port with good existing facilities and port operations. It does not require significant modification prior to use as a storage location. Apart from dedicated conveyor and ship-loading facilities, storage and handling can be conducted within the existing facilities and current operations of the port.
- The port is located on alienated land and therefore does not require the use of customary land as would likely be necessary elsewhere.

5.4 Mineral Resource

Resource² estimates were undertaken by Golder Associates (2008). Exploration and drilling programs at Solwara 1 have allowed the well-drilled central portions of the deposit to be classified as indicated, while the remaining majority of the deposit has been classified as inferred (Table 5.1).

Table 5.1 Indicated and inferred mineral resource estimate (4% Cu cut off)

Class	Ore (t)	Copper Grade (%)	Copper (t)	Gold Grade (g/t)	Gold (oz)
Indicated	870,000	6.8	59,160	4.8	134,264
Inferred	1,300,000	7.5	97,500	7.2	300,936

Mineralisation is hosted by sulphide-rich chimneys and sediments (see Section 7.3 for further information). Due to the process in which the deposit has formed, mineralisation occurs at the surface of the deposit, i.e., there is no significant hard-rock overburden. Parts of the deposit are covered by unconsolidated sediment, which will be moved prior to mining. Access to the base of the target ore will require some benching and any volumes of adjacent waste rock cut during benching will be side cast, along with ore below cut-off grades encountered during mining. Section 5.7 provides a description of mining methods.

During the 2007 core drilling campaign, 111 holes were drilled to a maximum depth of 20 m. At present, it is unclear to what depth below the seafloor the mineralised zone extends as 38% of core holes drilled during the campaign terminated within the orebody. This is shown in Figure 5.4 as a cross section through the Central Zone at Solwara 1. Additionally, mineralisation may occur laterally outside the identified zones of mineralisation.

Potential therefore exists for the mineral resource to be greater than that provided in Table 5.1, which may result in an extended mine life. If mineralisation continues below the 20-m drilling limit or extends laterally, mining will likely continue until mineralisation ceases or it becomes either financially, technically or environmentally unfeasible to continue.

In addition to the drilling campaign, an ocean floor electromagnetic (OFEM) survey was undertaken during the Wave Mercury 07 Campaign to delineate massive sulphide deposits at and immediately below the seafloor. The OFEM system remotely measures electromagnetic fields associated with induced seafloor electrical currents but cannot record how deep below the seafloor mineralised areas extend. Survey outputs were ground-truthed using drilling and bulk sampling results, allowing further delineation of the ore body at Solwara 1 (Figure 5.5).

Mineral resource investigations have identified five main zones of mineralisation, namely Far West, West, Central, East and Far East. All five zones are shown in Figure 5.5 and described further in Section 5.7.1.

5.5 Scale of the Project

Based on the current resource estimates, the Project has a mine life of approximately 30 months, if extracting ore at a maximum rate of up to 5,900 t/d is achieved. Mining could, however, extend

² A resource estimate is based primarily on geoscientific information only, with an expectation that it could be economic. A reserve must, however, consider those factors affecting extraction, including mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors, and should in most instances be estimated with input from a range of disciplines (MCA, 2004).

to 5 years and beyond depending upon discoveries of additional mineralisation at Solwara 1. The proposed mining activities at Solwara 1 are relatively small when compared to terrestrial mines in PNG (Table 5.2), particularly the open cut operations.

The portion of Solwara 1 to be mined covers an area of 0.112 km² (see Figure 5.5). Compared with existing mines in PNG, the volume of overburden (both unconsolidated sediment and competent waste material) that requires management at Solwara 1 over the life of the Project is minor.

Table 5.2 Comparison of the Solwara 1 Project with other PNG mines at time of EIS approval

Mine	Ore at Time of Project Approval (Mt/a)	Overburden (Mt/a)	Ore and Overburden (Mt/a)	Status	Type
Ok Tedi	15.2	23.7	38.9	Operations	Open cut
Hidden Valley	2.1	27.7	29.8	Constructing	Open cut
Lihir	7.2	20.6	27.8	Operations	Open cut
Porgera	17.0	2.7	19.7	Operations	Underground and open cut
Misima	5.1	6.3	11.4	Closed	Open cut
Ramu	4.6	1.1	5.7	Constructing	Open cut
Solwara 1	1.2	0.12	1.32	Seeking approval	Seafloor open cut
Kainantu	1.17	0.07	1.24	Operations	Underground
Simberi	1.1	0.0	1.1	Constructing	Open cut
Tolukuma	0.2	0.81	1.01	Operations	Underground
Wau CIP	0.4	0.39	0.79	Closed	Open cut

5.6 Offshore Mining Equipment

While the Project is a world first in terms of commercially mining SMS deposits, as stated in Chapter 2, much of the technology that will be newly applied to the mining industry is already in common usage in the offshore oil and gas, telecommunication and dredging industries.

Proven technology, such as the dynamically positioned vessel, ROVs, electric motors, pumps, riser pipes, hydraulic systems, umbilical power cables etc., will be directly transferable to the Project. Partnerships and alliances with key offshore equipment and service providers have resulted in development of suitable seafloor mining equipment. This section describes the specialised equipment to be used at Solwara 1. A diagram showing major components is provided in Figure 5.2.

5.6.1 Seafloor Mining Tool

Ore will be mined by a purpose-built Seafloor Mining Tool (SMT) (Figure 5.6). Two SMTs will be built for the Project and it is envisaged that, at any one time, one SMT will be mining the seafloor while the second SMT will either be on standby or undergoing maintenance on the MSV.

The SMTs will be built by Soil Machine Dynamics Ltd., one of the world's leading subsea equipment manufacturers. The SMTs are based on technology currently used in the offshore trenching, dredging and diamond-mining industries.

Each SMT will weigh 250 t in air and 190 t in water. The machine will measure 8 m tall, be 17 m long (with the boom extended) and 13 m wide. The tool is capable of working in depths up to 2,500 m and can operate in water temperatures ranging from 0°C to 35°C. Details of the SMT are set out below.

Control and Instrumentation

Each SMT will be electrically powered and controlled by an umbilical cable from a control room on the MSV. The umbilical cable will house copper conductors to transmit electricity at 3,000 V and fibre optic cables to transmit instructions to the SMT and carry data back to the control room.

Electricity supplied via the umbilical will power six 400-kW electro-hydraulic power units on the SMT. These units will in turn power the cutter head, slurry pump, movement system and other services.

The SMT will be fitted with a range of instrumentation and sensors as described in Table 5.3. All instruments and sensors will provide data to the control room in real time.

Table 5.3 SMT instrumentation and sensors

Instrument	Description and Purpose
SMT Instrumentation	
Video and still cameras	7 x monochrome and 2 colour units to allow visual observation of subsea operations. A number of the cameras will be able to tilt and pan.
Lamps	15 x incandescent and dimmable units to light the surrounding seafloor and water.
Multibeam sonar	5 x sonar systems will be fitted to the front and rear of the SMT and on the cutter head, and an additional 2 will be placed on the RALS or ROV. The sonar systems will map the seafloor and mining face in real time, allowing operators to control SMT movement and mining activities.
Gyrocompass	1 x sensor to provide SMT heading.
Acoustic positioning	2 x units fitted to the SMT will allow the MSV to track the position of the SMT.
Hydrophone	1 x sensor to measure cutting noise to assist in determined the differences in materials being mined.
SMT Sensors	
Pressure transducers	Placed at various locations on the SMT, these will include measurement of pressure of system hydraulics, the suction pipe at the crusher, the water pump inlet and outlet and the dilution pump.
Linear transducers	Fitted to critical components of the SMT to measure electronic component oil reservoir volumes, compensator levels and positions of the boom and dipper, cutter and spuds. Additionally, spud position and SMT travel are monitored.
Temperature	Sensors will monitor motor, electronics, hydraulic oil, valve pack and ambient seawater temperatures.
Moisture	Fitted to all electronics and components susceptible to damage by moisture.
Bathymetry	1 x sensor will be fitted to the SMT to provide information on SMT depth, altitude above the seafloor, temperature and conductivity.

Table 5.3 SMT instrumentation and sensors (cont'd)

Instrument	Description and Purpose
SMT Sensors (cont'd)	
Inclination	Pitch and roll will be measured to ensure stability of the SMT.
Speed and rotation	Both the cutter head and crusher (if fitted) will be monitored.
Load cells	Cells will measure lift load and loads on the riser, cutter boom, spuds and SMT belly.
Process monitoring	Flow and concentration of the mined ore will be measured.

Launch and Recovery

Each SMT will operate for approximately five days, after which time it will return to the surface for maintenance and be replaced with the standby SMT. The SMT will be deployed from the stern of the MSV using an A-frame system similar to that often used to launch and recover ROVs. The launching sequence can be summarised as follows:

- The SMT is raised off the deck of the MSV by a lift wire attached to a lift winch. It is then lowered over the back deck of the MSV into the water.
- The SMT is lowered down through the water column and guided by the ROV into position adjacent to the area to be mined.
- Once on the seafloor, the lift wire is disconnected from the top of the SMT and the Riser Transfer Pipe (RTP) is attached to the SMT by an ROV.

Recovery occurs in reverse order to that of the launch sequence.

Movement Along the Seafloor

The SMT will be capable of operating on seafloor slopes up to 20° and will use two methods to move along the seafloor. When operating in relatively rough terrain and when cutting mining ramps (see 'Cutting System' below), the SMT will 'walk' along the seafloor by employing four hydraulically powered spuds (Figure 5.6) as follows:

- The four spuds are planted into the seafloor and the SMT raises itself clear of the seafloor. The SMT then slides forward 2 m.
- The SMT is then lowered to the seafloor and the spuds are raised. At this point, it is possible for the SMT to rotate the chassis, cutter head and spuds to the left or right, allowing it to turn in either direction.
- The four spuds are moved forward and then lowered to the seafloor and the SMT is raised for another forward movement.

The above sequence allows the SMT to travel across the seafloor in any direction at a maximum rate of 30 m/h.

Where seafloor slopes are relatively flat, the SMT will be fitted with a tracked crawler drive system, allowing the SMT to move at maximum speed of 700 m/h.

Cutting System

A 2-m-diameter drum cutter head will be mounted on a hydraulic boom that is able to move both vertically and horizontally, maximising the amount of rock able to be cut while the SMT is stationary (see Figure 5.7).

The drum cutter will mine ore in downward cut swathes approximately 1.8 m wide and approximately 650 mm deep. A collection hood will sit behind the cutter head to capture mined ore via a suction pipe.

When cutting ore, it is expected that 30% of the material will be too large to be sucked into the collection system and will fall to the seafloor directly below where it was cut. This lost material will be reworked by the cutting and suction system. Due to design limitations, one third of the lost material (i.e., 10% of the original ore cut) will remain on the seafloor.

5.6.2 Riser and Lift System

The RALS will serve two main functions: pumping mined ore to the MSV and transferring return water from the MSV to drive the subsea slurry pump (SSLP) and thereafter discharging back to the ocean immediately above the seafloor.

The RALS, shown in Figure 5.8, consists of a bottom-tensioned vertical riser, dump valve, twin return water pipes, SSLP and associated stabilising mechanisms suspended from the MSV. A flexible riser transfer pipe (RTP) connects the base of the RALS to the SMT.

The SSLP will be recovered approximately every 100 days for servicing and preventative maintenance. This may or may not necessitate recovery of the entire riser system. The RALS handling and deployment equipment is all 'off the shelf' equipment, typical of offshore gas and oil exploration, which will be custom-fitted to the MSV.

Details of the RALS are provided below.

Riser Transfer Pipe

The RTP, made of 229-mm-diameter flexible pipe will be approximately 155 m in length. It will incorporate steel armouring, have a wear-resistant inner coating and will be fitted with buoyancy collars along the 100 m length closest to the SMT. The buoyancy collars will create an S-shaped vertical profile and allow the SMT to operate in the following ranges from the base of the RALS (see Figure 5.8):

- Horizontally between 80 and 130 m.
- Vertically between 10 and 60 m.

Operational flexibility within the RTP will allow a degree of freedom of movement between the SMT and MSV. The MSV will hold station above the SMT, and dynamically position itself so that the SMT is always within its operational range on the seafloor.

Subsea Slurry Lift Pump

The SSLP, located at the bottom of the riser pipe (see Figure 5.8), is the system by which the ore slurry is pumped to the surface. The SSLP includes two, multiple-chamber, positive-displacement pump modules. The modules are hydraulically driven by pressurised return water delivered to the system by the twin return water pipes. The system is controlled from the surface control room by umbilical cables attached to the riser pipe.

The SSLP incorporates design redundancy, which will allow it to continue operating (albeit at reduced pumping capacity) if any of the pump modules fail. In the event of an emergency shutdown or other unforeseen event leading to a loss of flow, an automatic dump valve will purge the slurry in the riser pipe to the seafloor, thereby avoiding blockage of the system.

If discharged to the environment, the maximum volume of purged ore would be approximately 11 m³. Once operations recommence, the dumped ore would be recovered by the SMT.

Riser and Return Water Pipes

The riser pipe consists of 20-m-long sections of 308-mm-diameter steel pipe. The sections, similar to those used for subsea drilling activities in the oil and gas industry, will be hoisted into position with a derrick tower onboard the MSV. They will be joined together and sequentially lowered to the seafloor.

Similarly, the twin return water lines, also in sections, will be joined sequentially. The pipes will be attached to the riser pipe and lowered to the seafloor at the same time. The bottom end of the triple pipe system will suspend the SSLP and the whole system will be suspended from the MSV.

Helical strakes will be fitted to the main riser pipe in the upper 800 m of the water column to minimise vortex-induced vibrations caused by ocean currents.

Water from the dewatering process will be pressurised by four centrifugal pumps on the MSV to approximately 110 bar. The water (including solid material less than 8 µm in diameter) will be pumped down the return water pipes and provide hydraulic pressure to drive the SSLP.

Once the return water has passed through the SSLP, the pipes will discharge directly upwards at a rate in the order of 0.3 m³/s, thereby allowing plume dispersion to occur at a faster rate than if the water was discharged directly downwards.

5.6.3 Mining Support Vessel

A MSV has been identified for the Project which is under build at the time of writing this EIS. The ship will be single-hulled, dynamically positioned and act as the platform for mining operations at Solwara 1 (Figure 5.9). Main technical details of the MSV are provided in Table 5.4.

Table 5.4 Mining support vessel technical details

Item	Detail
Flag	Malta
Overall length	160 m
Breadth	30 m
Maximum draft	7 m
Maximum speed	17 knots
Deadweight capacity	14,200 t
Deck area	2,900 m ²
Fuel oil capacity	2,000 m ³
Fresh water capacity	1,000 m ³
Water ballast	8,000 m ³
Main cranes	1 x 50 t deck crane, 1 x 400 t deck crane

Table 5.4 Mining support vessel technical details (cont'd)

Item	Detail
Power	21 MW
Diesel generators	6, producing 3,500 kW
Dynamic positioning thrusters	3 x 3,800 kW aft, 2 x 3,800 kW forward, 1 x 2,000 kW side
Accommodation	120 persons

Dynamic positioning will allow the MSV to position itself accurately during operations. Acoustic beacons deployed on the seafloor will provide the MSV with information on the location of the SMT and ensure that all components of the mining spread are located within operational limits.

The MSV will contain a large work moon pool. A derrick tower will sit above the moon pool and will be used to lower the RALS system from the surface to the seafloor.

The MSV will be capable of supporting mining activities and launching and recovering all subsea equipment, i.e., the SMT, RALS and ROVs in conditions up to sea state 5 (where significant wave heights³ can reach 3.5 m).

An ore dewatering system and ore transfer conveyor will be fitted to the MSV. These are described further in Section 5.7.2 below.

Operations at sea will use marine-grade diesel at an average rate of 40 t/d. To continue operations, the MSV requires refuelling every month, but will likely be refuelled more often to ensure sufficient fuel supplies are onboard the MSV at all times.

The MSV systems will be subject to an ongoing daily, weekly, monthly, six-monthly and annual maintenance schedule that will not require a shut down of operations. It is anticipated that dry docking of the MSV will not be necessary for the first five years of operations.

5.6.4 Remotely Operated Vehicles

Two work-class ROVs will be used to assist mining activities. During removal of the unconsolidated sediment prior to mining, each ROV will be fitted with a dredge skid and discharge pipe system to pump the material away from the mining area as described in sections 5.7.1 and 5.7.2 below.

5.7 Mining

Mining operations will occur 24 hours per day, 365 days per year with the exception of scheduled or unscheduled maintenance stops.

5.7.1 Mine Plan

The five mineralised areas of Solwara 1 targeted for mining are shown in Figure 5.5. Delineation of the mining area has been based on the results of the exploration program to data, which have included electromagnetic surveys, bulk chimney sampling and core drilling.

³ The average height (trough to crest) of the one-third of the largest waves.

Gold and copper grades vary across the deposit, but the five mineralised zones – Far West, West, Central, East and Far East – contain the highest-grade zones within the mining area. The zones will be mined in the following sequence:

- Mining will commence in the Far West Zone where the seafloor topography is flattest and therefore the easiest zone to mine. It is expected to take three months to complete mining activities within this zone.
- Central Zone will be mined next. Activities will commence in the northeast section of the zone and progress to the southwest.
- Once mining is complete within the Central Zone, it will continue in the West Zone. It is envisaged that mining of Central and West zones will take between 12 and 24 months, depending on conditions encountered.
- The final zones mined will be East Zone and Far East.

Temporary refuge areas will be incorporated into the mine plan (see Sections 9.6.2 and 13.4 for details).

Figure 5.10 shows the seafloor at Solwara 1 prior to mining and an estimation of how it will look following mining at the five zones.

Once ore has been extracted from the five zones, it is envisaged that mining at Solwara 1 will cease. However, if mineralisation is found to continue with depth, or additional exploration activities discover additional lateral resources (particularly to the north or west, which at this stage show signs of continuing mineralisation), mining may continue at Solwara 1.

Unconsolidated Sediment

Geotechnical investigations (Golder Associates, 2008 R104J) show the presence of a layer of unconsolidated sediment in low-lying areas of the proposed mine (Figure 5.11). The sediment layer, in some places up to 6 m deep, consists of silts and clays with an average density of 1.2 t/m³. Prior to mining, this unconsolidated sediment will be moved by a pump and pipe system attached to an ROV to areas outside the mining area (see Figure 5.11). Removal of the sediment will prevent an inflow of material at the mining face, thereby removing the potential to interfere with and slow mining activities.

Unconsolidated sediment removal rates are provided in Table 5.5 and show that the total amount of sediment to be removed is approximately 108,000 m³, or 130,000 t.

Table 5.5 Unconsolidated sediment removal rates

Month (from Start of Mining)	Monthly Unconsolidated Sediment Removal		Cumulative Unconsolidated Sediment Removal	
	(m ³)	(t)	(m ³)	(t)
1	1,059	1,271	1,059	1,271
2	3,343	4,012	4,402	5,283
3	12,081	14,497	16,483	19,779
4	4,408	5,290	20,891	25,069
5	6,574	7,889	27,466	32,959
6	14,854	17,825	42,319	50,783

Table 5.5 Unconsolidated sediment removal rates (cont'd)

Month (from Start of Mining)	Monthly Unconsolidated Sediment Removal		Cumulative Unconsolidated Sediment Removal	
	(m ³)	(t)	(m ³)	(t)
7	4,463	5,356	46,783	56,139
8	2,832	3,398	49,614	59,537
9	3,506	4,207	53,120	63,744
10	3,477	4,172	56,597	67,916
11	2,124	2,549	58,721	70,465
12	4,576	5,491	63,297	75,956
13	2,049	2,459	65,346	78,415
14	5,502	6,603	70,848	85,018
15	19,431	23,317	90,279	108,335
16	1,793	2,151	92,072	110,486
17	2,997	3,596	95,069	114,082
18	4,068	4,881	99,136	118,964
19	3,989	4,787	103,126	123,751
20	4,447	5,336	107,572	129,087
21	377	452	107,949	129,539

Competent Waste Material

Competent waste material, consisting of waste rock and ore below cut-off grades exists at various locations within the five mineralised mining zones. Additionally, as mining progresses below the seafloor to access the base of the orebody, some benching into waste material will occur.

When removing waste material, the SMT will be fitted with a diversion pipe to pump the material to the unconsolidated disposal points outside the mining area, where it will be side cast (see Figure 5.11). In total, approximately 115,000 t of competent waste material will be side cast over the first 19 months of mining as shown in Table 5.6.

Table 5.6 Competent waste material side casting rates

Month (from Start of Mining)	Monthly Competent Waste Removal (t)	Cumulative Competent Waste Removal (t)
1	500	500
2	1,380	1,880
3	3,550	5,430
4	1,120	6,550
5	5,450	12,000
6	4,070	16,070
7	2,040	28,110
8	6,400	34,510
9	6,590	41,100
10	7,170	48,270

Table 5.6 Competent waste material side casting rates (cont'd)

Month (from Start of Mining)	Monthly Competent Waste Removal (t)	Cumulative Competent Waste Removal (t)
11	3,190	51,460
12	3,120	54,580
13	2,750	57,330
14	4,050	61,380
15	8,170	69,550
16	5,380	74,930
17	5,770	80,700
18	34,280	114,980
19	640	115,620

5.7.2 General Mining Sequence

The general sequence of mining activities will be the same for high-grade and lower-grade zones within the deposit and will include:

- Pre-mining inspections with ROVs, including selective removal and relocation of some organisms (as practicable) from the area to be mined.
- Removal of any unconsolidated sediment material and any competent waste material.
- Levelling of chimneys and cutting of a mining bench with the SMT. Chimneys and any mineralised bench cut materials will be treated as ore and pumped to the MSV via the RALS.
- Open-cut mining with the SMT and pumping of ore via the RALS to the MSV at the surface.
- Dewatering of ore and return of water to the seafloor.
- Transfer of dewatered ore to shuttle barges for transport to temporary storage facilities at the Port of Rabaul.
- Transport of ore from the Port of Rabaul to overseas processing facilities.
- Ongoing environmental monitoring.

Pre-mining Activities

Prior to mining an area, a visual inspection will be carried out by at least one ROV. The ROV will visually survey the area to determine ground conditions prior to the SMT moving into the area. Additionally, the ROV may remove a number of vent-specific snail species (i.e., *Ipremeria* and *Alviniconcha*) and associated fauna from areas to be mined and relocate them in appropriate habitats in areas that have already been mined (see Section 9.6.2 for further details).

Removal of Unconsolidated Sediments and Competent Waste Material

The removal of unconsolidated sediments will be undertaken by one of the ROVs fitted with a suction pump and discharge pipeline. The discharge pipeline will be laid across the seafloor and terminate outside the mining area (see Figure 5.11), where material will be discharged at a rate of 250 m³/h (at a solids to seawater ratio of 4:96).

Competent waste will be removed by the SMT fitted with a discharge pipeline laid across the seafloor and terminating at the same locations as the unconsolidated sediment discharge points. Material will be discharged at a rate of 1,000 m³/h (with a solids to seawater ratio of 1:9).

Ore Mining and Transport to the Surface

Although the operations will be continuous, ore extraction is not expected to be undertaken for more than 20 hours per day, with the remaining time being dedicated to maintenance and re-positioning of the SMT as the mine face advances.

Using the SMT, ore will be mined at a maximum rate of 5,900 t/d and pumped to the MSV via the RALS. Benches formed during ore extraction are expected to be between 2.5 to 3.5 m high. The mine face will advance at an average rate of 180 m/d. Any chimney to be mined will first be knocked over by the SMT cutter head and then mined from the seafloor.

Material will be pumped to the surface at a maximum rate of 1,000 m³/h and will comprise a ratio of seawater to ore of 9:1.

From the time it has been mined, it will take six minutes for the material to be pumped from the seafloor to the surface (a distance of 1,600 m). Material will be drawn in the SMT cutter head at around 3°C and, by the time it reaches the surface, it will have increased in temperature to a maximum of 5.2°C.

Ore Dewatering and Return Water

Once at the surface, ore will be separated from the seawater in the MSV dewatering system, consisting of screens, centrifuges, hydrocyclones and disk filters. Figures 5.12 and 5.13 show the onboard dewatering process. All solid material greater than 8 µm will be recovered and transferred directly via a conveyor to a shuttle barge alongside the MSV for subsequent transport to the Port of Rabaul. By their nature, conveyors are designed to minimise spillage when transporting materials. In addition to inherent designs that will minimise ore spillage, additional measures to further minimise spillage during transfer from the MSV to shuttle barges include:

- Stopping mining and dewatering operations when shuttle barges are being changed over.
- Running the conveyor until it is empty prior to moving loading operations to a new shuttle barge.
- Using removable 'hungry boards' on the conveyors, which assist in containing ore while it is being conveyed.

Dewatered ore will have the following characteristics:

- Minimum bulk density: 2 t/m³.
- Specific gravity: 2.5 to 3.8.
- Moisture content: 5 to 10% by weight.

Separated seawater and solid material less than 8 µm with an expected total suspended solids concentration of 6,350 mg/L will be transferred to a header tank where surface seawater will be added at a rate of 0.04 m³/s (or as required) to ensure a constant volume of water is present in the tank. Prior to being pumped into the header tank, the surface seawater will pass through a 100-µm filter to remove anything that could damage the pumping system.

The seawater mix in the header tank will be pressurised to 100 bar in a two-stage surface pump system onboard the MSV, consisting of a bank of injection pumps and a bank of charge pumps.

The pressurised water will then be pumped down the twin return water pipes to power the subsea slurry lift pump at the base of the RALS (Section 5.6.2). The pipes terminate immediately below the pump, i.e., between 25 m and 50 m above the seafloor, and will discharge return water upwards at a rate of 0.3 m³/s. Upward discharge will allow plume dispersion to occur at a faster rate than if the water was discharged directly downward (see Section 9.5.2 for further details).

The onboard dewatering process will take around 12 minutes and it will take a further 6 minutes for return water to be pumped from the surface to the point of discharge above the seafloor. During descent, the water will be cooled by surrounding seawater due to the relatively large surface area of the return water pipes. Discharge temperatures are expected to vary between 5.8 and 11.4°C, depending on operating conditions (Technip USA, 2008).

Ore Transfer and Barging to the Port of Rabaul

Each shuttle barge will be capable of holding 6,000 t of ore and will either be self-propelled or maneuvered and towed by a dedicated tug boat.

Once the shuttle barge is filled with ore, it will be covered for transit to the Port of Rabaul. It is anticipated that shuttle barges will be filled and transit to the Port of Rabaul between three and nine times each week. A fleet of two tug boats (Plate 5.1) and shuttle barge ore transporters will be utilised for ore transfer activities. The shuttle barges will have the following typical dimensions (Plate 5.2):

- Overall length: 85 m.
- Breadth: 25 m.
- Maximum draft: 5 m.

It will take approximately seven hours for a shuttle barge to be towed between Solwara 1 and the Port of Rabaul at a speed of 4.5 knots.

The shuttle barges will be equipped with sufficient below-deck storage and ore drainage systems to capture any water that drains from the ore during transit. This water will be stored on board the shuttle barges until they return to the MSV, where it will be transferred to the dewatering system during barge loading.

Shore Transfer and Storage in Rabaul

Once at the Port of Rabaul, the tug boat will maneuver the shuttle barge to Berth 1 (Figure 5.3). Ore will be offloaded from the shuttle barge using front end loaders via ramps at a rate of 500 t/h. It is anticipated to take 14 hours to offload all of the ore.

Ore will be transported via conveyor to the storage area and unloaded to a feed pile where it will be fed into a mobile stacker (Plate 5.3) by a front-end loader. The stacker will deposit the ore on one of two stockpiles, each capable of storing 25,000 t. If required, dust suppression will be achieved by spraying recycled water onto conveyors and stockpiles.

The stockpiles will be covered in new-built structures open at two ends as shown in Plate 5.4. The base of each stockpile will be lined with a polymer membrane impervious layer to prevent any runoff or drainage water infiltrating the ground, and bunding will direct runoff water to sedimentation ponds for treatment to ANZECC/ARMCANZ (2000) standards prior to use in dust suppression or return to the MSV for discharge at depth with return water discharge.

Export of Ore

Handysize bulk carriers will export ore to existing overseas concentrators. Characteristics of the carriers are:

- 25,000 deadweight t.
- 160 m overall length.
- 25 m breadth.
- 9 m maximum draft.

The carriers will dock and be loaded at Berth 2 shown in Figure 5.3. The current maximum vessel size capable of berthing at the wharfs is 35,000 dwt. To accommodate potential larger bulk carriers which may be required from time to time by the Project, dredging of the seafloor next to the wharf, which is already part of existing operations at the Port of Rabaul, may be undertaken.

Ore will be loaded onto the bulk carrier via a dedicated mobile ship loader (see Figure 5.3 and Plate 5.5) at a rate of 1,000 t/h. At this rate, it will take between one and two days to load the bulk carrier, depending on its size. Once loaded, the bulk carrier will export the ore to an overseas processing facility. To meet mining rates, between three and six bulk carriers will be required each month.

5.8 Hazardous Materials Management

The classification, packaging, labeling and safe transport of dangerous goods will be the responsibility of manufacturers, suppliers and transport contractors⁴. However, where Nautilus has these responsibilities, it will comply with the relevant statutory requirements (typically the Australian Dangerous Goods Code 2008 (NTC, 2008) and Nautilus will seek the advice of the appropriate authority, where necessary.

Process chemicals will not be required for any stage of mining at Solwara 1 or storage of ore at the Port of Rabaul. Materials to be used that will require management procedures include fuels, solvents, grease, detergents, hydraulic fluid, etc.

5.8.1 Transportation

In most cases, the transportation of materials bound for the MSV will be delivered to the Port of Rabaul and will be the responsibility of contractors until they are delivered to the port. A logistics contractor will be in charge of transporting goods from the Port of Rabaul (or other PNG ports) to the MSV.

A transport procedure will be prepared and included in relevant company documentation, and will include:

- Loading and unloading procedures.
- Control of emissions and spills.
- Cleanup and contingency procedures.
- Vehicle cleaning procedures.
- Operator training and audit procedures.

⁴ Suppliers and transport contractors will be required to comply with Nautilus' standards, which will be defined in their contracts.

Responsibility for each aspect of dangerous goods transport will be clearly established. Written agreements between Nautilus and the producer, PNG Ports Corporation, stevedores and transporters will address the following:

- Packaging as per relevant authority (United Nations (for international sector) and PNG).
- Labelling in both English and Pidgin languages.
- Transport to Port of Rabaul and the MSV.
- Any unloading at Port of Rabaul that may occur.
- Safety of transportation vehicle and security throughout transportation.
- Training of handlers during transportation and unloading.
- Emergency response for the duration of the transportation.

5.8.2 Storage, Handling and Disposal

Storage and handling of hazardous substances will be in accordance with Australian Standards AS 2243.10 (AS/NZS, 1993) and AS 2508 (AS, 2000 and 2001). Nautilus will maintain a register that will include information cards (which will be displayed as required in Pidgin as well as English) and material safety data sheets, prepared by manufacturers or suppliers. Containers of hazardous substances will be labeled in both Pidgin and English.

Nautilus will develop a dangerous goods management procedure, which will include the following:

- Lists of dangerous goods and their quantities and locations.
- Required handling and storage practices.
- Safety and hazard management.
- Audit procedures.
- Contingency, cleanup and disposal procedures.
- Personnel training procedures.

Waste oils, solvents and other hazardous materials will be collected in drums and stored in bunded areas onshore or until transferred to shore (in the case of offshore operations) for collection by the supplier for recycling or disposal to an approved waste disposal facility.

5.8.3 Fuel and Oil

Nautilus will maintain a fuel and oil storage log, including the following information:

- Types and volumes of fuel and oils on the MSV and at Port of Rabaul.
- Locations of storage facilities, storage (both primary and secondary containment) methods.
- Pumping, piping, transfer and separation procedures.
- Fire protection measures.
- Spill containment and cleanup procedures.
- Maintenance, testing and audit procedures.
- Waste oil collection, treatment, recycling/disposal procedures.

5.8.4 Explosives

Explosives are not required by the Project.

5.9 Workforce

5.9.1 Employment Policy

Where practicable, based on Nautilus' Recruitment and Training Policy, preferential employment will be given to suitably qualified PNG citizens (in order of preference: residents of New Ireland,

residents of the New Guinea Islands region, other PNG nationals). Any skills not available within the national community will be provided by expatriates until such time as PNG citizens have been suitably trained.

5.9.2 Workforce

Construction of all offshore Project components will occur at specialised international facilities and, at this stage, no construction is expected to occur within PNG. During operations, the Project is expected to employ approximately 130 people on the MSV and shuttle barge tugs (Table 5.7). The MSV will operate two crews working 12 hours per day (i.e., two shifts per day).

Onshore work involving ore transfer and storage will be undertaken by existing PNG Ports Corporation Ltd employees and no net increase in employment is expected.

Table 5.7 Offshore operations workforce

Department	No. of Employees
MSV	70
Shuttle barge tugs	30
Vessel team	30
Office	10
Total	140 (including office staff)

The offshore workforce will work a roster of four weeks on, four weeks off. Non-resident staff will fly-in, fly-out from Port Moresby on a similar roster. Crew transfers to and from the MSV are expected to be serviced out of Kokopo and or Rabaul.

5.10 Construction and Operating Standards

5.10.1 Design Codes

Equipment and facilities design and construction will be in accordance with applicable codes for PNG. Where no PNG code exists, designs will be in accordance with the appropriate codes and regulations for Australia. If there are no PNG or Australian standards, then appropriate international standards will be used, for example, those of the American National Standards Institute (ANSI) or International Standards Organisation (ISO).

5.10.2 Health and Safety

An occupational health and safety management system (OH&SMS) exists which defines Nautilus' safety policy, and will be implemented to achieve high safety performance. The management system generally complies with the Australian Standard AS/NZS 4804 (AS/NZS, 2001). The OH&SMS will take into account the operating complexities of working offshore, the Project's location and the cultural backgrounds of the workforce.

Components of the management system will include:

- Safety induction, training and awareness education.
- Publication and distribution of a series of safety manuals.
- Hazard identification and risk control.
- Work procedure compliance.
- Auditing and monitoring of safety performance.
- Recognition and achievement of targets.

Written standards for engineering controls, training, chemical storage and transportation will be established and enforced.

A first-aid clinic will be established on the MSV and the first-aid facilities at the Port of Rabaul will be inspected and upgraded if necessary, with procedures in place for medical evacuation to hospitals at Rabaul or Kavieng, Port Moresby, or Australia, as deemed necessary.

Preventable health care will focus on issues that control sanitation (particularly potable water), garbage disposal, food services, pest control, laundry services, personal hygiene and protective measures.

5.11 Commissioning

The ramp-up process for offshore operations at Solwara 1 will be gradual. Full commissioning of the offshore mining activities is expected to take approximately three to six months by which time the operation, both offshore and onshore, should be operating at full capacity.

5.12 Decommissioning and Closure

When the mining operations are complete, the underlying natural hydrothermal energy, which has remained unchanged, will enable venting to resume and associated chimneys to reform at the same or nearby locations to where they previously occurred. As the vents provide the sulphidic trophic basis for the ecological characteristics of the Project area, a succession of vent-dependent communities is expected to re-establish over time. The process of recovery at Solwara 1 will be enhanced by various mitigation strategies described in Section 9.6.2, and regular monitoring of recolonisation by those and other organisms forms a part of the environmental management and monitoring program as described in Section 13.

Specific aspects of decommissioning and closure of offshore infrastructure and onshore facilities are considered below.

5.12.1 Offshore Infrastructure

Once mining is complete at Solwara 1, all components of the offshore mining operation, e.g., the MSV, SMT and RALS, will be recovered and removed from Solwara 1. The equipment will be shipped to another site to commence mining in a location where seafloor mining has been approved, either within PNG or overseas.

5.12.2 Onshore Facilities

Operations at the Port of Rabaul are expected to cease prior to completion of mining activities at Solwara 1, i.e., when Phase 2 of the Solwara Project commences, all onshore operations will be transferred to the yet-to-be-determined location of Phase 2 operations.

Decommissioning of infrastructure at the Port of Rabaul will be limited to the conveyors and ship loaders. This equipment will either be sold to the port authority or dismantled and taken for use at the Phase 2 facility.

Ore stockpile areas will be returned to a state suitable for alternative uses as agreed with the port authority. Any contaminated stockpile soil, and the impervious lining and bunds will be safely buried or treated.

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6. DEVELOPMENT TIMETABLE

The overall schedule to first ore, including government approvals and Project development, is shown in Figure 6.1.

Engineering and mine design have occurred concurrently with the environmental investigations and preparation of the EIS. Results of the EIS investigations have informed the design of the mine layout and selection of equipment required for the Project.

Key milestones in the Project timetable are:

- Submission of the EIS and mining lease application in the third quarter of 2008.
- Development Forum to be held during the first quarter of 2009.
- Memorandum of Agreement to be completed in the first quarter of 2009.
- Receipt of EIS approval and issue of a mining lease by the end of the first quarter of 2009.
- Port of Rabaul facilities commissioned in the second quarter of 2010.
- Mining equipment integration completed and pre commissioned by the third quarter of 2010.
- First ore in the fourth quarter of 2010.

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7. DESCRIPTION OF THE EXISTING ENVIRONMENT

7.1 General

This chapter describes the current environmental setting of the offshore, nearshore and onshore Project area. That is, the offshore area of the mineral resource at Solwara 1, the nearshore and onshore area of the port operations at and directly offshore the Port of Rabaul in Simpson Harbour and the route between, as defined in Sections 1.7 and 5.1 and shown in Figures 1.2 and 1.3. Much of the information summarised in this chapter is taken from studies that have been undertaken by Nautilus and these are described in Section 7.2, supplemented with other relevant literature, observations made during field studies and personal communications. The existing offshore environment is described under headings of hydrothermal vents (Section 7.3), meteorology and air quality (Section 7.4), oceanography (Section 7.5), water quality (Section 7.6), sediment quality and mineralogy (Section 7.7) and biological environment (Section 7.8). The nearshore and onshore environment at the Port of Rabaul is discussed in (Section 7.9).

Geological processes including regional tectonics, seismicity and volcanism significantly impact on the environmental conditions within the Project area. As a result, sometimes air, water and sediment quality parameters fail to meet national, international and Project-adopted criteria (Chapter 3). Biological communities in the Project area are those that have adapted to and can cope with these conditions. In addition, these communities are exposed to periodic sudden changes (such as volcanism, variability of hydrothermal venting activity, etc.). In other words the environmental setting in the Project area is not constant, and can even fluctuate wildly over relatively short time frames.

Solwara 1 is a deep sea site which exhibits some hydrothermal venting. Hydrothermal vent ecosystems are based on chemosynthesis (Van Dover, 2000a), meaning the immediate vent organisms derive energy from chemical nutrients rather than sunlight, which is used for energy in photosynthesis. Applying water or sediment quality criteria or toxicity protection limits developed for surface organisms is not relevant for these vent organisms. Where such data is used in this EIS, it is provided to allow comparative (and most likely conservative) indications of conditions. The data does not represent any thresholds for organisms of the hydrothermal seafloor areas of the deep sea.

7.1.1 Tectonics and Seismicity

PNG straddles several major tectonic plate boundaries and is part of the Pacific 'Ring of Fire'¹ (Figure 7.1). Modelling indicates that the India–Australia and Pacific plates are moving towards each other at a rate between 3 and 10 cm/a (Greenbaum et. al., 1995). The complex movement of the plates has resulted in significant faulting and seismic activity, creating the potential for both shallow- and large-magnitude earthquakes on land and in the sea. Consequently, the PNG region is one of the most seismically active zones in the world, regularly experiencing earthquakes of

¹ The Pacific 'Ring of Fire' is an area of frequent earthquakes and eruptions encircling the Pacific Ocean in a horseshoe shape. It is associated with an almost continuous chain of oceanic trenches, volcanic arcs and belts, and plate movements. Over 50% and 90% of the world's volcanoes (active and dormant) and earthquakes, respectively, are located along the 'Pacific Ring of Fire' (USGS, 2003).

magnitude 7.0 or more on the Richter scale (Figure 7.2). The geological setting of the project seafloor area is described in more detail in Section 7.7.

Solwara 1 is located on volcanic rocks relating to the Bismarck Sea Seismic Lineation (BSSL), which divides the North and South Bismarck plates and is spreading at a rate of 11 to 14 cm/a. Most earthquakes produced on the BSSL have been small and shallow and no damaging earthquakes have originated from here in recorded history (Appendix 14).

The PNG earthquake loadings code indicates that the Solwara 1 deposit is located within Zone 2 (where Zone 1 is most unstable) and the Port of Rabaul component of the Project is located within Zone 1 (PNGS, 1982). The more stringent Global Seismic Hazard Assessment Program (GSHAP) specifies a 10% chance of exceedance (of a ground motion parameter) within the assumed life of the structure – PNGS (1982) specifies 15% – and has assessed the Rabaul area as having a peak ground acceleration range of 4.0 g to 4.8 g (a very high hazard) for a return period of 475 years (Giardini, et. al., undated)) (Figure 7.3).

7.1.2 Volcanism

Volcanic activity and hydrothermal venting associated with the Solwara 1 site are described in Section 7.3.

The plate movements described in Section 7.1.1 have resulted in a significant subduction zone where the Solomon Plate has moved beneath the South Bismarck Plate. An island arc, the Bismarck Volcanic Arc System that extends from the East Sepik Province to Rabaul, is associated with this subduction (Greenbaum et. al., 1995) (see Figure 7.2). There are 14 active volcanoes in PNG, most of which are located on the Bismarck Volcanic Arc System (Geological Survey PNG, undated).

The Rabaul Caldera is located on the Gazelle Peninsula (northeast New Britain Island; see Figure 7.4) and was formed by a volcanic eruption approximately 7,100 years ago that was thought to have originated offshore to the north. Simpson Harbour was formed by the flooding of the caldera about 1,400 years ago. Volcanoes within the Rabaul Caldera have formed during large post-caldera eruptions and have produced major explosive activity (Volcano World, 2005).

Of the eight active vents in the Rabaul Caldera, two erupted simultaneously in 1994 destroying the town of Rabaul (Volcano Live, 2008). Aeroplane pilots flying in the area reported ash clouds up to 18 km above the town that extended over the PNG mainland. Ash fell over extensive areas of land turning to mud with rain and then drying as hard as cement. Lava flowed and rocks were thrown into the bay causing flooding (Geoscience Australia, 2008), buildings collapsed and the airport was permanently closed.

There have been a number of eruptions since 1994, with the most recent activity in the Rabaul Caldera focussing on Tavurvur Volcano, which is constantly active (Plates 7.1 and 7.2).

7.1.3 Tsunamis

Tsunamis are waves caused by large-scale underwater movement, such as earthquakes, volcanoes or landslides that displace water. Transfer of energy from falling debris (e.g., from volcanic eruptions) which fall at a rate faster than the ocean can absorb, can also displace large volumes of water causing a tsunami. These tsunamis however, are more localised and may dissipate quickly.

Since 1888, there have been 14 tsunami-induced tidal surges recorded at Rabaul, of which 9 occurred last century and 4 this century. Associated wave heights depend on location and historically have ranged from less than one metre up to tens of metres for an individual event (Saunders, pers. com., 2008a). One of the more devastating tsunamis occurred on 17 July 1998 when a series of tsunamis hit the north coast of PNG near the settlement of Aitape in West Sepik Province. The tsunamis were caused by an earthquake of magnitude 7.0 that occurred approximately 25 km off the coast and resulted in a subsea landslide (slumping seabed sediments), which in turn triggered the tsunami. Wave heights of 10 to 15 m were estimated and the tsunami resulted in the deaths of over 2,000 people.

7.2 Studies Completed

Nautilus and others have actively explored the Manus Basin, including Solwara 1, since the early 1990s. The main objective of the exploration activities has been to assess the mineral resources of the seafloor massive sulphide deposits and to provide the equipment platform for conducting baseline environmental studies of the area. Once the potential viability of the resource became apparent in the mid to late 1990s, significant ship and ROV time has been devoted to gathering baseline environmental data from the area in order to understand the oceanographical, chemical and biological setting of the area, and this now represents the most comprehensive sampling of vent sites in Manus Basin and of inactive sulphide mounds to date. The studies are listed below, under the headings of:

- Biological.
- Engineering.
- Geophysical.
- Oceanography.
- Resource investigation.
- Water quality.
- Other.

These are summarised, where applicable, in Chapters 7 and 8 and listed in Table 7.1.

Table 7.1 Geophysical and environmental studies completed at Manus Basin

Type of Survey/Study	Company/ Research Group	Date Studied	Brief Description of the Study	Reference
Biological	E.A. Blake, K.L. Erickson and C.L. van Dover	1985 to 1998	A review of the biology of chemosynthetic ecosystems in Manus Basin.	Blake <i>et al.</i> , 2005
	E.C. Southward and S.V. Galkin	May 1990	A new vestimentiferan (Pogonophora: Obturata) from hydrothermal vent fields in the Manus Back-arc Basin (Bismarck Sea).	Southward & Galkin, 1997
	S.V. Galkin	June 1990	Megafauna associated with hydrothermal vents in the Manus Back-arc Basin (Bismarck Sea).	Galkin, 1997
	CSIRO (Australia)	1991 to 2007	CSIRO was engaged to complete three modules of study for the Manus Basin baseline environmental study. Module 1 identified information already available from the Bismarck Sea (incl. initial and preliminary studies), Module 2 provided a gap analysis and Module 3 involves sediment analysis, vent plume mapping, water analysis and endemism studies.	Appendix 1, Appendix 2, CSIRO, 2005; CSIRO, 2007.

Table 7.1 Geophysical and environmental studies completed at Manus Basin (cont'd)

Type of Survey/Study	Company/ Research Group	Date Studied	Brief Description of the Study	Reference
Biological (cont'd)	Specialised Hydrothermal Vent Research Group	1996 and 1998	Results of the BIOACCESS cruises '96 and '98 over hydrothermal vent communities in the Manus Basin, Papua New Guinea.	Hashimoto <i>et al.</i> , 1999
	L. Kumoru	1998 to 2002 (but mainly focuses on 2002)	The shark longline fishery in Papua New Guinea.	Kumoru, 2003
	L. Kumoru and L. Koren	2001 to 2005	Tuna fisheries report in Papua New Guinea.	Kumoru & Koren, 2007
	C. L. van Dover	2005 - ongoing	Global sulphide mound ecosystems research that compared different hydrothermal vent sites in terms of their associated biology and vent activity.	
	James Cook University (Australia)	January/ February 2006	Macrofauna research project that investigated the macrofauna of the sediments and sedimentary characteristics of the Solwara 1 hydrothermal field. Sample material collected using ROV-operated box cores.	
	University of Toronto (Canada)	January/ February 2006	Microfauna research project that investigated the microfauna of the Solwara 1 hydrothermal field. Sample material collected using ROV-operated push cores.	
	Hydrobiology (Australia)	March 2007	Solwara 1 Project biomass, biodiversity and bioaccumulation desktop study.	Appendix 10
	Duke University and College of William and Mary (USA)	2007 to 2008	Characterisation and comparison of macrofauna at inactive and active sulphide mounds at Solwara 1 and South Su (Manus Basin).	Appendix 4
	Scripps Institution of Oceanography, La Jolla (USA)	2008	Macroinfauna of active and inactive hydrothermal sediments from Solwara 1 and South Su, Manus Basin, Papua New Guinea.	Appendix 5
Engineering	Earth Mechanics Institute	2004	Linear cutting test results for mechanical mining of sub-sea poly-metallic sulphides.	Earth Mechanics Institute, 2004
	E. Jackson	2004 to 2005	Solwara 1 Project rock-cutting test program.	Jackson, 2006
	Technip Offshore Inc. (France)	2005	Pre-feed report.	Technip Offshore, 2005

Table 7.1 Geophysical and environmental studies completed at Manus Basin (cont'd)

Type of Survey/Study	Company/ Research Group	Date Studied	Brief Description of the Study	Reference
Engineering (cont'd)	Worley Parsons Services Pty Ltd	June 2005	Pre-feasibility study (PFS), which concluded that much of the technology required for the project was already available from the offshore oil, gas and telecommunications industries. The study further assessed the Project on a financial basis and found that the mining venture could be economically competitive with terrestrial mines.	Worley Parson, 2005
	Technip Offshore Inc. (France)	January 2006	A riser and jumper analysis report.	Technip Offshore, 2006a
	Technip Offshore Inc. (France)	February 2006	Investigation of potential dewatering systems for Solwara 1.	Technip Offshore, 2006b
	Cellula Robotics (Canada)	February 2006	Subsea cutting test that investigated the performance of an excavator deployed to the ocean floor at depth 1,500 to 1,700 m. The purpose of the trial was to determine excavator and cutterhead performance under hydrostatic pressure and depth.	Devaux & Clarke, 2006
	Cellula Robotics (Canada)	August 2006	A description of various mining concepts for Solwara 1.	Cellula Robotics, 2006
	Klohn Crippen Berger Ltd. (KCBL)	November 2006	Assessment of various sites in PNG for suitability for establishing the on-land (site processing) facilities for the operation.	Klohn Crippen Berger, 2006
Geophysical	F. Martinez and B. Taylor	1985	Back-arc spreading, rifting, and microplate rotation, between transform faults in the Manus Basin. Primarily based on the results from the RV <i>Moana Wave</i> cruise.	Martinez & Taylor, 1996
	Williamson and Associates	February 2005	A geophysical survey using geophysics, sonar, IP, resistivity, SP, magnetics and gravity measurements.	
	Century Subsea (UK) and Williamson and Associates	2005 to 2006	Generation of a detailed bathymetric map of Solwara 1 site using side scan sonar.	

Table 7.1 Geophysical and environmental studies completed at Manus Basin (cont'd)

Type of Survey/Study	Company/ Research Group	Date Studied	Brief Description of the Study	Reference
Geophysical (cont'd)	Collaboration of College of William and Mary (USA), James Cook University (Australia) and University of Toronto (Canada) on behalf of Placer Dome and Nautilus	January 2006	Video survey of the seafloor, including chimney locations and other geological and biological observations.	
	E. Hrischeva and S. Scott	2006 to 2007	Quality including trace elements of sediments from the SuSu Knolls, Manus Basin, Bismarck Sea, Papua New Guinea. Draft report prepared for Nautilus Minerals Inc, Milton, Queensland.	Appendix 6
Oceanographic	G. Cresswell	1985 to 2002	Regional oceanographic characterisation.	Cresswell, 2007
	AIMS and The Nature Conservancy	1997 to 2002 (currents and temperatures), 1998 to 2001 (sea surface temperature)	Currents in the Bismarck Sea and Kimbe Bay, Papua New Guinea.	Steinberg <i>et al.</i> , 2006
	Enesar Consulting Pty Ltd. (Australia)	December 2005, January 2006	Two full ocean water column current metering profiles and two profiles of conductivity, temperature, salinity and transmissivity.	Enesar, 2006a
	Triton Consultants Ltd.	April 2006	Metocean data summary that examined commercial sources of meteorological and oceanographic data.	Triton, 2006
	RPS MetOcean	August 2008	Study identifying specific meteorological and oceanographic criteria for mining system components.	RPS Metocean, 2008
Resource investigation	R. Moss, S. D. Scott and R. A. Binns	1991, 1993, 1995, 1996	Gold content of Eastern Manus Basin volcanic rocks and its implications for enrichment in associated hydrothermal precipitates.	Moss <i>et al.</i> , 2001
	R. A. Binns and S. D. Scott	October 1991	Actively forming polymetallic sulphide deposits associated with felsic volcanic rocks in the Eastern Manus Basin.	Binns & Scott, 1993

Table 7.1 Geophysical and environmental studies completed at Manus Basin (cont'd)

Type of Survey/Study	Company/ Research Group	Date Studied	Brief Description of the Study	Reference
Resource investigation (cont'd)	R. Moss and S. D. Scott	PACMANUS cruises II, III, and IV (1993, 1996-1997) and 1995 <i>Manusflux</i> cruise	Geochemistry and mineralogy of gold-rich hydrothermal precipitates from the Eastern Manus Basin, Papua New Guinea.	Moss & Scott, 2001
	E. Hrischeva, S.D. Scott, and R. Weston	1996 to 1997	Metalliferous sediments associated with presently forming volcanogenic massive sulphides in the SuSu Knolls hydrothermal field, Eastern Manus Basin, Papua New Guinea.	Hrischeva <i>et al.</i> , 2007
	A.M.M. Pinto, F.J.A.S. Barriga and S.D. Scott	2000 to 2001	Sulphide and oxide mineral chemistry of an active back arc hydrothermal systems: PACMANUS, ODP holes 1188A, 1188F, 1189A, and 1189B.	Pinto <i>et al.</i> , 2003
	A.M.M. Pinto, J.M.R.S. Relvas, F.J.A.S. Barriga, J. Munha, N. Pacheco and S.D. Scott	2005	Gold mineralisation in recent and ancient volcanic-hosted massive sulphides: the PACMANUS field and the Neves Corvo deposit.	Pinto <i>et al.</i> , 2005
	Placer Dome	January 2006	Detailed mineralogical analyses of the polymetallic sulphide material mined from the Manus Basin.	
	Seacore (UK)	January/February 2006	Drilling program, including trial cutting tests and bulk sampling, that provided an opportunity for a number of environmental investigations.	
	Donald Bren School of Environmental Science and Management Thesis	2006	A case study of potential deep-sea mining of seafloor massive sulphides in Papua New Guinea.	Birney <i>et al.</i> , 2006
Water quality	Enesar Consulting Pty Ltd. (Australia)	February 2006	Water sampling undertaken during the drilling program. Parameters measured included physico-chemical variables, inorganic species and total organic carbon.	Enesar, 2006b
	CSIRO Land and Water, Australia	April 2007	Water and sediment characterisation and toxicity assessment for the Solwara 1 Project.	Appendix 7

Table 7.1 Geophysical and environmental studies completed at Manus Basin (cont'd)

Type of Survey/Study	Company/ Research Group	Date Studied	Brief Description of the Study	Reference
Other	S. D. Scott and R. A. Binns	1995	Hydrothermal processes and contrasting styles of mineralisation in the western Woodlark and eastern Manus Basins of the western Pacific.	Scott & Binns, 1995
	J.M. Parr and E.A. Binns	1997	Report on the PACMANUS-III cruise, RV <i>Franklin</i> , Eastern Manus Basin, Papua New Guinea: Exploration and Mining.	Parr & Binns, 1997
	D.A. Vanko, W. Bach, S. Roberts, C.J. Yeats and S.D. Scott	2000 to 2001	Fluid inclusion evidence for subsurface phase separation and variable fluid mixing regimes beneath the deep-sea PACMANUS hydrothermal field, Manus Basin back-arc rift, Papua New Guinea.	Vanko <i>et al.</i> , 2004
	R. Binns	2004	Guides for volcanogenic massive sulphide exploration from a modern seafloor analogue, Eastern Manus Basin, Papua New Guinea.	Binns, 2004
	SRK Consulting	February to March 2005	Independent technical assessment of exploration tenements in the Bismarck Sea and the Solomon Sea, Papua New Guinea.	Hodkiewicz <i>et al.</i> , 2005
	SRK Consulting	February to March 2005	Independent technical assessment of seafloor massive sulphide exploration tenements in Papua New Guinea and Fiji.	Jankowski & Hodkiewicz, 2006
	M. Tivey, W. Bach, J. Seewald, M. Tivey, and D. Vanko	2006	Fluid chemistry and magnetic structure as guides to seafloor processes in hydrothermal systems in the Eastern Manus Basin.	Tivey <i>et al.</i> , 2006
	S. Saunders	2008	The potential for natural disasters being triggered by mineral extraction at the Solwara 1 seafloor hydrothermal vent site.	Appendix 14

7.3 Hydrothermal Vents

7.3.1 Introduction

Seafloor hydrothermal vents were first discovered in 1976 on the Galapagos Rift in the Pacific Ocean and the first major studies commenced in 1977 (Desbruyères *et al.*, 2006). Since then, hydrothermal vents have been found on the seafloor close to tectonic plate boundaries all over the world (Halbach *et al.*, 2003). Hydrothermal vents are of particular interest to biologists as they support a much higher abundance of fauna compared to surrounding deep-sea environments. Locations of some well-studied hydrothermal vent sites are provided in Figure 7.5.

Hydrothermal vents are usually found along mid-ocean ridges and back-arc basins. Mid-ocean ridges are underwater mountain ranges that are formed through the movement of tectonic plates away from each other and typically have a valley, known as a rift, running along their axis (Van Dover, 2000b). Back-arc basins, such as the Manus Basin, are formed where tectonic plates meet and move towards one another, with one plate sliding underneath the other. The downward force of the sinking plate pulls on the edge of the overlying plate, causing it to split. This split allows magma to flow upwards, forming underwater volcanoes. The back-arc basin is the basin formed behind these volcanoes (Figure 7.6).

Hydrothermal vent systems are formed when cold seawater is drawn into the oceanic crust in the seafloor near the mid-ocean ridges and back-arc basins. This water becomes heated to temperatures of up to 400°C by molten magma, rises to the surface and flows out of openings along cracks (i.e., hydrothermal vents) in the ridges and basins (Alt & Bach, 2003, Halbach *et al.*, 2003).

Chimneys are often associated with hydrothermal vents and are formed when the hot and acidic hydrothermal vent fluid (approximately 350°C) interacts with cold seawater (2°C), releasing elements into the water and causing minerals to precipitate as shown in Figure 7.7. These minerals form chimney-like structures around the vents and can sometimes produce smoke-like clouds, which can be rich in copper, gold, zinc, iron, manganese, carbon dioxide and sulphur (Halbach *et al.*, 2003).

When chimneys first form, their walls are comprised of calcium sulphate (anhydrite) and as the chimneys develop, the anhydrite forms a surface onto which copper-iron-sulphide (chalcopyrite) precipitate binds (see Figure 7.7). Chimneys become more metal rich with time as aqueous ions including copper, iron, hydrogen sulphide, zinc, sodium, chloride and magnesium are transported from areas of high concentration to areas of low concentration by diffusion and deposit on the inner walls of the chimneys (Tivey, 1998).

Large concentrations of sulphides can accumulate near hydrothermal vents, such as at Solwara 1, and are known as Seafloor Massive Sulphide (SMS) deposits (Alt & Bach, 2003; Halbach *et al.*, 2003). The formation of these deposits is caused by the precipitation of sulphides in the chimneys and underlying volcanic rock. Mounds of sulphide talus often form on the seafloor when chimneys fall over and as further sulphides precipitate within the mound, the size of the deposit slowly increases (see Figure 7.7) (Alt & Bach, 2003; Halbach *et al.*, 2003).

7.3.2 Vent Environment and Biology

There are a number of fundamental characteristics of active hydrothermal areas that influence biology, the most important of which is the chemistry of the fluid emitted from actively venting chimneys or as diffuse flow.

Some micro-organisms² can make use of the chemicals from the fluid chemistry to produce energy (note: there is no photosynthetic primary production at these depths). Some animals consume the micro-organisms directly, while in others, the micro-organisms reside as endosymbionts, i.e., living within the host animal tissues to provide the source of energy. The

² These include Eubacteria and Archaea, which are bacteria-like prokaryotes, having no cell nucleus or any other organelles within their cells.

animal communities around the vents typically include species of tube worms, gastropods, bivalves and crustaceans.

The endosymbiotic relationship enables the generation of extremely high biomass, and the animals are adapted for tolerance of sulphides and heavy metals at levels to which surface organisms are not typically exposed. Many of these animals are dependent on the micro-organisms that break down hydrogen sulphide and cannot exist away from the influence of vents activity. Where the vent system has become inactive or extinct, the animals cannot survive and these are termed vent-dependent or vent-obligate species.

Vent temperatures are highly variable and cover a range from a few degrees above ambient to 350°C (Tivey, 1998). The microbial populations can survive in temperatures up to 121°C (Kashefi & Lovley, 2003), whereas the host invertebrate populations (for example, *Alviniconcha* sp.) tend to live at more modest temperatures, generally at or below 40°C (Henry *et al.*, 2008).

Since their first discovery, the number of species recognised from published descriptions of deep-sea hydrothermal environments, including those associated with the dominant snail, worm and mussel beds, is over 500 (Desbruyeres *et al.*, 2006). In vent sediments, one or two species usually make up 70 to 90% of total abundance. In non-vent deep sea sediments, abundances are more evenly distributed among species, with the single most common species making up less than 20% of the total (Van Dover, 2000a).

With increasing distance from active areas, seafloor sediments show a transition to inactive areas, where there is no flux of hydrothermal fluids. In these areas, macrofauna communities are different from those at active areas. Apart from those associated with whale falls, methane seeps and cuttings piles around petroleum drilling, for example, animals occur at much lower biomass in the inactive sites. In some areas, inactive SMS deposits may cap thermal systems and these may begin to vent if they are disturbed, for example, by drilling. This was observed at Solwara 1 where, following drilling, active venting was seen to occur from a drill hole (see Section 7.8.2) as shown in Plate 7.3.

7.3.3 Issues and Studies

Scientific interest in the biological communities of hydrothermal vent systems has greatly increased since first discovery. As scientific understanding has grown, so to have concerns about the potential impacts of exploitation. Workshops and seminars of the International Seabed Authority and other forums have discussed a need to consider management and conservation. While there are positive scientific impacts of exploration, including discoveries of new sites and opportunities to study ecosystems in extreme environments, actual development by mining could have negative impacts such as:

- Potential loss of habitat and degradation of habitat quality.
- Potential local, regional or wider-scale loss of endemic or rare species.
- Potential decreased diversity of species or higher taxonomic levels.
- Potential loss of knowledge or of other future opportunities (i.e., of what we do not know).

In consequence, Nautilus has committed from the outset to combine exploration work and background research by engaging world experts in deep-sea hydrothermal vent ecology and by devoting substantial ship and ROV time specifically to environmental studies. The nature of these studies and the tasks undertaken were developed in consultation with marine and deep sea experts and also with input from other government and NGO stakeholders, as described in Chapter 4.

The earlier PACMANUS discovery cruises provided an extensive baseline of the seafloor geological and biological setting of the offshore Project area from which to extend those studies, and to determine the risks from mining to the seafloor environment at Solwara 1, South and North Su. The reports of these studies are attached to this EIS and the results are summarised mainly in Chapters 7 and 9. The area is now the best-studied hydrothermal vent ecosystem in the Manus Basin and the scientists were involved in the designing of the mitigation measures that have been developed to meet environmental protection, as described in Chapters 9 and 13.

7.4 Meteorology and Air Quality

7.4.1 Climate

The climate of the Project area, based on data collected from East New Britain and central New Ireland, is described as Lowland Humid (McAlpine *et al.*, 1983), a category which includes regions with elevations between 0 and 500 m and annual rainfall between 2,000 and 3,500 mm. Relative humidity is high throughout the year and shows little seasonal variation, with an annual average of about 80 to 85%.

Temperature and Rainfall

Temperature in the Project area is fairly constant with the monthly average ranging between 27 and 30°C year round. The consistency in temperature explains why the degree of seasonality in PNG is actually a reflection of the difference between the wettest and the driest periods of the year (McAlpine *et al.*, 1983).

During the northwest monsoon season (the wet season), the highest rainfall occurs in January. In Rabaul (East New Britain) and Namatanai (central New Ireland), the average monthly rainfall in January is 352 mm and 438 mm, respectively (McAlpine *et al.*, 1975). During the southeast monsoon season (the dry season), the lowest rainfall is recorded in September, during which time the average monthly rainfalls for Rabaul and Namatanai are 86 and 125 mm, respectively.

Winds

Weather in the Bismarck Sea is driven by the larger weather patterns over the Pacific Ocean and the Project area experiences two very distinct seasons associated with the Southeast Asian/Australian monsoon system. The southeast monsoon season extends from May to October and the northwest monsoon season occurs from November to April.

Northwest trade winds bring in low-pressure troughs resulting in heavy rainfall during the northwest monsoon (wet) season. Historical data collected over 23 years from 1946 to 1969 shows that northwesterly winds dominate the Project area in January and strengthen during the day. The northwesterlies are not as well developed in the transition period around April and are replaced in July by moderate to fresh south-southeasterly winds that are relatively constant throughout the day. The southeasterly monsoon season gradually weakens and the cycle is completed by the strengthening of the northwesterly component and return to January conditions (McAlpine *et al.*, 1983).

Relevant climatic data for the Bismarck Sea is held by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and was obtained for the purposes of this report from the CSIRO Division of Marine Research. Wind roses prepared using the CSIRO data, collected over 16 years up until 2002, are shown in Figure 7.8.

Cyclones

The frequency of tropical cyclones, with sustained surface winds of greater than 34 kt (62 km/h), is very low in the PNG region (McAlpine *et al.*, 1983), the near-equatorial latitudes being outside the cyclone belt. The Bismarck Sea has, in recent history, been free of tropical cyclone activity (Triton, 2004).

7.4.2 Air Quality

Air quality at Solwara 1 has not been monitored. However, given the remoteness of the site, which is situated in the Bismarck Sea at least 50 km from any significant industrial and other anthropogenic sources, background air quality is likely to be near pristine. Localised, episodic periods of elevated particulate matter may occur due to the activities of Tavurvur Volcano, located 50 km to the south at the entrance to Simpson Harbour, Rabaul. Figure 7.9 shows a plume of ash and steam from the active Tavurvur Volcano adjacent to Rabaul (see Figure 7.4) extending over the Bismarck Sea on 29 May 2008.

Air quality for the onshore component of the Project is discussed in Section 7.9.5.

7.5 Physical Oceanography and Deep Sea Sedimentation

Oceanographic conditions at Solwara 1 and South Su have been characterised through a number of investigations, including:

- A review of existing oceanographic data in the Bismarck Sea (Cresswell, 2007).
- Oceanographic profiles through the water column (i.e., temperature, salinity, conductivity, transmissivity and photosynthetically active radiation [PAR]).
- In situ measurements of ocean currents over the entire water column (surface to the seafloor), covering a non-contiguous, 12-month period.
- Deep-sea sedimentation rates and the chemical properties of the material collected (with the latter discussed in Section 7.7).

Findings are summarised below and a detailed analysis of results are provided in Appendix 3.

7.5.1 Regional Current Circulation

Surface Currents

During the southeast monsoon season (May to October) the major surface current system of the Pacific Ocean involves a broad westward flow of water on the northern arm of the South Pacific gyre³.

This wind-driven, surface-current system, known as the Southern Equatorial Current (SEC) produces current flows through the Coral Sea that branch north when they meet northeastern Australia. These currents meet to form the New Guinea Coastal Current (NGCC) (Figure 7.10). The NGCC flows through the Louisiade Archipelago and Vitiaz Strait into the Bismarck Sea (see

³ A gyre is any manner of swirling vortex. It is often used to describe large-scale wind or ocean currents. Gyres are caused by the Coriolis effect, the planetary vorticity along with horizontal and vertical friction that determine the circulation patterns from the wind curl (torque).

Figure 7.1 for the location of seas, archipelagos and other features). The more northern component of the SEC tends to flow past the Solomon Islands and can either enter the Bismarck Sea through St Georges Channel or Ysabel Channel from the north.

During the northwest monsoon season (November to April), the NGCC and the northern arm of the East Australian Current can reverse direction and flow southeast through the Vitiaz Strait along the northern coast of Papua New Guinea (Steinberg *et al.*, 2006).

The Bismarck Archipelago acts as a barrier to the main SEC flow and any circulation outside the major current pathways is likely to be characterised by complex flows and recirculations in the sheltered side of the island arcs, especially during the prevailing southeast monsoon season (Steinberg *et al.*, 2006).

Computer modelling indicated that surface currents enter and leave the eastern Bismarck Sea in the vicinity of Solwara 1 through St Georges Channel (King, pers. com., 2007).

Sub-surface Currents

Below the surface, large-scale sub-surface currents flow through the waters of PNG (Wells *et al.*, 1999). The New Guinea Coastal Undercurrent transports water at 220 m depth from the Solomon Sea, through the Vitiaz Strait and into the Bismarck Sea (Figure 7.10). Further to the east, the St Georges Undercurrent enters the Bismarck Sea from the Solomon Sea, eventually flowing in a westerly direction at 220 m water depth. The two sub-surface currents flow in the same direction year-round. They meet in the eastern Bismarck Sea and flow to the northwest until reaching the equator, where they turn to the east and form the Equatorial Undercurrent.

7.5.2 Tides in the Eastern Bismarck Sea

The Bismarck Sea predominantly experiences diurnal tides (one high and one low per day) with flooding and ebbing occurring over 12 hours (with a correspondingly large tidal excursion⁴). Tides have a maximum vertical range of 1 m (during spring tides), and sea level anomalies (tides, seasonal cycles and trend removed) for the region are highly correlated with the Southern Oscillation Index (SOI)⁵, as the Bismarck Sea is located in the Western Pacific Warm Pool⁶. Local trade wind changes associated with El Nino Southern Oscillation (ENSO) therefore directly affect the local sea levels (Steinberg *et al.*, 2006).

7.5.3 Oceanography at Solwara 1

Water Column Structure

CSIRO undertook six oceanographic campaigns between 1985 and 2005 in the Bismarck Sea in close proximity to (and directly over) Solwara 1. During this period, over 80 oceanographic profiles were performed from the surface to the seafloor and measured the changes in temperature, salinity, oxygen and turbidity with depth.

⁴ The net horizontal distance over which a water particle moves during one tidal cycle of flood and ebb; the distances traversed during ebb and flood are rarely equal in nature, since there is usually a layered circulation, with a net surface flow in one direction compensated by an opposite flow at depth.

⁵ SOI is based on the (atmospheric) pressure difference between Tahiti and Darwin, Australia.

⁶ The Western Pacific Warm Pool has the highest mean annual sea surface temperatures on earth ranging from 28°C to greater than 29.5°C. Because of the high temperatures, the Warm Pool supplies the earth's atmosphere with a large portion of its water vapor and heat, largely in the form of latent heat.

In addition, Nautilus has thus far conducted over 35 oceanographic profiles at Solwara 1 from 2005 to 2008 and measured salinity, temperature, transmissivity and photosynthetically active radiation (PAR).

Interpretation of available data indicates that the surface mixed layer⁷ at Solwara 1 varies in depth from the surface to 185 m below the surface (Figure 7.11), while the euphotic zone⁸ thickness has a range of 33 to 80 m below the surface. Surface light does penetrate below the euphotic zone, and in some cases reaches depths of over 200 m, but is insufficient for photosynthesis to take place and is known as the dysphotic zone.

Current Velocity

Current velocity data has been collected at Solwara 1 over the period August 2006 to February 2008 using four Acoustic Doppler Current Profiler (ADCP) current meters (Plates 7.4 and 7.5 and Figure 7.12) which enabled the measurement of three-dimensional currents through the water column (i.e., from the surface to the seafloor). An additional earlier short-term survey in January 2006 was undertaken at Solwara 1 using a number of current meters.

On average, current speed in the upper 400 m of the water column at Solwara 1 ranges between 10 and 20 cm/s. Strongest horizontal current speeds across the whole water column were observed at approximately 250 m depth and occasionally exceeded 40 cm/s. Year-round net water drift in the upper water column is to the northwest (as shown in Figure 7.13); this direction is likely governed by the St Georges Undercurrent (Section 7.5.1).

Water speed in the mid-water column (from 400 to 800 m) is also generally between 10 to 20 cm/s. Net drift in the mid water during the northwest monsoon season is to the southeast but changes direction and flows to the west-northwest during the southeast monsoon season (Figure 7.13).

Net water movement between 800 and 1,200 m water depth is generally to the east-northeast but can move to the west on occasions, as shown in the progressive vector diagrams in Figure 7.13 and 7.14. The direction in which naturally occurring particulate plumes measured between 1996 and 1997 – also shown in Figure 7.14 – are influenced by currents at these depths.

Currents at and immediately above the seafloor at Solwara 1 are relatively weak, averaging 6 cm/s and exceeding 15 cm/s only 5% of the time (see Appendix 3). The current regime at this depth can be summarised as follows:

- At short time scales (i.e., days), flow directions are dominated by tidal influences. Figure 7.15 shows that during any given month in the year currents typically flow to the north-northeast and west-southwest, corresponding to the tidal axis at this depth.
- The overall net drift over longer time scales (i.e., weeks to months) above Solwara 1 is from the southeast to the northwest, away from North Su and South Su (Figure 7.13).

⁷ The surface mixed layer is the upper layer in the ocean, which is kept well mixed by the turbulent action of wind and waves and therefore tends to be composed of water of similar temperature, salinity and density. Surface mixed layers near the coast are generally shallower than in the open sea, as is the case at Solwara 1.

⁸ The euphotic zone is the zone in the upper ocean where photosynthesis takes place. The base of the euphotic zone is defined as the depth which is reached by only 1% of transmitted light from the surface.

Upwelling

Vertical currents from the surface to 400 m depth at Solwara 1 are dominated by regular upward and downward movements, which do not match tidal frequencies. Instead the downward motions peak at sunrise every day and the upward motions begin at sunset and continue for four to five hours after sunset. The vertical motions are interpreted to represent the vertical migrations of zooplankton. It has been estimated that each creature travels about 150 m vertically through the water column during each migration. Further information is provided in Appendix 3.

Tidal Influence

In the upper water column (from 150 m to 250 m below the surface), northwesterly wind-driven currents are relatively strong. The velocity of the both the upper and deep-water currents increases as the southeast monsoon season commences.

Analysis of currents (Appendix 3) suggest that from the surface to 1,200 m depth currents appear to be driven by wind and large-scale water surface and sub-surface currents (Section 7.5.1). In the deeper waters (from 1,470 m to the seafloor), the currents are primarily driven by tides.

7.5.4 Deep Sea Sedimentation

Sedimentation Rates in the Pacific Ocean

Sedimentation rates in the ocean are controlled by a number of factors:

- Proximity to continental land masses with associated increased detrital input and the occurrence of boundary currents.
- Proximity to the equator and other regions of high biological productivity and the concomitant increased biogenous sedimentation.
- Depth, i.e., increased dissolution of carbonate.

In general, detrital sediments only form a small portion of the pelagic sediments of the Pacific Ocean (averaging less than 10%); hence, the total accumulation rate largely represents biogenous sedimentation.

A belt of high biogenous sediment accumulation has proven to exist along the equator (Worsely & Davies, 1979). Accumulation rates along this belt are high for total sediment and carbonate, the difference between the two being an approximate measure of the rate of biogenous silica accumulation in the equatorial region during the time period in question. As Solwara 1 is located 420 km south of the equator, it falls within this equatorial belt.

Between latitudes 3° south to 4° south (which includes the location of Solwara 1) composition and rate of sediment deposition on the seafloor generally accumulate at 0.055 g/m²/d for total sediment and range between 0.003 and 0.006 g/m²/d for organic carbon. Inorganic carbon flux shows a clear latitudinal trend. At similar latitudes, sedimentation rates are 0.005 g/m²/d (Lampitt & Antia, 1997).

Sedimentation Rates at Solwara 1

An average sedimentation rate of 0.95 g/m²/d was measured at Solwara 1 via the deployment of six sediment traps around Solwara 1 (see Figure 7.12). On average, the total inorganic carbon content accounts for 1.70% of the material collected (at an average rate of 0.02 g/m²/d).

The average sedimentation rate determined from six sediment traps deployed at South Su was 0.82 g/m²/d.

Average sedimentation rates at Solwara 1 and South Su are higher than those determined from open ocean global trends (Lampitt & Antia, 1997). The higher rate of sedimentation is likely due to hydrothermal vent activity in the area, combined with volcanic venting of North Su, which discharges material into the water column (Figure 7.14), thereby increasing sedimentation rates at Solwara 1 and South Su (see Section 7.3).

7.6 Water Quality

In open oceanic waters away from influences of terrestrial discharges, background natural levels of trace metals are typically low and well below the various international standards and guideline levels and below limits of detection by analytical methods applied to compare against standards. Typical background ocean levels would be expected within the majority of the water column at the offshore project site, which is in deep water and more than 30 km from the nearest shore. However, given the nature of the area, deep layers of the water column near to the seabed are likely to be naturally influenced by discharges from active vents of Solwara 1, and from the plumes observed at depths around 1,000 m, generated by vents and submerged volcanic activity, for example from North Su. Studies were therefore undertaken to determine if any effects from these natural phenomena could be detectable on water quality.

Two water-column-sampling programs have been undertaken to date at the Solwara 1 location. The first was during January and February 2006 when Nautilus undertook a drilling and bulk sampling program in the Solwara 1 prospect area. This program opportunistically included a number of environmental investigations including water sampling.

Water samples were taken with 1.5-L Niskin[®] bottles mounted on an ROV. Of interest are the five samples taken when no drilling and bulk sampling contamination was present: at water depths 383 m (duplicates at this depth), 1,125 m, 1,490 m, and 1,518 m. Results for general water quality parameters and nutrients, and filtered metals (passing <0.45 µm filter) are shown in Table 7.2.

Table 7.2 shows that concentrations of filtered metals are at or near detection limits except for arsenic and zinc. Concentrations of all filtered metals are less than PNG water quality criteria and ANZECC/ARMCANZ (2000) trigger values (ANZECC/ARMCANZ, 2000).

There is an ammonia anomaly, but any high results from this program need to be assessed with caution since the field blanks indicate contamination with ammonia from an unknown source.

The second field sampling of waters was conducted by CSIRO Centre of Environmental Contaminants Research during the Wave Mercury 07 Campaign, using ultra-trace metal techniques to determine background concentrations of metals in the water column in the vicinity of the SMS deposits, and metal concentrations in plumes created during sampling of these deposits. Samples were collected from 1, 5, 10 and 20 m from the seafloor above active vents at Solwara 1, with background samples collected from 500 m depth in the water column above Solwara 1. Samples from depths of 1,000 m were also taken to determine water quality where naturally occurring plumes had previously been observed (note that plume activity was weak at the time of sampling). Details of methods and results are provided in Appendix 7.

Table 7.2 General water quality and filtered metals at Solwara 1 in 2006

Sample Number	Latitude	Longitude	Depth	DO	Trans	Turbidity (NTU)	TSS	Hydroxide alkalinity as CaCO ₃	Carbonate alkalinity as CaCO ₃	Bicarbonate alkalinity as CaCO ₃	Total alkalinity as CaCO ₃	TOC	Sulfide as S ₂	Nutrients				
														Ammonia as N	Nitrite as N	Nitrate as N	SRP as P	Dissolved Silicon
Detection Limit							1	1	1	1	1	1	0.1	0.010	0.010	0.010	0.010	0.05
Units			m	mg/L	%		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
853_04	S03 47.3067	E152 05.6533	383	7.9	86.8	5.0	10.0	<1	<1	131.0	131.0	<1	<0.1	<0.010	0.370	<0.010	<0.010	0.42
853_05	S03 47.3067	E152 05.6533	383	7.9	86.8	5.0	14.0	<1	<1	132.0	132.0	1	<0.1	<0.010	0.406	<0.010	<0.010	0.40
853_18	S03 47.4905	E152 05.5837	1,125	7.8	78.0	3.0	14.0	<1	<1	136.0	136.0	<1	<0.1	0.059	0.614	<0.010	<0.010	2.86
MEAN				7.9	83.9	4.3	12.7	<1	<1	133.0	133.0	<1	<0.1	0.023	0.463	<0.010	<0.010	1.23
STANDARD DEVIATION																		
853_06	S03 47.3344	E152 05.7341	1,490	5.9	90.2	5.0	10.0	<1	<1	136.0	136.0	<1	<0.1	<0.010	0.609	<0.010	<0.010	4.75
853_15	S03 47.2817	E152 05.7100	1,518	7.4	91.3	3.0	12.0	<1	<1	138.0	138.0	<1	<0.1	0.055	0.657	<0.010	<0.010	4.07
MEAN				6.7	90.8	4.0	11.0	<1	<1	137.0	137.0	<1	<0.1	0.030	0.633	<0.010	<0.010	4.41
STANDARD DEVIATION																		
853_02	S03 47.3321	E152 05.6464	1,507	6.8	38.3	4.0	10.0	<1	<1	132.0	132.0	<1	<0.1	<0.010	0.667	<0.010	<0.010	4.24
853_07	S03 47.1377	E152 05.6423	1,565	7.2	17.6	5.0	14.0	<1	<1	144.0	144.0	1	<0.1	<0.010	0.677	<0.010	<0.010	4.37
853_08	S03 47.4332	E152 05.4631	1,568	6.8	28.0	6.0	13.0	<1	<1	139.0	139.0	<1	<0.1	<0.010	0.690	<0.010	<0.010	4.43
853_09	S03 47.4332	E152 05.4631	1,568	6.7	17.4	5.0	12.0	<1	<1	139.0	139.0	<1	<0.1	<0.010	0.714	0.026	<0.010	4.19
853_10	S03 47.4835	E152 05.4632	1,562	7.4	101.7	5.0	17.0	<1	<1	139.0	139.0	<1	<0.1	<0.010	0.642	<0.010	<0.010	4.13
853_11	S03 47.1123	E152 05.4602	1,561	6.8	7.2	3.0	10.0	<1	<1	139.0	139.0	<1	<0.1	0.024	0.704	<0.010	<0.010	4.13
853_12	S03 47.4357	E152 05.4639	1,560	6.8	3.8	10.0	10.0	<1	<1	138.0	138.0	<1	<0.1	0.042	0.658	0.021	<0.010	4.24
853_13	S03 47.2814	E152 05.6558	1,523	6.5	1.3	4.0	17.0	<1	<1	138.0	138.0	<1	<0.1	0.030	0.628	<0.010	<0.010	4.15
853_17	S03 47.4082	E152 05.5878	1,508	6.7	1.4	105.0	36.0	<1	<1	140.0	140.0	<1	<0.1	0.051	0.703	<0.010	<0.010	4.85
MEAN				6.9	24.1	16.3	15.4	<1	<1	138.7	138.7	<1	<0.1	0.020	0.676	<0.010	<0.010	4.30
STANDARD DEVIATION																		
				0.3	31.7	33.3	8.2	-	-	3.1	3.1	-	-	0.012	0.030	-	-	0.23

Table 7.2 General water quality and filtered metals at Solwara 1 in 2006 (cont'd)

Sample Number	Latitude	Longitude	Depth	DO	Trans	Turbidity (NTU)	TSS	Hydroxide alkalinity as CaCO ₃	Carbonate alkalinity as CaCO ₃	Bicarbonate alkalinity as CaCO ₃	Total alkalinity as CaCO ₃	TOC	Sulfide as S ₂	Nutrients				
														Ammonia as N	Nitrite as N	Nitrate as N	SRP as P	Dissolved Silicon
Detection Limit							1	1	1	1	1	1	0.1	0.010	0.010	0.010	0.010	0.05
Units			m	mg/L	%		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
853_01	S03 47.3318	E152 05.6464	1,507	6.0	84.0	3.0	13.0	<1	<1	130.0	130.0	<1	<0.1	0.071	0.025	0.509	<0.010	4.54
853_14	S03 47.2866	E152 05.7080	1,504	6.3	81.0	13.0	11.0	<1	<1	139.0	139.0	1	<0.1	0.049	<0.010	0.684	<0.010	4.40
853_16	S03 47.2867	E152 05.6914	1,513	6.8	53.5	4.0	9.0	<1	<1	140.0	140.0	<1	<0.1	0.064	<0.010	0.633	<0.010	4.12
853_03	S03 47.3321	E152 05.6464	1,507	6.9	28.7	4.0	13.0	<1	<1	131.0	131.0	<1	<0.1	<0.010	<0.010	0.631	<0.010	4.66
MEAN				6.5	61.8	6.0	11.5	<1	<1	135.0	135.0	<1	<0.1	0.061	<0.010	0.614	<0.010	4.43
STANDARD DEVIATION				0.4	26.0	4.7	1.9	-	-	5.2	5.2	-	-	0.011	-	0.074	-	0.23
POST - CUTTING																		

At sites within 20 m of the seafloor, total (unfiltered) concentrations of arsenic, selenium and mercury in the waters collected in the vicinity of the proposed mining operations were at concentrations typical of ocean water. Total concentrations of copper, lead and zinc exceeded water quality guidelines for dissolved concentrations of these metals (ANZECC/ARMCANZ, 2000) in a number of water samples. This indicated the need for measurements of filtered (<0.45 µm filtered) metal concentrations using trace level techniques. Results showed that filtered metal concentrations in the waters near the proposed ore body, and in the surrounding ocean waters, were generally very low and below water quality guideline concentrations for all metals (95% protection levels, ANZECC/ARMCANZ 2000), and for all metals except zinc (99% protection levels), the latter possibly a result of sample zinc contamination.

For the background 500-m site, total and dissolved concentrations of silver, cobalt, and lead were typical of ocean waters, while concentrations of cadmium, chromium, copper, nickel and zinc were a little higher than typical. Samples from 1,000 m did not indicate presence of plumes at the time of sampling, as total suspended solid (TSS) values were low and total metals were also low. Concentrations of TSS were generally low (mean 1.2 mg/L and range from 0.1 to 6.6 mg/L) in all samples. Compared with other water quality indicators in open seawater around the world, concentrations of filtered cadmium and zinc were generally greater at Solwara 1 than at other regions (Appendix 7). Summaries of results of dissolved metal concentrations in relation to ANZECC/ARMCANZ (2000) standards are given in Table 7.3.

Table 7.3 Wave Mercury 07 Campaign filtered metal concentrations at Solwara 1

Location		Dissolved Metal, µg/L							
		Ag	Cd	Co	Cr	Cu	Ni	Pb	Zn
Seawater at 500 m depth	Min	<0.005	0.044	<0.024	0.20	0.054	0.29	<0.015	5.0
	Max	<0.005	0.045	<0.024	0.24	0.12	0.38	0.034	7.4
1 to 20 m above seafloor	Min	<0.005	0.015	<0.024	0.15	0.099	0.52	0.015	1.5
	Max	0.0072	0.087	0.053	0.23	0.21	0.67	0.21	8.0
Guidelines ANZECC/ARMCANZ (2000)	95% PL	1.4	5.5	14	4.4 ^b	1.4	120	4.4	15
	99% PL	0.8	0.7	1	0.14 ^b	0.3	14	2.2	7
Number of samples with dissolved metal concentrations exceeding the Guidelines	95% PL	0	0	0	0	0	0	0	0
	99% PL	0	0	0	0 ^c	0	0	0	4 ^d
Number of samples with total metal concentrations exceeding the Guidelines ^a	95% PL	0	0	0	0	6	0	3	3
	99% PL	0	0	1	0 ^c	13	1	4	6

^a Total metal analysis is used to assess unfiltered waters; however, dissolved metal guideline values were used for comparisons as no guidelines exist for total metals, where PL = protection level.

^b Guidelines for Cr(VI), with corresponding guidelines for Cr(III) of 10 and 0.8 µg/L, respectively.

^c If all Cr was present as Cr(VI), then all 21 samples, including field blanks exceeded the Cr guideline; however, as less than half the Cr is expected to be present as Cr(III), the guideline is not considered to be exceeded.

^d The highest dissolved zinc concentrations were measured in the field blanks and indicate a possible source of sample contamination.

7.7 Sediment Quality

7.7.1 Seafloor Geological Setting

The Manus Basin in the Bismarck Sea is bounded along its northeast side by a series of Eocene to Oligocene island arcs generated by subduction of the Pacific Plate along the now inactive Manus Trench (Martinez & Taylor, 1996). On its western border lies the mainland of Papua New Guinea and, to the south, the New Britain island arc. On the south side of this volcanically active island arc is the New Britain Trench, which is the current locus of subduction of the northward-moving, Indo-Australian Plate. Subduction along this trench is believed to have begun at approximately 15 million years ago (Ma), after subduction of the westward moving Pacific Plate came to a halt upon collision of the Ontong Java Plateau with the Manus Trench (Martinez & Taylor, 1996).

The Manus Basin shows typical back-arc characteristics with basalt-dominated volcanism occurring along the more mature western and central seafloor spreading segments, whereas mafic to felsic magmas characterise the rifting of the eastern Manus Basin. These three zones of active volcanism are separated by northwest to west-northwest- trending transform faults (Martinez & Taylor, 1996). The eastern Manus Basin, which is the least mature of the three active extensional zones, is an 80 to 100-km-wide, pull-apart structure bounded by a set of sinistral faults; on its western edge, the Djaul Fault, and on its eastern edge, the Weitin Fault (Figure 7.16).

It is between these transform faults that the mineral-rich PACMANUS and SuSu Knolls hydrothermal fields were discovered (Binns & Scott, 1993; Scott & Binns, 1995; Binns *et al.*, 1997, cited in Appendix 6). Rifting began in the Pliocene at approximately 3.5 million years ago (Binns *et al.*, 1995, cited in Appendix 6). Located in this immature back-arc basin is a series of northeast-trending oblique volcanic ridges with rock types ranging from basaltic andesite to highly differentiated dacite and rhyolite. Exposures of Eocene to Oligocene arc crust on the islands of New Britain and New Ireland are thought to be a continuation of the basement lithologies of the eastern Manus Basin (Binns *et al.*, 1995, cited in Appendix 6).

Solwara 1 (originally known as Suzette) is a sulphide mound that is part of SuSu Knolls. The SuSu Knolls are in the eastern part of eastern Manus Basin, at a water depth of 1,160 to 1,550 m and extending for approximately 4 km in a north-northwest to south-southeast direction. They consist of two prominent porphyritic dacite domes, North Su and South Su, and a deeper and lower andesite complex, Solwara 1 (Binns *et al.*, 1997, cited in Appendix 6). The hydrothermal field at SuSu Knolls consists of four main sites: Solwara 1, South Su, North Su and a valley between North Su and Solwara 1 (see Figure 1.2).

The PACMANUS and SuSu Knolls hydrothermal fields were discovered during the 1991 PACMANUS I and 1996 PACMANUS III marine expeditions, respectively (Binns & Scott, 1993; Scott & Binns, 1995; Binns *et al.*, 1997, cited in Appendix 6; Parr & Binns, 1997) by means of multiple real-time CTD (conductivity, temperature, depth) and transmissometry plume-detection profiles across what was believed, from their bathymetry, to be active volcanoes (Parr & Binns, 1997; McDonald *et al.*, 1998, cited in Appendix 6). During the 1996 PACMANUS III expedition, two recognisable particulate plumes were detected (Figure 7.14); a lower plume at 1,260 to 1,460 m water depth and an upper plume at 1,060 to 1,140 m water depth. Fallout from these plumes could have contributed hydrothermal constituents to the seafloor sediments. Eleven months later during the 1997 PACMANUS IV cruise, the lower plume had all but disappeared but the upper plume had intensified. The upper plume clearly emanated from the top of North Su. The lower

plume appeared to have had two sources; a strong source from South Su and a weaker one from Solwara 1.

The South Su and North Su sites are characterised by extensive natroalunite-bearing alteration of the porphyritic dacite as well as scattered sulphide chimneys and mounds dominated by pyrite-enargite-fukuchilite mineralisation (Yeats *et al.*, 2000, cited in Appendix 6; Binns, 2004). In contrast, the deeper and lower andesitic complex at Solwara 1 displays a north–south aligned field of pyrite-poor, chalcopyrite- and gold-rich chimneys with barite gangue, similar to those of the PACMANUS site, located 50 km to the west (Binns & Scott, 1993; Scott & Binns, 1995; Moss & Scott, 2001 cited in Appendix 6).

The SuSu Knolls are covered by a thick (up to several meters) and widespread ‘tuffite’ apron of layered, dark, locally sulphidic sandy sediment (Binns, 2004).

7.7.2 Sediment Mineralogy and Geochemistry

Sediment Mineralogy

The unconsolidated sediment cover of grey volcanic sandy silts and silty sands (Appendix 6) over Solwara 1 can be over 6 m deep in some areas and, in parts of the mound, blocks of chimneys and volcanic rocks are buried under sediment. This material is called unconsolidated sediment throughout this EIS. These volcanoclastic sediments of Solwara 1 and South Su have similar mineral compositions suggesting a common source. They are composed of angular fragments of volcanic rock, calcium plagioclase and pyroxene that are equivalent to the plagioclase-pyroxene porphyritic dacite lavas building North Su and South Su (Binns, 2004). The sediments also contain cristobalite, alunite, pyrite and barite that are products of sub-seafloor hydrothermal alteration and mineralisation of volcanic rocks and are found in altered volcanics in the eastern Manus Basin (Yeats *et al.*, 2000, cited in Appendix 6). Binns (2004) proposed derivation of components of the volcanoclastic sediment at SuSu Knolls from violent hydrothermal eruptions at North Su.

The Nautilus 2006 and 2007 core sample results support this interpretation. Locations of sample sites are shown in Figure 7.17. The grey volcanoclastic sediments at Solwara 1 exhibit characteristics similar to those of volcanoclastic deposits interpreted to be a product of phreatic eruptions (Heiken & Wohletz, 1985, cited in Appendix 6), including those occurring at or below 1,350 m water depth (Clague *et al.*, 2003, cited in Appendix 6). The ash produced from these eruptions consists of fragments from vent walls and crater fields, including hydrothermal alteration products. The volcanoclastic sediment could have been emplaced as submarine ash falls, turbidity currents or both.

Large aggregates of pyrite and iron-copper sulphide that account for increased sulphide concentrations (up to 5 wt %) were found in greyish-black volcanic sands from the 23 to 33 cm interval of core SC-4 from the southeastern rim of Solwara 1 (see Figure 7.17).

Sediment traps were placed around the Solwara 1 mound in 2007 (see Section 7.5.4) with the average sedimentation rate determined to be 0.95 g/m²/d. The average copper content measured in the trap sediments was determined to be approximately 1,500 mg/kg, and the average iron was approximately 33,000 mg/kg.

Faecal Pellets

Some of the sediments at Solwara 1 contain patches and layers that appear to have a biogenic origin. A characteristic feature of Solwara 1 is the occurrence of greenish, greenish-brown and greenish-black volcanoclastic sediments on the western rim and slope of the mound where they

are covered by grey volcanoclastic sediments. The greenish, greenish-brown and greenish-black sediments contain up to 10 % clay and faecal pellets at different stages of preservation (see parts E and F of Figure 7.18). An interpretation by Hrischeva *et al.*, (2007) has concluded that the sediments were originally deposited near chimney fields where there was an abundance of organisms producing faecal pellets. The organisms were ingesting sediment particles including hydrothermal particles. The sediments were later transported and re-deposited on the slopes of the mound together with glass fragments. The absence of well-preserved faecal pellets in sediments away from the mound could be a result of their destruction during the down-slope transportation.

Sulphide Chimneys

A previous study of an 80-cm-long gravity core (MS-36) close to the western rim of Solwara 1 showed the occurrence of copper- and gold-rich metalliferous sediment that contains glass fragments, amorphous silica-rich material, pyrite, chalcopyrite, barite, gypsum and atacamite (Hrischeva *et al.*, 2007). The highly metalliferous sediment was recovered below 39 cm depth and was overlaid by grey volcanoclastic sediment. It was proposed that the metalliferous sediment originated from erosion of old oxidised sulphide chimneys and is an indicator for proximity to a previous chimney field. Similar metalliferous sediments may have broader distribution in depth along the western rim of Solwara 1. During the Wave Mercury 07 Campaign, attempts were made to collect 1-m-long push cores from the western rim of the mound in the hope of recovering such metalliferous sediment. However, the attempts were not successful as the maximum recovered depth was 28 cm.

Sediment Geochemistry

The grey volcanoclastic sediments of Solwara 1 have similar major element compositions that are analogous to that of the feldspar-porphyrific dacite across the broader SuSu Knolls (Moss *et al.*, 2001). The grey volcanoclastic sediments also have comparable background concentrations of trace metals and arsenic. The background concentration of copper in the sediments of Solwara 1 (Figure 7.19) is higher than average copper in continental shelf sediments of eastern Manus Basin (Hrischeva *et al.*, 2007), in continental shelf Pacific sediments from other areas (Goodfellow & Peter, 1991, cited in Appendix 6) and in typical volcanoclastic sediments (Cronan *et al.*, 1984, cited in Appendix 6).

Copper and gold have background concentrations that are significantly higher than in the SuSu Knolls dacite (Moss *et al.*, 2001). Sources for the anomalous copper and gold are probably the products of volcanic rock alteration and mineralisation in the volcanoclastic sediments. The background concentrations of zinc, lead, barium, cobalt, chromium, nickel and molybdenum in the grey volcanoclastic sediments of Solwara 1 are comparable to the average concentrations of these elements in continental shelf sediments although the study was not as detailed.

In contrast, the volcanoclastic sediments of Solwara 1 show patchy anomalies in the concentrations of trace metals and arsenic. It is suggested that there are two major sources of metal anomalies: dispersal of hydrothermal particles from eroded chimneys and deposition of hydrothermal particles within faecal pellets. Fallout from particulate plumes appears to be minor compared to that from violent hydrothermal eruptions. Dispersal of chimney fragments does not leave large-scale anomalies in the sediments over the mound, but has only local expression. A strong anomaly created by dispersal of sulphides and barite that were probably derived from erosion of proximal chimneys was found at a depth below 25 cm in core SC-4 (see Figure 7.17) from the southeastern rim of Solwara 1.

In most cases, volcanoclastic sediments as deep as 25 cm that are proximal to chimneys and chimney fragments, do not exhibit metal anomalies created by dispersal of chimney fragments. Probably anomalies created by mass wasting of chimneys are more extensive in deeper intervals of sediments from the western rim of the mound, as suggested by a previous study (Hrischeva *et al.*, 2007). Organisms inhabiting areas close to venting are another factor that may have contributed to the metal enrichment of the sediments of Solwara 1. Presence of hydrothermal particles in faecal pellets has created small-scale metal anomalies in black and brownish-green patches of grey volcanoclastic sediments. Biogenic deposition of hydrothermal particles is a likely factor for the more widespread anomalies found in greenish, greenish-brown and greenish-black volcanoclastic sediments from the western slope of Solwara 1. Barite and sulphides dispersed from chimneys may have also contributed to the metal anomalies in these sediments.

Venting Plume

The plumes from local venting at Solwara 1 and South Su (see Figure 7.14) are not producing obvious, extensive anomalies in metal concentrations over much of the surface sediments. Only local metal enrichments in sediments of two sites (cores SC-28 and SC-83) (see Figures 7.17 and 7.19) near active vents at Solwara 1 could be the result of settling of hydrothermal particles from distinct chimney plumes (although from observation during Nautilus surveys, there are few chimneys present).

The lack of a clear signal from plume fallout could be attributed to recent deposition of volcanoclastic material. Continental shelf sediments, indicative of long-time exposure to the water column, were not recovered during the sampling in 2006 and 2007. Sediments as far as approximately 350 m to the west of Solwara 1 are volcanoclastic sediments re-deposited from the mound. Therefore, there is no data on concentrations of trace metals in continental shelf sediments from the area surrounding Solwara 1 that could be potentially contaminated during mining at Solwara 1.

However, the background concentrations of metals, except for copper, in the volcanoclastic sediments of Solwara 1 are comparable to metal concentrations in continental shelf sediment approximately 10 km east of the SuSu Knolls (Hrischeva *et al.*, 2007) and could be referred to as pre-mining concentrations of metals in sediments from a broader area surrounding the SuSu Knolls.

7.8 Biological Environment

This section describes the biological environment of the seawater surface, mid-water and deep-water zones at the offshore Project area of Solwara 1. It also includes the barge transportation route between the offshore project area and the Port of Rabaul. The seafloor, or benthic environment, including the overlying water up to 50 m above the seafloor at Solwara 1, is described in Section 7.8.2. The nearshore and onshore Project area of the Port of Rabaul is described in Section 7.9.

Information presented in this section is primarily based on the supporting study by Hydrobiology Pty Ltd, which is provided as Appendix 10. Hydrobiology's study included a desktop review of scientific literature and analysis of underwater footage from the ROV as it descended through the water column at Solwara 1 during the Wave Mercury 07 Campaign. Additional information presented in this section has been sourced from the relevant literature.

7.8.1 Surface and Water Column

Within PNG, the local coastal people have expressed most concern for the quality of the marine environments, and the protection of the reefs and fisheries upon which they depend, as well as on the wellbeing of the larger animals that are present such as whales, sharks and turtles.

Habitat Zones

The water column can be divided into the following depth zones, broadly characterised by the degree of light penetration (Figure 7.20):

- Epipelagic zone: Well lit (0 to 200 m).
- Mesopelagic zone: Some light penetration (200 to 1,000 m).
- Bathypelagic zone: No light penetration (greater than 1,000 m).

Epipelagic Zone

The epipelagic zone includes the euphotic zone, which is defined as the deepest extent to which light penetration allows photosynthesis and net oxygen production (maximum depth to 80 m), and the surface mixed layer (see Section 7.5 for a definition). Below the surface mixed layer is the thermocline, within which temperatures drop steadily with increasing depth. The depth of the surface mixed layer varies but typically ranges from the surface to 185 m below the surface (see Section 7.5).

The epipelagic zone generally contains the highest biological diversity of the water column zones and is inhabited by plankton, large agile predatory fish (such as tuna and sharks) and prey species (such as smaller fish and invertebrates). Food webs in this zone are based on phytoplankton (driven by photosynthesis and various microbial processes), leading to secondary production of zooplankton, larger consumers and finally to large mobile predators.

While photosynthesis only occurs where there is sufficient penetration of sunlight (i.e., the euphotic zone), it supports life in deeper parts of the ocean through the vertical migration and feeding of animals (Figure 7.21), and the downward drift of particulate organic matter, known as 'marine snow' derived from surface productivity. As animal biomass declines exponentially with depth through the water column, the epipelagic zone generally has the greatest biomass.

Mesopelagic Zone

The mesopelagic zone encompasses the water column between approximately 200 and 1,000 m depth. This zone is below the top of the surface mixed layer and euphotic zone, and is characterised by low light and low temperatures. Typically, the mesopelagic zone has lower dissolved oxygen than the epipelagic zone, as it is below the euphotic zone of photosynthetic oxygen production. However, oceanographic structure within the mesopelagic zone and internal waves or other topographically induced currents can result in layers of relatively high nutrients and oxygen. In this zone, bioluminescence becomes more common, and various colouration and body morphological adaptations exist to camouflage animals against weak, down-welling surface light by counter-illumination. Fish and invertebrate species also use bioluminescence for finding prey and for communication with others of the same species for reproduction.

Bathypelagic Zone

The bathypelagic zone and, to a lesser extent, the mesopelagic zone typically have higher concentrations of nutrients than the epipelagic zone. While oxygen concentrations can sometimes be higher in the bathypelagic zone than in the mesopelagic zone, for example where the deep water originates from subducted temperate region waters, dissolved oxygen is nevertheless low.

In these conditions and zones abundance and biomass of animals is reduced, partly due to diminished food supply falling from the surface.

Animals adapted to tolerate these conditions generally have low metabolic rates, soft skeletons, reduced protein levels and slow swimming ability. Bioluminescence plays a crucial role in these zones, and organisms are highly opportunistic feeders. The delivery of organic matter to the bathypelagic zone in the form of marine snow can be slow with sporadic events, such as whale-falls, providing a significant attractant to scavengers. Close to the seafloor, free-swimming animals are more abundant and some have stronger musculature possibly because there is a greater abundance of food sources at the sediment-water interface.

The bathypelagic zone around Solwara 1 differs from typical oceanic environments due to the plumes generated by hydrothermal activity (e.g., at Solwara 1 and South Su, and from eruptions of the underwater volcano at North Su). The presence of these plumes is discussed in Sections 7.5 and 7.7 and, as shown in Figure 7.14, these plumes often drift over Solwara 1. While the influence of volcanic activity on the environment in and around the offshore Project area is primarily limited to the benthos (i.e., where the sediments of Solwara 1 and South Su are covered by an apron of dark grey volcanic sandy silts; see Section 7.7), these plumes also create an environment of higher turbidity and suspended sediments at the depths where they occur (see also Sections 7.5 and 7.6).

Fish

There are many species of epipelagic, mesopelagic and bathypelagic fish that are likely to occur in the offshore Project area and these are described and listed in Attachment 1 of Appendix 10.

Species of particular importance within this area include those targeted by commercial fisheries, such as tuna and shark (see Section 8.3). While these commercial species mainly occur in the surface epipelagic layers, they sometimes forage deeper and a number of tuna and tuna schools were observed in ROV footage at depths within the mesopelagic zone and, in one instance, a tuna was seen to swim past the ROV at 615 m depth. While this observation represents a vertical range for these species that extends well into the mesopelagic zone, most observations of tuna were made in water depths less than 200 m (Plate 7.6).

Although it is considered unlikely that the foraging range of the tunas would extend into the permanently dark bathypelagic zone, their observed depth range extends the potential for trophic interactions between the surface and mesopelagic zones in the ocean water column via vertically migrating zooplankton (see Section 7.5.1), micronekton (small fish, squid and shrimps) and larger predatory fish (Appendix 10). Figure 7.21 shows the potential trophic links between surface and middle zones. Most of the bathypelagic species remain in deep waters at all times and rely on nutrient flow descending from above.

The large predatory fish of the epipelagic zone (including tuna and sharks) feed on smaller pelagic fish in the surface waters and also on micronekton, which are caught at times when vertical migration brings the micronekton into the epipelagic or upper mesopelagic zones and when there is enough light for predators to hunt visually.

Fish that inhabit zones where there is little or no light (i.e., the lower mesopelagic zone and the bathypelagic zone) often use bioluminescence for attracting prey, predator evasion and communication. The most common types of fish in the bathypelagic zone include bristlemouths, hatchetfish, lanternfish and deep-sea angler fish. Fish in these great depths are typically small-

bodied, have less developed gills and muscles, and have smaller eyes than those fish that reside higher in the water column.

Crustaceans

Crustaceans are found in all zones of the open ocean and feed primarily on microplankton. They are an important part of the diet of many large predators, including tuna.

Crustaceans likely to be found in the water column above Solwara 1 include caridean shrimps (of the families Oplophoridae, Pandalidae, Pasiphaeidae and Palaemonidae) and penaeid prawns (of the families Sergestidae, Aristaeidae, Benthesicymidae and Solenoceridae). Some were observed in midwater from the operations of the ROV at Solwara 1.

Deepsea crustaceans are often camouflaged a deep red colour: red light does not penetrate water as well as other colours and therefore predators do not easily see red-coloured animals. Some crustacean species also utilise bioluminescence for defense by expelling bioluminescent clouds.

Molluscs

There are three classes of molluscs: bivalves, gastropods and cephalopods. While most marine molluscs have a planktonic larval stage, some are found in the water column as free-swimming adults. Bivalves and gastropods primarily inhabit benthic environments as adults and, as such, are described in Section 7.8.2.

The cephalopod class consists of four main animal types: octopi, squid, cuttlefish and nautili. They commonly occur in the mesopelagic zone and migrate to the epipelagic zone at night. ROV footage show squid occur in high concentrations above Solwara 1 at 400 m water depth in the early hours of the morning (i.e., 1 a.m.). Plate 7.7 shows a squid at 16 m water depth at 2.50 a.m.

Many species of cephalopod utilise bioluminescence for both attracting prey (e.g., some species of squid have luminescent arm tips used to lure prey) and as a defense mechanism (e.g., some species expel bioluminescent clouds to confuse predators).

Cephalopods, particularly squid, are of considerable importance in marine pelagic food webs as they provide a key trophic link from vertically migrating micronekton and small mesopelagic fish schools to high trophic level predators in the epipelagic zone, such as tuna and billfish.

Marine Mammals

Cetaceans

Cetaceans are the group of marine mammals that include whales and dolphins. Cetacean species that are likely to occur at Solwara 1 are listed in Table 7.4. These species were recorded in Kimbe Bay, Bismarck Sea during a monitoring program in 2003, (Visser, 2003) During the survey, multiple sightings of each species were recorded over a short sampling period and cetaceans were observed resting, foraging and mating.

All of the cetaceans listed are toothed whales, as opposed to the plankton-feeding baleen whales. Toothed whales are high trophic level species (feeding mainly on fish and squid) and the presence of 15 cetacean species, some at relatively high numbers, indicates that the area has high biodiversity and supports a multitude of lower trophic level species.

Table 7.4 Cetacean species likely to occur at Solwara 1

Scientific Name	Common Name
<i>Feressa attenuata</i>	Pygmy killer whale
<i>Globicephala macrohynchus</i>	Pilot whale
<i>Grampus griseus</i>	Risso's dolphin
<i>Kogia breviceps</i>	Pygmy sperm whale
<i>Mesoplodon densirostris</i>	Densebeak whale
<i>Orcinus orca</i>	Orca
<i>Peponecephala electra</i>	Melon-headed whale
<i>Physeter macrocephalus</i>	Sperm whale
<i>Pseudorca crassidens</i>	False killer whale
<i>Stenallas longirostris</i>	Spinner dolphin
<i>Stenella attenuata</i>	Pantropical spotted dolphin
<i>Steno bredanensis</i>	Rough-toothed dolphin
<i>Tursiops aduncas</i>	Indo-Pacific bottlenose dolphin
<i>Tursiops truncates</i>	Bottlenose dolphin
<i>Ziphius cavirostris</i>	Cuvier's beaked whale

Source: Visser, 2003.

Sperm whales are known to occur in Bismark Sea. Approximately 200 sperm whales (along with other cetacean species) were seen in this area during February to August 2001, as part of Ocean Alliance's Voyage of the Odyssey Program (Visser & Bonoccorso, 2003). Groups of sperm whales in differing compositions of abundance, sex and age and several mother/calf pairs were observed during this program, indicating that the Bismarck Sea is a breeding and calving ground for the sperm whale (Johnson, 2001).

There have been 94 sightings of killer whales in PNG as part of research undertaken by Orca Research Trust (Visser & Bonoccorso, 2003). Thirty-seven of these sightings have been recorded with exact data and location information, while a further 57 sightings are anecdotal. This research indicates that killer whales are present in PNG waters between March and December and are often found in association with sperm whales and spinner dolphins (Visser & Bonoccorso, 2003).

In the Project area, sightings of whales are not common. During the Wave Mercury 07 Campaign, located at Solwara 1 and South Su between 22 March and 28 April 2007, only two pods of approximately 12 pilot whales were observed. Although there were no dedicated whale observations, crew and researchers were on deck at all times and it is unlikely that any more significant presence of whales went unnoticed. Nevertheless, it is possible that some of the species listed in Table 7.4 occur in the Project area.

While cetaceans primarily inhabit the epipelagic zone, many species, such as pilot whales (Soto *et al.*, 2008) and sperm whales, are known to dive to depths over 1,000 m into the mesopelagic and bathypelagic zones to hunt prey.

Dugongs

The dugong (*Dugong dugon*) is a herbivorous mammal and the only surviving member of the family Dugongidae (Marsh *et al.*, 1996). Worldwide, the dugong has an extensive distribution and occurs along the coast of the northern half of Australia and throughout the coastline of the South Pacific, Asia and Africa (Marsh, 2006). It is believed that the dugong is represented across this

range (about 26° north and south of the equator) by relict populations separated by large areas where it is rare or extinct. The largest known population of dugongs occurs in Torres Strait, between PNG and Australia (Marsh *et al.*, 1996). Dugongs feed on all available species of seagrass and their range generally does not extend far from their feeding grounds.

While dugongs have been recorded feeding on seagrass up to 58 km offshore (Marsh *et al.*, 1999), the water depth at Solwara 1 is too great to support seagrass and dugongs are unlikely to be found in this area.

Dugongs are not regularly sighted in Simpson Harbour but are seen near the Duke of York Islands group (see Figure 1.1) and the Credner Islands (located between Kokopo and the Duke of York Islands) (Alexander, pers. com., 2008a).

Marine Reptiles

The three main groups of marine reptiles inhabiting PNG's marine waters are crocodiles, turtles and sea snakes.

Crocodiles

The saltwater crocodile, (*Crocodilus porosus*), occurs in many areas along PNG's coast. This species primarily inhabits nearshore areas and, while they do periodically move locations, it is most unlikely that they would be found at Solwara 1. There is no known resident crocodile populations in Simpson Harbour; however, transient individuals are infrequently seen (Alexander, pers. com., 2008b). Crocodiles are known to occur around Matupit Harbour (see Figure 7.4) and the Duke of York Islands group (see Figure 1.1), and there are healthy crocodile populations along the coast of New Ireland (Alexander, pers. com., 2008b).

Turtles

All seven of the world's marine turtle species are listed on the International Union for Conservation of Nature (IUCN) Redlist (IUCN, 2008a) and are therefore a high international conservation priority. Six of these, namely the green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), leatherback turtle (*Dermochelys coriacea*), olive ridley turtle (*Lepidochelys olivacea*), loggerhead turtle (*Caretta caretta*) and flatback turtle (*Natator depressus*) have been recorded in PNG (WWF, 2001).

Leatherback turtles are found from tropical to sub-polar oceans (Sarti Martinez, 2000) and are known to nest along the Morobe coast of PNG, between Labu Butu and Busama beach and along the Madang coast. Quin *et al.*, (1983) estimated that 1,000 to 1,500 leatherbacks nest annually in this area. However, this region has witnessed a 90% decrease in the number of nesting leatherbacks since the Quin *et al.* (1983) survey was conducted. The Tagging of Pacific Predators (TOPP) Project found that leatherbacks migrate through the Bismarck Sea en route from Papua to the coast of southeastern Australia (TOPP, 2008).

The green turtle is the most common marine turtle in PNG. There are known nesting beaches at Manus, Madang, New Ireland, Milne Bay, around the Engineer and Conflict island groups and the Calvados chain (WWF, 2001).

There are 25 known hawksbill turtle nesting beaches in PNG (Spring, 1995), including sites at Manus, New Hanover, New Ireland and northeast New Britain (WWF, 2001). The largest hawksbill nesting beach in the South Pacific is on the Arnovan Islands (between Choiseul and Santa Isabel islands in the Solomon Islands). Turtles that nest on these islands migrate through PNG waters.

While the loggerhead turtle has been recorded in PNG, there are no known loggerhead nesting beaches. Tag and recapture data collected over a 21-year period by Limpus *et al.*, (1992) indicate that adult loggerhead turtles travel to PNG waters between nesting seasons in Australia; however, there is no specific data indicating the presence of loggerheads in the Project area.

Olive ridley nesting beaches occur on Rambutyo Island, the island of New Britain (WWF, 2001). The Bismarck Sea area is listed in an IUCN update for the olive ridley as being a foraging and migratory area (IUCN, 2008b).

The flatback turtle has a limited distribution in southern PNG waters and has only been recorded on a few occasions (WWF, 2001). There is no specific data indicating the presence of flatback turtles in the Project area.

Published literature on turtle migratory pathways (UNEP-WCMC, 2006) does not indicate major routes between New Ireland and New Britain, although data are from tagging, which does not reveal detailed movements and it is expected that most species may travel past the project area from time to time. There are few nesting sites recorded in this database for the Bismarck Sea, but this is not taken to assume that there is no nesting in the area.

Sea Snakes

There are 23 species of sea snake known to inhabit PNG waters. While most sea snakes species occupy nearshore waters and estuaries, some species inhabit the open sea and can dive to depths in excess of 100 m (Williams *et al.*, 2004). Therefore, it is possible that sea snakes are present in Simpson Harbour, Rabaul, and possibly also at Solwara 1.

Marine Birds

There are several species of marine birds that potentially occur within the Project area. Two of these, Beck's petrel (*Pseudobulweria becki*) and Heinroth's shearwater (*Puffinus heinrothi*), are of particular conservation significance as they are listed as critically endangered and vulnerable, respectively (IUCN, 2007).

The Beck's petrel was observed in the Bismarck Sea by Shirihai (2008) in 2007. The highest concentration of Beck's petrel occurs at Cape St George, approximately 145 km to the southeast of Solwara 1 and they are thought to nest around the southern montane forests of southern New Ireland (Shirihai, 2008). As the species are thought to prefer sea mounds and areas where the water depth is between 1,000 and 2,000, it is possible that they may occur at Solwara 1.

The Heinroth's shearwater is mainly found off Bougainville, PNG and Kolombangara, Solomon Islands, where their breeding grounds are thought to occur. However, some sightings of the species have occurred in the Bismarck Sea and it is possible that they occur at Solwara 1 (BirdLife International, 2008).

7.8.2 Seafloor

Seafloor Habitats

The defining features of the offshore Project area include the seafloor massive sulphide mounds of Solwara 1 and South Su located respectively about 1 km to the northwest and southeast of the central North Su active submarine volcano (see Figure 1.2). The mineralised ore body of Solwara 1 forms a mound approximately 2 km in diameter that rises about 200 m above the seafloor. Mineral resource investigations have identified five main zones of mineralisation, namely Far West, West, Central, East and Far East (see Figure 5.5), which will form the basis of mining activities. Within these zones, temporary refuge areas will be established for protection of vent-

specific organisms (see Sections 9.6.2 and 13 for details) during mining. Within these mineralised areas, clusters of seafloor chimney structures exist, some of which are actively or intermittently venting hydrothermal fluids, while some are dormant (Figure 7.22).

At Solwara 1, it is estimated that there may be up to 40,000 chimneys over 0.25 m high (Riley, pers. com., 17 July 2008). Some typical chimneys at Solwara 1 are shown in Plate 7.8. Between the chimneys, the seafloor consists of exposed hard surfaces and areas of sedimentary deposits. The hard surfaces are comprised either of heavily mineralised sulphidic rock/ore, or outcrops of dacite (volcanic glass-like material). The latter are located mainly outside, and generally to the north of, the main mineralised area as shown in Plate 7.9.

The sediments at Solwara 1 and South Su have been described as resembling a variable apron of dark grey, volcanic sandy silt including volcanic rock fragments, volcanic glass and other minerals (Appendix 6). It is likely that the source of these sediments is from local subsea volcanic activity, e.g., North Su, which is approximately 1 km up-current from Solwara 1. Nearby active land-based volcanoes may also contribute to the sediment composition by fallout of ash (e.g., Tavurvur is an active volcanic vent sitting at the mouth of Blanche Bay, Rabaul).

In many parts of Solwara 1, soft, unconsolidated sediments exhibit patchiness and surface colour differences. These colour differences may be attributed to a number of factors, including iron or sulphur compounds, microbial mats, and/or the presence of faecal pellets at various stages of decomposition, as described in Appendix 6. These sediments can be active or dormant, depending on whether or not they are influenced by diffuse fluxing of hydrothermal fluids, according to their proximity to active chimneys (Appendix 5).

The unconsolidated sediments occurring within the five mineralised zones are shown in Figure 5.11. The sediments are generally less than 2 m deep but in some locations can have depths greater than 6 m.

The temperature of the fluids within the chimneys can reach up to 300°C or more, although, as discussed in Section 7.3.2, the known maximum temperature limit of life is thought to be 121°C (Kashefi & Lovley, 2003). The animals colonise the outer surfaces of chimneys that are formed by the deposition of minerals from the hydrothermal flow, where the temperature drops rapidly from the point of fluid exit. To date, there is limited data on temperatures inside and immediately outside Solwara 1 chimneys, or at more diffuse venting through softer seafloors. The measurements that exist suggest temperatures of venting fluids at Solwara 1 vary from 5°C to a maximum recorded of 302°C (Tivey *et al.*, 2006).

Variable Vent Activity

The ROV research work conducted by Nautilus enabled visual comparisons to be made between venting areas observed in 2006 and the same areas visited in 2007, which show that venting activity at Solwara 1 is variable. Some areas observed to be venting in the 2006 survey were not venting when subsequently re-surveyed during 2007, and conversely, venting was observed in 2007 in some areas where it had not previously been observed in 2006 (Figure 7.22). Some of these differences may be due to sampling or observation frequency but some show clear evidence of switching on and off of vents, and this pattern is also suggested on a macro-scale through regional plume studies that likewise show variability from year to year (Appendix 1 and 2; Parr & Binns, 1997).

Hydrothermal vent fauna can often tolerate changes to their environment. For example, Johnson *et al.* (1994) measured variable environmental conditions at a vent community at the Galapagos

Spreading Centre and demonstrated that the mussel, *Bathymodiolus thermophilus*, was able to tolerate these wide ranges in conditions through adaptations in feeding strategies. Van Dover (2000a) also notes that fauna of short-lived vents that are relatively close together are unlikely to become extinct from the shut-down of a particular vent. This is due to the high likelihood of the species being able to disperse to an adjacent vent that is actively venting.

During the 2006, 2007 and 2008 Nautilus offshore campaigns, patches of apparently dead snails were observed at several areas where venting had ceased and which could no longer support these vent-dependent species (see Plates 7.10 and 7.11 and Figure 7.23). Both *Ifremeria nautilei* (a gastropod snail, with dark coloured shell) and *Alviniconcha* sp. (a species of gastropod snail, with a shell of hairy appearance) reside in elevated temperatures (up to 25°C) compared to that of ambient seawater (approximately 3°C). Recent studies have shown that the normal habitat temperature ranges of *Ifremeria nautilei* and *Alviniconcha* sp in the Lau Basin are 6 to 21°C and 15 to 33.5°C respectively (Henry *et al.*, 2008) but they can tolerate elevated temperatures (up to 40°C for *Ifremeria nautilei* and 45°C for *Alviniconcha* sp).

The patches of dead snails were always observed in areas where there was no venting (either sedimented seafloor areas or at the base of inactive chimneys) and their presence may indicate where venting had switched off and/or the movement of snails in search of venting fluid. The movement of snails (*Alviniconcha* sp) was observed (Nautilus observations) when live individuals were removed from one active vent and placed at the foot of another active vent. Each time this was done, the snails moved towards the new active vent, presumably seeking out the vent fluid/heat source. In contrast, moved individuals of *Ifremeria nautilei* tended to clump together and did not show the same movement.

These observations are of significance in characterising the existing seafloor habitats of Solwara 1 and South Su, and show that vents naturally turn on and off. It is a dynamic system and no areas are guaranteed to be constantly venting at Solwara 1, i.e., there is no durable differentiation of active and inactive areas.

The presence of vent-dependent species can be used to define locations of currently active sites, since these species cannot exist away from their chemotrophic energy source. Accordingly, the absence of vent-dependent species may indicate a currently inactive habitat in terms of hydrothermal activity, which may be associated with peripheral areas where there may be intermittent activity or partial (e.g., down-current) influence.

The active venting sites at Solwara 1 and at South Su, are characterised by a number of biomass-dominant species including *Alviniconcha* sp and *Ifremeria nautilei* as well as *Eochionelasmus* sp. (a barnacle) and, at South Su only, the mussel *Bathymodiolus manusensis* (Appendix 4). These occur at various densities at different vent sites. Pictures of these animals in high and low densities around vents are given in Plates 7.12 and 7.13.

Images taken by ROV of the Solwara 1 mound during the exploration phases of the Project have revealed three main zones of actively venting areas, in addition to intermittently venting areas and non-venting areas, as determined by presence of particular species. Actively venting chimneys are also visually apparent by the shimmering from the exit of the hot fluids into the ambient cold seawater (Plate 7.14), which has a temperature of around 3°C. In some cases, there is also the emission of plumes of sediment (Plate 7.15), but on Solwara 1 and South Su, there are relatively few examples of large plumes typical of chimneys that have been found at other vent systems around the world. Solwara 1 is a weakly active system, thought to be waning. At the neighbouring Solwara 5 area, 2.4 km to the northwest (see Figure 5.1), there are no signs of active venting,

suggesting perhaps the thermal 'hot spot' in the Susu Knolls area has migrated progressively south-southeast over time.

The non-venting areas can be hard (sulphide or dacite) or unconsolidated sediments, as described in Appendices 5 and 6. In contrast, ROV images of the actively erupting North Su volcano have been difficult to obtain because of the extensive plumes generated from its crater.

Some small-scale releases of hydrothermal fluids from a previously non-venting area were observed in 2007, possibly initiated by exploration drilling although, if so, this was a very localised phenomenon. There have been no observed cases where the exploration or sampling activity has caused any venting to cease. In some areas, after chimneys or parts of chimneys had been sampled, formation of new chimney lattice material was seen to occur in as little as 21 hours (see Plate 7.3), indicating the dynamic nature of these areas. In other cases, numbers of the vent-dependent snail species were seen actively moving towards and colonising areas where venting had started following the disturbances of exploration.

Given this natural variability in venting activity, the seafloor habitats in the project area are therefore most practically characterised as follows:

- Active and intermittently active hydrothermal vents, as defined by the presence of vent-dependent macrofauna and/or visible signs of venting of warm water fluids.
- Hard surfaces close to vents, with potential for peripheral influence of chemotrophic energy source, but without vent-dependent species or visible signs of venting.
- Hard surfaces remote from vent influences.
- Unconsolidated sediments close to hot vent fluids, with diffuse venting or peripheral influence of chemotrophic energy source.
- Unconsolidated sediments remote from hot vent fluids.

Biological Communities

Global Level Studies

Since the discovery of hydrothermal vents in 1977 (see Section 7.3), studies of vent communities have been undertaken in many areas of the world (see Van Dover, 2000a and Figure 7.5). While a detailed summary of these studies and findings is beyond the scope of this chapter, the distribution of the main areas of study includes:

- Mid-Atlantic Ridge (e.g., Lucky Strike (1,700 m depth), TransAtlantic Geotraverse (3,600 m depth) and Snake Pit (3,600 m depth)).
- Northeast Pacific Ridge (e.g., Explorer Ridge (1,850 m depth) and Gorda Ridge (3,250 m depth)).
- East Pacific Rise (e.g., Guaymas Basin, 9°N, 21°N, 13°N and the Spike Area; all at 2,600 m water depth).
- Galapagos Spreading Centre (e.g., Rose Garden at 2,500 m water depth).
- Western Pacific (e.g., Okinawa (550 m depth), Mariana Arc (3,600 m depth), North Fiji Basin (2,000 m depth), Lau Basin (1,800 m depth), Manus Basin (2,500 m depth)).

Some general zoogeographic characteristics of these areas can be very briefly summarised as follows. The Mid-Atlantic Ridge, including the Lucky Strike, TransAtlantic Geotraverse (TAG) and Snake Pit areas, has been well studied. Lucky Strike is dominated by a sulphide-colonising mussel species (*Bathymodiolus azoricus*). No tube worms or clams have been found in this area. TAG is a single large sulphide mound, approximately 200 m in diameter, which is dominated by shrimp and anemones. Snake Pit communities are comprised of fauna similar to that at TAG; however, mussels (*Bathymodiolus puteoserpentis*) are also present, predominately at the base of the sulphide mounds.

Several areas along the Northeast Pacific Ridge system have been studied. Communities at the Explorer Ridge, Endeavour Ridge, Axial Seamount, CoAxial Site and Cleft Segment have similar faunal compositions, including tube worms (*Ridgea piscesae*), polychaetes and small gastropods (including *Lepetodrilus fucensis* and *Depressigyra globulosus*). The soft sediment environment of the Gorda Ridge supports species not found at other Northeast Pacific Ridge sites, including a variety of polychaete species and thyasirid clams.

Areas studied within the East Pacific Rise, a fast-spreading ridge system, include the Guaymas Basin, 9°N, 21°N, 13°N and the Spike Area. The Guaymas Basin has large populations of giant tube worms (*Riftia pachyptila*), scale worms and paralvinellid polychaetes. Infauna includes bivalves and polychaetes and bivalves such as mussels (*Bathymodiolus thermophilus*) and giant clams (*Calyptogena magnifica*). Communities at 9°N, 21°N, 13°N and the Spike Area are similar; however, mussels are not present at 21°N.

The Rose Garden on the Galapagos Spreading Centre, upon discovery, supported typical vent fauna such as tube worms, clams, mussels, limpets, alvinocarid shrimp, bythograeid crabs, serpulid worms, anemones, etc. High-temperature vents were not found in this area and therefore high temperature taxa such as *Alvinella* spp. were not recorded. Since discovery, the site known as Rose Garden has been overrun by lava and no longer exists (Van Dover, pers. com., 2008).

Studies areas of the Western Pacific include Okinawa, Mariana, North Fiji Basin, Lau Basin and Manus Basin. The Okinawa site is dominated by the mussel *Bathymodiolus japonicus*, and also supports tube worms, clams, crabs and other mussel species. Mariana fauna includes hairy gastropods (*Alviniconcha hessleri*), suspension-feeding barnacles, alvinocarid shrimp and bythograeid crabs. Tube worms have not been found at this site. The Fiji and Lau basins are dominated by gastropods (*Ifremeria nautilei* and *A. hessleri*) and mussels (*Bathymodiolus brevior*). Faunal communities of the Manus Basin are similar to that of the Fiji and Lau basins and are described in more detail below.

Manus Basin Studies

Previous faunal studies of the Manus Basin provide descriptions of the macrofauna communities typical of the western Pacific back-arc basins. The first biological material sampled from the Project area was taken during the PACMANUS and Binatang cruises in 2000 from PACMANUS sites and SuSu Knolls (including South Su and Solwara 1) (Appendix 2).

Further studies of species collected from the PACMANUS sites during these cruises (CSIRO, 2007) described the abundances of mussels of the genus *Bathymodiolus* (although not located at Solwara 1), large gastropods of the genera *Alviniconcha* and *Ifremeria*, vestimentiferan tube worms of the genus *Alaysia* and species of crabs, squat lobsters and barnacles. Results of DNA analyses of 85 animal specimens of these animals showed that one species of tube worm *Alaysia spiralis* has a range from Tonga to the east Manus Basin, while another new species of *Alaysia* was found. The data for *Alviniconcha hessleri*, the only currently recognised species, suggests

that it is widely distributed across vent systems of the Western Pacific, including East Manus, Lau, North Fiji and Okinawa Trough (see Figure 7.5) (CSIRO, 2007). However, two undescribed species are reported from the Manus and North Fiji Basins and further DNA studies (see Appendix 4) suggested these are not *Alviniconcha hessleri*.

This distribution may also be similar for the vent-dependent snail *Ifremeria nautili*. Others, such as the mussel *Bathymodiolus*, appeared to have a high degree of endemism and were found only in limited geographic areas. Two species of *Bathymodiolus* were present; one (provisionally named *Bathymodiolus manusensis*) only known from the Manus Basin and the other extending to New Zealand. However, whether separate species occur could not be confirmed at the time of this study without additional sampling and more detailed taxonomy, including analysis of DNA data undertaken by Nautilus. The study also highlighted the generally poor understanding of the macrobenthic fauna of inactive hydrothermal sites.

Prospect Level Studies (Solwara 1, South Su)

With this understanding of the environmental setting of the seafloor of the offshore Project area, Nautilus commissioned further extensive biological surveys of the macrobenthos of both active and inactive hard surfaces (chimneys and sulphide/dacite substrata) and also of the active and inactive sediments around the Solwara 1 and South Su areas. The studies were carried out to provide the environmental baseline and understanding for the present Project. The Wave Mercury 07 research campaign (March to April 2007) allowed the most comprehensive sampling of active hydrothermal vents and inactive sites in Manus Basin to date (Appendix 4). Benthic habitat studies were designed and undertaken in collaboration with international hydrothermal vent experts, and key issues for study were identified during a March 2007 workshop in Port Moresby (see Chapter 4). Some aspects of the studies have extended beyond that necessary for the EIS and impact prediction, and ongoing taxonomic work will add to the more general level of scientific knowledge of the Manus Basin. It is also Nautilus' intention that material collected during baseline and future monitoring studies will be available for experts around the world to pursue research (with approval from PNG authorities) and all of the scientists who have contributed to the baseline studies are free to publish their findings in the scientific literature.

The aim of the studies was to characterise benthic habitats, not only at active chimneys but also areas adjacent to the chimneys, including both active and inactive hard and soft substrates. Studies combined visual assessment from video transects with quantitative sampling of both hard and soft substrates (Appendix 4 and Appendix 5) and the main findings are summarised in the sections below. Note that in these studies, macrofauna of active and inactive hard substrates (Appendix 4) included all animals retained on sieve size of 250 μm , this being the mesh size on the ROV sampling suction chamber. Macrofauna of active and inactive sediments (Appendix 5) included all animals retained on sieve of 300 μm in order to maximise numbers for analyses. Meiofauna included all those animals passing through 500 μm and being retained on sieve of 53 μm , as is standard for meiofauna studies generally.

Macrofauna at Active Vents

Solwara 1 and South Su Studies

The macrofaunal (invertebrate) communities at active vents were studied by Van Dover *et al.*, (as cited in Appendix 4), with the objectives of building an inventory of macroinvertebrate species associated with active sulphide mounds, and comparing communities at Solwara 1 to those at South Su, a potential non-mined control site, a little over 2 km southeast of Solwara 1 (see Figure 1.2).

Active sites were defined by the presence of the typical vent-dependent species that host symbionts (e.g., *Ifremaria nautilei*, *Alviniconcha* sp. and/or *Bathymodiolus manusensis*) and/or by the visual evidence of warm water effluents and plumes. Sampling was only carried out where animals were observed, and the specimens were carefully collected using suction sampling or mechanical arms on an ROV. This sampling was undertaken quantitatively, with parallel replicate samples of equivalent numbers at Solwara 1 and South Su sites, to enable statistical analysis.

The active-vent sites at South Su and Solwara 1 share three visually similar, and generally concentric, habitat zones, characterised by the biomass-dominant species of gastropod *Alviniconcha* sp. (closest to the vent) and *Ifremaria nautilei* (middle zone) and the barnacle *Eochionelasmus ohtai* (outer zone), surrounding the host vent (Plate 7.16). The zones are most likely correlated with fluid activity, fluid chemistry and temperature along a gradient from the centre of vent activity to the outside. While this has not been demonstrated at Solwara 1, the correlation is based on evidence from other areas (Appendix 4). The species of mussel, *Bathymodiolus manusensis* and the vestimentiferan tube worms (*Alaysia* sp. and *Arcovestia ivanovi*) were only observed at South Su, where they occupied the outer barnacle zone. These species are shown in Plates 7.17 and 7.18 respectively.

These zones of dense animal biomass also provide habitat for many other species, including crabs, squat lobsters, shrimps, limpets and polychaete worms that live in association with the biomass-dominant snails and barnacles. More detailed descriptions of these groups with plates are given in Appendix 4. Many of these species were found at both Solwara 1 and South Su but some only at either site. In total, over 24,800 individuals were collected for quantitative analyses, of which 49 species were identified. Of these, 23 were common to both areas, 10 were only observed at Solwara 1, and 16 were only observed at South Su.

Statistically, there were few significant differences in the indices of species density and species diversity between the *Alviniconcha* and *Eochionelasmus* zones from Solwara 1 and South Su. However, diversity was significantly higher in the *Ifremaria* zone samples from South Su compared to Solwara 1. This was due to the large proportion of a single mollusc species, *Lepetodrilus schrolli*, of which 10,000 more individuals were collected at South Su. Community analyses of species abundance data using multivariate analyses showed no overall significant difference between Solwara 1 and South Su sites.

The main difference between Solwara 1 and South Su was the relative proportion of numerically dominant species rather than the composition, i.e., of the 23 species shared between South Su and Solwara 1, most were represented by less than 5 individuals at Solwara 1. In contrast, at South Su, these species were more abundant, with one species of limpet *Lepetodrilus schrolli* being particularly abundant. Another difference at South Su was the presence of the mussel beds and tube worms. These are characteristic elements of vent-dependent species in other vent systems but were not observed at Solwara 1. South Su is a suitable control insofar as it shares the same faunal elements and densities found at Solwara 1. South Su also has greater abundance of those and other organisms not at Solwara 1, and, in that respect, is a potential up-current source of recolonising larvae.

Comparison to other Hydrothermal Vent Sites

Overall, the studies undertaken during the Wave Mercury 07 Campaign represents the most comprehensive and systematic survey of the Manus Basin to date (Appendix 4) and at least 20 new species have been added to the species list at active vent sites. The community structure observed at South Su and Solwara 1 is visually similar to Lau and North Fiji basins. Clear alliances between Manus, Lau and North Fiji faunal composition are apparent at the genus level.

Both Solwara 1 and South Su active vent sites are similar in faunal zonation and composition. They differ mainly in the superabundance of the limpet *Lepetodrilus schrolli* and the presence of mussels and tube worms at South Su.

However, the species density (i.e., numbers of species per sample) and diversity at both Solwara 1 and South Su was low for all of the habitat zones when compared with other vent systems worldwide, such as the East Pacific Rise (see Figure 7.5), where the vestimentiferan tube worm habitats (characteristic of vents) are typically more extensive and provide habitats for much greater numbers of epifaunal animals.

While not fully understood, and beyond the scope of this project to research reasons why differences occur, the presence of the mussel *Bathymodiolus manusensis*, and the small colonies of tube worms, *Alaysia* sp. and *Acovestia ivanovi* at South Su but not at Solwara 1, may indicate different stages in successional sequence. It is possible that the naturally variable nature of active venting (i.e., turning on and off) at Solwara 1 is likely to have some bearing on the succession and establishment of communities and their duration. The evidence of the collections of dead (or possibly dormant) snails observed at vents where venting has been intermittent suggests that the processes of colonisation are periodically extinguished naturally, with succession reset with the strength of venting. The periodic episodes of volcanic ash deposition may also contribute to mortality and the continuous process of succession.

While the turning on and off of vents at South Su was not determined to the same extent during the exploration period, it provides a logical explanation of the differences in composition and relative abundances of species at Solwara 1.

Macrofauna of Inactive Hard Surfaces

In the past, with the natural focus on vents, the inactive sulphide substrates have not been well studied and the level of knowledge of fauna is poor (CSIRO, 2007). To provide the necessary information and as part of the above macrofauna study (Appendix 4), macrofauna on hard surfaces away from active vents at Solwara 1 and South Su were also sampled during the Wave Mercury 07 Campaign to provide essential descriptions of the macrofaunal characteristics of these habitats. Termed 'inactive hard substrates' in Appendix 4, the sample areas were determined by the presence of hard sulphidic or dacite (basaltic, non-sulphidic) substrata but without any characteristic vent-dependent snail and barnacle species or visible evidence of venting. Sampling was at least 10 m from the nearest chimney.

From these inactive hard surfaces, 91 species were collected, of which 32 were common to both Solwara 1 and South Su, 26 were only observed at South Su and 33 only observed at Solwara 1.

The most conspicuous and characteristic species colonising inactive sites were:

- Suspension-feeding bamboo corals *Keratoisis* sp. (Plate 7.19).
- Stalked barnacles *Vulcanolepas parensis* (Plate 7.20).
- Hydroids (Plate 7.21).
- Carnivorous sponges *Abyssocladia* sp. (Plate 7.22).

Of the species associated with these main groups, amphipods of the family Stenothoidae were one of the most abundant at both sites. This family is well represented at other vent sites worldwide, where they live in association with sponges, tunicates and other colonial animals outside the direct influence of vents. A large diversity of barnacles was observed and is thought likely to occur elsewhere on hard substrate in the surrounding seafloor environment.

Bivalves were well represented in samples from inactive sites but also included species that are known from other locations to be vent-dependent. Other species sampled at these inactive sites were previously thought to be active-vent fauna, including some limpets, gastropods, shrimps and squat lobsters. Recruitment of 'active-vent taxa' to non-venting areas has been reported before (Van Dover *et al.*, 1988; Mullineaux *et al.*, 1998) and their survival is likely to be dependent on the exposure to influence of nearby hydrothermal activity.

However, clear discrimination between active and inactive hard surfaces is not straightforward. This may be partly because inactive sites are comparatively less well studied than active areas and partly because other influences may apply: the inactive sampled areas may be in a dormant phase of intermittent venting, they may receive some influence of nearby but unseen vents or they may be exposed to sulphidic influences in near-seafloor current flows or in sub-surface fissures (Appendix 4). For example, species were observed from inactive dacite (basaltic, non-sulphide substrata) areas that were about 450 m from the nearest observed active chimney, but were northwest and down-current from Solwara 1, which may have provided sources of food. It is likely that animals observed exhibit scales of dependence, or ability to utilise such energy source that reflect distance from vents and frequency of exposure to vent influence. Given the dynamic and variable nature of venting activity, attempts at clear differentiation of zones with or without venting influences is not practicable.

Overall, there were no obvious differences between Solwara 1 and South Su in terms of the most abundant macroinvertebrate fauna associated with the inactive hard surfaces. Differences in the character of the fauna of inactive sulphide mounds between sites were due mainly to differences in assemblages of the least abundant, rarely sampled species. While the species richness and composition of biomass-dominant species were similar at each site, species effort curves⁹ had not levelled out at these sites, suggesting incomplete characterisation of the lesser abundant species. However, it is expected that the species colonising inactive sulphide mounds would occur elsewhere (Appendix 4), and endemism at the scale of sampling sites is unlikely. As with all benthic baseline and monitoring studies, it is unlikely that all of the more rare species will be observed.

Prior to the work outlined here, the focus of most studies completed to date has been on active vent areas rather than the peripheral areas, making it difficult to set the biodiversity context of the present findings. Overall, coral and sponge areas were the prominent biogenic features of inactive hard substrates. Assemblages are similar to those observed at seamounts, where dense coral and sponge meadows are prominent biogenic features that rely on enhanced delivery of particulate food in flow regimes associated with topographic relief. The bamboo corals are a diverse group of deep-water corals colonising seamounts and flat-bottom areas. They represent a biogenic habitat that supports other associated fauna. They are thought to be a long-lived species, with some colonies estimated at being over 100 years old. As discussed in Appendix 4, there is evidence that the bamboo corals near hydrothermal systems derive some of their organic sulphur from nearby chemotrophic sources. At Solwara 1, they were observed on sulphidic and

⁹ A graph recording the cumulative number of species of living things recorded in a particular environment as a function of the cumulative effort expended searching for them (usually measured in area or volume or number of individuals). The species effort curve will necessarily be increasing, and will normally be negatively accelerated (that is, as more species are discovered and added to the curve, its rate of increase will slow down). Plotting the curve gives a way of estimating the number of additional species that will be discovered with further effort.

dacite substrata, which may indicate different species or more likely, different growth forms in areas of greater exposure to chemotrophic energy (i.e., they can use but are not dependent on this energy).

Characterising the degree of endemism of these bamboo corals and their taxonomic relationship with those from other areas is currently difficult and beyond the scope of this EIS. They are a diverse and widely distributed group, with current literature divided regarding endemism versus widespread distribution. Notwithstanding, they are prominent biogenic features of the 'inactive' hard surfaces that support associated invertebrates, and will be considered along with the vent fauna in management and mitigation of impacts of mining.

Active and Inactive Sediments

Active sediments include unconsolidated sediments close to vents, where there is diffuse venting or influence of chemotrophic energy source. Typically, it is mostly hard substrates that are found at hydrothermal systems but, at Solwara 1 and South Su, sediment deposits of volcanic origin occur in some areas through which there is diffuse flux of fluids where these deposits are close to active vents. These sediments represent transitional habitats from the active sediments peripheral to the chimneys to sediments with progressively less influence of hydrothermal activity, with inactive sediments outside of this range. Given the natural variations in vent activity already described, there may be no durable distinction between active and inactive sediments beyond that at the time of sampling, and faunal communities may be at some successional stage reflecting this.

Macrobenthos

Levin *et al.*, (as cited in Appendix 5) studied benthic macrofaunal communities (greater than 0.3 mm) in active and inactive sediments in order to quantify and compare communities at Solwara 1 and at South Su. The activity status of the sediments was determined by proximity to actively venting chimneys, with areas more than 20 to 50 m from vents likely to represent inactive conditions.

As for the hard surfaces, a parallel quantitative sampling design of the sediments involved careful sampling of macroinvertebrates from active and inactive areas at Solwara 1 and South Su using a push-core sampling device attached to the ROV arm (Plate 7.23). Replicate samples at equivalent numbers of sites at Solwara 1 and South Su were taken (as far as was practicable) to enable statistical comparisons between the communities. A total of 35 push-core (55 mm internal diameter) samples were taken, 17 from Solwara 1 (7 inactive; 10 active) and 18 from South Su (8 inactive; 10 active) and, where possible, analyses of different depth horizons within the cores was made. In order to supplement the core sampling, a total of 16 scoop samples were also taken to provide additional material for analysis. However, the scoop samples allowed semi-quantitative analysis only.

Results show that faunal densities in active and inactive sediments are very low compared with published literature from studies undertaken at other sediment-hosted hydrothermal vent sites (Appendix 5). Only 220 individuals representing 15 species were observed in 35 cores sampled. Most of the fauna were found in the top 2 cm of sediment, and none below 5 cm from the seawater-sediment interface. Compared with the macrofauna of sediment-hosted hydrothermal vents known from the eastern Pacific Ocean, which are all much deeper than the Manus Basin, densities of animals observed at Solwara 1 and South Su were much lower. In the eastern Pacific examples, numbers from 3,000 to 18,000 individuals/m² have been recorded (Desbruyeres *et al.*, 2006; Grassle & Petrecca, 1991; as cited in Appendix 5) while Solwara 1 and South Su densities

(active and inactive sites) ranged from 445 to 3,494 individuals/m². Only in areas of hot muds (up to 94°C) were macrofaunal densities as low as those observed at Solwara 1 and South Su inactive sites.

The dominant taxa were tanaids (crustaceans) and nuculanoid bivalves at both Solwara 1 sites and at the South Su inactive site. The tanaids belong to two species: *Paraleptognathia* sp. (family Anarthruridae; subfamily Akanthophoreinae) and *Pseudotanais* sp. (family Pseudotanaidae). The spionid polychaete *Prionospio (Minuspio)* sp. was the dominant taxon at the active South Su site, comprising 76% of the total number of individuals. Other taxa present included polychaetes from seven families, crustaceans (gammarid amphipods, cumaceans, isopods) and limpets (*Lepetodrilus*). Appendix 5 describes these main species (including plates of all species found) in greater detail.

Despite the density differences compared with other regions, the fauna show some taxonomic similarities with those described from the east Pacific, in particular, the genera *Prionospio*, and nuculanoid bivalves, although it is likely that the species collected at Solwara 1 and South Su are undescribed. The small extent of sampling of these kinds of hydrothermal sediments does not necessarily imply localised endemism, and cumulative species curves suggest that increased sampling would reveal more species. However, the low densities make quantitative comparisons difficult. Of the 15 species observed, 5 were observed at Solwara 1 only, 6 were observed at South Su only, and 4 were common to both areas.

Statistically, the results were not consistent between areas and sites, mostly because of the low numbers and variability. However, the following differences were apparent:

- Faunal densities were significantly higher in the active South Su sediments than in the South Su inactive or Solwara 1 sites, which were not significantly different from each other.
- Within each area, the active site densities were generally higher than the inactive site densities but because of variability, these differences were significant only at South Su.
- Biomass was higher at the inactive than active Solwara 1 sites, but the South Su active site had biomass over 100 times higher than the inactive site and South Su active macrofaunal biomass was significantly higher than that observed at the three other sites.
- Diversity indices were highest in Solwara 1 active sediments, intermediate in Solwara 1 inactive and South Su inactive sediments, and much lower in South Su active sediments.
- Dominance, or the proportion of the most abundant species, is inversely correlated with diversity and hence was highest in South Su active sediments because of the high abundance of *Prionospio* and in Solwara 1 inactive sediments (*Paraleptognathia* sp.), and slightly lower (but still high) in South Su inactive sediments (nuculanoid bivalves) and active Solwara 1 sediments (*Paraleptognathia* sp.).

Multivariate analyses of community composition showed that active sites differed from inactive, and Solwara 1 differed from South Su. The difference in densities of tanaids, nuculanoid bivalves and *Prionospio* sp. accounted for most of the observed among-site differences.

In addition to the cores, 16 scoop samples were taken to provide additional material for faunal characterisation. The scoop samples contained a total of 664 individuals belonging to more than 31 taxa. In general, dominant taxa in scoops resembled those in cores, with tanaids the most abundant group at the Solwara 1 sites (two species) and nuculanoids (one specie) most abundant at South Su. Isopods, found mainly at Solwara 1, belonged to three species in three families:

Notoxenoides sp. (Paramunnidae), *Janirella* sp. (Janirellidae), and *Ilyarachna* sp. (Munopsidae). These species are undescribed and true distributions not currently known. As was found for the macrofauna on hard substrates and in the cores, the species effort curves had not levelled, suggesting that more species would be found with increased sampling effort.

Apart from the effect of the large numbers of biomass-dominant species (particularly *Prionospio*) in the active sediments at South Su, it is difficult to interpret any other minor differences in indices of species density, biomass and diversity between Solwara 1 and South Su, and between active and inactive sediments. This was partly because of the low number and partly because of the uncertainty of classifying sediments as active or inactive on the basis of proximity to the nearest known active vent.

The differentiation of active versus inactive sediment is also compounded by the visible heterogeneity of sediments over scales of centimetres to tens of metres. The variations included colour (orange, tan, brown, grey/orange, grey/white, greenish etc.), physical appearance (ripples, iron oxide crusts), and biological activity (microbial mats, faecal pellets, worm casts). These observations are consistent with those of Hrischeva and Scott (2008) (Appendix 6). Not all of these sediment types were sampled during the Wave Mercury 07 Campaign, but it is anticipated that each would most likely show some faunal differences if even more sampling effort were to be applied. However, given the sampling effort applied, numbers and densities of animals were so low that more extensive sampling of these sediments would be necessary to capture all of the rarer species and would require a level of effort beyond the scope of baseline characterisation studies.

Despite density differences between the Manus Basin and the eastern Pacific hydrothermal sediments, there are some similarities in taxonomic composition, most notably the abundance of the genus *Prionospio* (*Minuspio*) (only sampled at South Su active) and nuculanoid bivalves (sampled at all sites). The genus *Prionospio* is a widespread and species-rich genus and reported from many areas of the eastern Pacific and Atlantic oceans. Similarly, the nuculanoid bivalves, which comprised 17 to 43% of the fauna at the Solwara 1 and South Su sites are also abundant in eastern Pacific hydrothermal areas.

The tanaids appeared more abundant in the Manus Basin than in other hydrothermal sediments, but related taxa are reported from other eastern Pacific troughs (Appendix 5). Overall, there are obvious similarities at the generic level or higher that appear widespread over Pacific and Atlantic oceans. In comparison with other vents in the eastern Pacific, the Manus Basin macrofauna sampled are not particularly abundant or diverse, although those present are likely to be new species of more widely abundant genera and families.

Meiobenthos

Meiobenthos are microscopic metazoan benthic animals that live in the interstitial spaces of the top few centimetres of the seafloor sediments and pass through a sieve of 0.5 mm (500 µm) but are retained on sieve size of 53 µm. They are much more abundant than the macrofauna (in this study, animals greater than 300 µm) and therefore more suitable for quantitative monitoring of benthos of deep-sea sediments. Samples were taken from the top 1 cm (i.e., the surface) of core samples collected from active and inactive sediments at South Su and Solwara 1 during the 2007 Wave Mercury 07 Campaign. These are not reported in Appendix 5 but have subsequently been identified separately to the level of major taxa (Neira, unpublished data). This is usual for meiobenthos, for which identification to genus or species level requires considerable effort, and, in the case of samples from deep water, the majority of animals are likely to be species that are undescribed. Nevertheless, statistical comparisons of community composition and diversity can

still be achieved if required where the animals are just identified to major taxa (Clarke & Warwick, 1994) as is currently done with other deep-sea monitoring projects for other mines in PNG and elsewhere. The numbers of the different meiobenthos groups found in active and inactive sediment samples from South Su and Solwara 1 are given in Table 7.5.

At South Su, the numbers are higher in the inactive compared with the active sediments, while at Solwara 1, there is greater variability between samples and no consistent difference between counts from active and inactive areas. Typically, nematodes and harpacticoid copepods are the most abundant of the groups. However, the numbers of animals observed are at the lower end of the ranges of those typically observed in deep-sea sediments around the world (Coull, 1988), where numbers in excess of 1,000 are commonly recorded. This is also consistent with the low numbers of macrobenthos observed in the sediment samples from the same sampling locations (220 individuals representing 15 species observed in 35 cores sampled); conceivably, dynamic changes at the sediment surface due to the natural fallout of sediment from the overlying plumes, particularly from the North Su subsea volcano, may account for the low numbers.

Abysal Plain

During March 2008, sediment samples were collected along a transect from three locations 2.9, 7.6, and 10.4 km from Solwara 1 (see Figure 7.24) in order to sample the meiobenthos (microscopic metazoan animals between 53 µm and 500 µm) of the abyssal plain sediments outside the influence of the hydrothermal activity of Solwara 1. In these abyssal sediments, macrofauna are generally so sparse that only the microscopic meiobenthos can be sampled quantitatively. Samples were collected at depths from 2,000 to 2,020 m by means of a multi-corer (4 cores, each 55 mm internal diameter), deployed from the research vessel *Miss Rankin*. The multi-corer is appropriate for quantitative sampling of meiobenthos in sediments as it retrieves the sediment with minimal disturbance to the surface layers in which most of the meiobenthic animals occur. The sampling device is shown in Plate 7.24.

Table 7.5 Meiobenthos from sediments at Solwara 1 and South Su (numbers of individuals/10 cm² in top 1 cm of sediment)

Location	South Su Active		South Su Inactive		Solwara 1 Active					Solwara 1 Inactive				
	~1,300*	1,312	1,347	1,430	1,511	1,515	1,516	1,530	1,532	1,335	1,601	1,623	1,625	1,634
Major Taxa		T												
Nematoda	69	9	114	157	1	13	19	26	35	29	94	16	13	3
Harpacticoida	11	7	27	7	0	3	36	33	49	26	7	11	0	2
Nauplii	0	1	16	0	0	1	1	20	4	3	0	2	0	0
Rotifera	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Tanaidacea	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Polychaeta	0	0	0	5	0	0	0	0	0	0	0	2	0	0
Total	80	17	157	169	1	17	58	79	88	58	101	32	13	5

* No depth given therefore assumed around 1,300 m.

Analyses of the samples involved separation of the samples by elutriation, collecting on sieves of 53 µm and microscopic identification to the level of main taxa, as was undertaken for those from South Su and Solwara 1. Counts of meiobenthos are given in Table 7.6¹⁰.

Table 7.6 Meiobenthos taxa (number of individuals/10 cm²) in abyssal plain sediments remote from Solwara 1

Taxa	Sample Site		
	SISS04 (10.4 km west of Solwara 1)	SISS03 (7.6 km west of Solwara 1)	SISS06 (2.9 km west of Solwara 1)
Nematoda	590	89	178
Harpacticoida	55	7	20
Nauplii	8	1	1
Calanoid copepods	1	0	0
Ostracoda	14	0	2
Polychaeta	7	2	11
Tanaiida	1	0	0
Kinorhyncha	3	1	1
Isopoda	0	0	1

The results in Table 7.6 show higher numbers of main taxa and higher abundances of the dominant nematodes compared with those at Solwara 1 and South Su (see Table 7.5). This may reflect the greater distance from the North Su volcano (and lessening effect from its fallout), and different sediment composition and grain sizes.

Endemism

A genetic characterisation of macrofauna collected from active hydrothermal vents during the Wave Mercury 07 Campaign was undertaken by Van Dover *et al.*, (Appendix 14). Its aim was to determine the taxonomic and genetic similarities of the Solwara 1 and South Su species, and to compare with species of vent communities at other regional back-arc basins and other hydrothermal vent areas. The method involved extraction and sequencing of the DNA from tissues of the animals, followed by polymerase chain reaction (PCR) methods to amplify mitochondrial cytochrome oxidase subunit 1 genes (CO1).

A database of CO1 gene sequences (GenBank) is maintained by the US National Center for Biological Information, and includes some species of invertebrate macrofauna from hydrothermal vent areas. This allows a rapid assessment of whether the gene sequences from species found at Solwara 1 and South Su match any that have already been included in the GenBank database. The detailed methods are described in Appendix 4.

At present, the GenBank includes very few gene sequences from hydrothermal vent species, making it difficult to perform phylogenetic comparisons on more than those species currently included. The sequence data lodged by the Project will be extremely valuable in increasing the geographic range of source material and will enable consistent comparisons in future. However,

¹⁰ Identifications made by Dr John Moverley.

being one of the leaders in applying these techniques to hydrothermal vent species, comparisons will necessarily be slow while material from other areas is similarly analysed.

In the present study, a total of 126 individuals of 26 morphologically identified species were successfully sequenced. Exact matches with species from the GenBank (greater than 99% similarity) were documented for six species (*Alviniconcha*, itself differentiated into two species sp1 and sp2; *Ifremaria nautilei*, *Bathymodiolus manusensis*, *Arcovestia ivanovi*, *Paraescarpia* sp, and *Munidopsis lauensis*). There were six other morphological species that had close matches to GenBank species of the same genus (*Lepetodrilus*, *Alaysia*, *Lamellibrachia*, *Prionospio*, *Alvinocaris*, *Lebbeus*), and an additional two genera (*Nereis* sp., *Opaepele* sp.) that matched GenBank sequences of species in the same families.

These results are consistent with, and have extended the findings from, an earlier study (CSIRO, 2007) to show that:

- The biomass-dominant species of gastropod *Alviniconcha* sp 1 and sp. 2 from Solwara 1 and South Su also occur in the North Fiji Basin but were distinct from those in the Lau Basin.
- Gene sequences from the gastropod *Ifremaria nautilei* from Solwara 1 and South Su matched specimens collected from Manus, North Fiji and Lau basins.
- The vestimentiferan tube worm *Arcovestia ivanovi* occurs in Fiji and Manus basins, (including South Su but not Solwara 1).
- The squat lobster species *Munidopsis lauensis* occurs in Manus, North Fiji and Lau basins.
- The bivalve mussel *Bathymodiolus manusensis* is so far only known from the Manus Basin. It was observed at South Su (and also Solwara 4, 6 and 8) but not at Solwara 1.

In summary, some biomass dominant species (*Ifremaria nautilei*, *Munidopsis lauensis*) have ranges that extend across all regional back-arc basins, while other species (*Alviniconcha* sp 1 and 2, *Arcovestia ivanovi*) inhabit some basins but not all, and some species (*Bathymodiolus manusensis*) are so far only observed in the Manus Basin. While these results indicate the geographical ranges of species, they do not indicate the degree of genetic interaction among and between the populations in different geographical ranges.

Fish

It was not practicable to sample fish from the areas around the vents and non-venting habitats of Solwara 1 and South Su. However, during the ROV sampling, at least 10 species of fish were observed, either present around the vents or attracted to the lights of the ROV (Appendix 4).

Several species of Chimaera were observed and provisionally identified on the basis of visual images only. These are cartilaginous fish in the order Chimaeriformes and they are related to the sharks and rays, and are sometimes called ghost sharks, or ratfish. The species provisionally identified from the visual images included the pointy-nosed blue chimaera (*Hydrolagus trolli*), which is known from depths from 600 to 1,700 m in the western Pacific, including New Zealand and New Caledonia. The Pacific spookfish (*Rhinochimaera pacifica*) was also observed and this species has a distribution in the western Pacific and Indian Ocean.

Various other species of fish were also observed; *Hexatrygon bickelli* among sulphide deposits near chimneys, *Lepidion schmidti* (gadoid or cod family), feeding on vent animals (6-gilled stingray) and *Psychrolutes marcidus* (blobfish) in small numbers at the base of chimneys. *Pyrolycus manusanus*, a vent-endemic zoarcid eelpout, was common at Solwara 1 and South Su,

although it was more frequently observed at South Su. As far as could be determined from video observation, no new or unidentifiable taxa of fish was observed. Plates of these species are provided in Appendix 4.

7.8.3 Underwater Light, Noise and Vibrations

Marine Light Environment

Appendix 10 provides a review of the underwater light environment of the different depths in the ocean, including bioluminescence from deep-sea organisms. The two main natural sources of light in the sea are from celestial bodies (sun, moon and stars), and bioluminescence produced by aquatic organisms.

Natural daylight penetrates through the sea but intensity diminishes with depth as it is absorbed and virtually no daylight that can be perceived by animals reaches past 1,000 m. In clear water, such as in the Project area, surface waters are generally well lit. Photosynthetically active radiation – that of sufficient intensity for plant photosynthesis and net oxygen production i.e., the euphotic zone – is mostly within the first 80 m. Light may reach as deep as 200 m, although at intensities not strong enough to allow photosynthesis to occur (Section 7.5.3).

Different wavelengths are transmitted differently: blue light (475 nm) penetrates further than orange-red light (550nm), which is almost entirely absorbed within 100 m depth. The mesopelagic waters between the euphotic zone (80 m) and the bathypelagic zone (1,000 m) are characterised by very low levels of light, (sometimes referred to as the twilight zone) below the photosynthetic compensation point, and hence lower dissolved oxygen than the euphotic zone. In this zone, animals receive a constant blue light and an exponential decline of intensity with depth. At the mesopelagic zone and below, bioluminescence begins to play an important ecological role.

Surface lights, such as the light of the moon, are used by some marine fauna for navigation. Seaturtles navigate to and from nesting beaches by using the light of the moon and hatchlings migrate out to sea using the same navigational technique. Other species will alter their vertical migration pattern in the water column based on the phase of the moon. They will migrate closer to the surface when the moon is full.

There are many species of bioluminescent organisms that are likely to inhabit these depths in the Manus Basin, including invertebrates (salps, coelentrates, ctenophores, shrimps, squid) and many species of fish such as hatchetfish and lanternfish, and anglerfishes in deeper water. Bioluminescence in deep water serves many ecological functions. Primarily, it is a defence mechanism, where light or flashes of light serve to change outlines of the animal or distract predators. It also serves to aid feeding, for example by illuminating and attracting prey. Some species use bioluminescence for signalling behaviour and (it is assumed) to aid location between sexes.

Marine Acoustics

The principal sources of ambient ocean noise in the project area are from:

- Air ocean interaction and other oceanic processes.
- Naturally occurring and biogenic background noise.
- Noise from shipping activities.

Natural Physical Sources

Ambient background noises are given in a review by the National Research Council of the National Academy of Sciences (NRC, 2003) and are summarised below. The dominant source of

naturally occurring noise across the band frequencies from 1 to 100 Hz is associated with ocean surface waves generated by wind. Average ambient noise levels of 98 dB, 20 to 1,000 Hz have been determined in the Canadian Beaufort Sea (Richardson *et al.*, 1990). In the generally calm waters of the Bismarck Sea, levels from wind would be expected to be at the lower end of the range. Below 5 to 10 Hz, the dominant ambient source is non-linear interaction of oppositely propagating ocean surface waves (called microseisms). Above 100 Hz, thermal noise caused by the pressure fluctuations associated with thermal agitation of the ocean is the dominant contributor. Across the remainder of the band, the main sources are bubbles oscillating individually or collectively in the water column.

Meteorological processes that may be experienced in the project area vary in frequency and are largely dependent on seasons. Sources of noise such as raindrops on the sea surface can increase the ambient noise levels by up to 35 dB across a broad range of frequencies extending from several hundred hertz to >20 kHz. Thunder and lightning has characteristic spectra peaks between 50 to 250 Hz and up to 15 dB above ambient have been recorded 5 to 10 km away (NRC, 2003). Seismic energy from geological and tectonic sources can travel over great distances, extending to frequencies higher than 100 Hz with sharp onset and variable duration. Submarine volcanoes and hydrothermal vents are evident within the project area and have the potential to influence ambient noise levels substantially, particularly with low frequency sounds that may be audible for great distances. Recent studies have discovered what were believed to be relatively silent, black smokers actually generate significant acoustic emissions at all frequencies up to 500 Hz (Crone *et al.*, 2006). It is estimated that the broadband signals generated by these hydrothermal vents would be above the ambient noise levels. However of all physical processes, in the project area, wind action on surface waves and hydrothermal vent activity are expected to be the dominant contributors of natural noise.

Natural Biological Sources

Marine animals such as whales, dolphins, fish and invertebrates are responsible for creating biological noise associated with communication, navigation, echolocation and feeding strategies. Biological sources make contributions to the ambient ocean noise at certain seasons or periods of the day.

Marine mammal vocalisations are associated with behavioural adaptations and cover a wide range of frequencies. Odontocetes (dolphins and toothed whales) produce broadband clicks that are characteristic of species, and cover a wide energy range from less than 10 Hz to more than 200 kHz (NRC, 2003). Vocalisations of mysticetes (baleen whales) are significantly lower in frequency than those of odontocetes and are broadly categorised as low-frequency moans. Peaks around 20 Hz, created by calls of large baleen whales are often present in deep ocean noise spectra. However, there are a wide variation of calls and songs, potentially used in long-distance communication and topological echolocation (NRC, 2003).

Source levels for whale and dolphin vocalisations have been reported as high as 228 dB re1 μ Pa for echolocation of false killer whales (Thomas and Turl, cited in NRC, 2003) and bottle-nosed dolphins echolocating in the presence of noise (Au, cited in NRC, 2003). The highest levels are calculated at 232 dB re1 μ Pa for adult male sperm whales (Møhl *et al.*, cited in NRC, 2003). Such high source levels are required for acoustic imaging of the environment using return echoes from objects with low target strength. The short duration of the echolocating clicks (50 to 200 μ s) means that the energy content integrated over time is low, even though the source levels are high (Au, cited in NRC, 2003). Baleen whale vocalisations have the potential to be detected over long distances because of their low frequencies. Blue whales and fin whales produce low frequency

(10 to 25 Hz) moans with estimated source levels up to 190 dB re1 μ Pa (NRC, 2003). Vocalisations below 1 kHz and source levels above 180 dB re1 μ Pa have also been recorded for other large baleen whales such as bowhead, southern right and humpback whales (Richardson *et al.*, 1995). Humpback whales can significantly increase background noise during breeding season. Time-averaged peak levels recorded 2.5 km offshore (Hawaii) reached 125 dB re1 μ Pa. (NRC, 2003) and it is the baleen whales that can be detected over the longest distances.

The diversity of fish inhabiting the project area may also contribute to the ambient noise levels. Many species of marine fish and invertebrates produce sound and use it primarily for communication. Fish produce sounds by means such as striking bony structures against one another, or by muscle movement amplified by the gas-filled swim bladder (NRC, 2003). Many species participate in regular chorusing behaviour (when a large number of individuals call simultaneously), often at dawn or sunset, with characteristic peak frequency of 1 KHz at broadband levels of 86 dB re 1 μ Pa (APPEA, 2005). Snapping shrimps are capable of generating very distinct broad peaks within the 2,000-15,000 Hz frequency bands by snapping closed its large front claw (McCarthy, 2004).

Man-made Sources

Commercial shipping is a major contributor to ambient noise levels, especially at low frequencies between 5-500 Hz (NRC, 2003). Low frequency ship noise sources include propeller noise (cavitation, blade frequency and blade passage forces), hydrodynamic hull flow, engines and other machinery. The noise of merchant shipping falls into two categories: first, the noise of distant traffic that is not really audible as a ship but contributes to elevated sea noise levels across a defined frequency range affecting large geographic areas and, second, from nearby traffic that is identifiable as such. Sound levels and frequency characteristics are roughly related to ship size and speed, but vessel signatures can be specific. Generally, the more distant the source, the more indiscernible are the characteristics, and the geography of the project area between New Ireland and New Britain may shield noise from distant shipping. Richardson *et al.* (1995) reports data from commercial vessels from literature sources. Noise levels measured for the larger class vessels (e.g., supertankers) are highest, with a recorded value of more than 180 dB, at the lower frequency band of 20 Hz. National and local cargo transporters travel through the Bismarck Sea to PNG ports including Port Moresby, Kimbe Bay, Rabaul, Madang and Lae but few pass through the project area. Most marine traffic comprises of coastal trading ships and smaller fishing vessels moving between New Ireland and East New Britain.

To put the audibility range of these sources in context, it is important to note that long-range sound propagation in the ocean is common for both natural and man-made sounds. For example, low frequency sounds produced by the nearby North Su subsea volcano are likely to be audible for thousands of kilometres, and other seismic events such as earthquakes can produce sounds that are well above ambient noise levels at ranges of thousands to tens of thousands of kilometres. In the case of man-made sources, sounds produced by airgun arrays during seismic surveys have been recorded by the authors at ranges of several thousand kilometers (Appendix 13).

7.9 Description of the Existing Nearshore and Onshore Environment

Ore will be stored in stockpiles in a purpose-built covered storage facility at the Port of Rabaul until enough material has accumulated for transfer to bulk carriers for shipping to an overseas

processing facility (see Section 5.7 for further details). This section provides a description of the existing environment at and around the Port of Rabaul.

7.9.1 General

Rabaul is situated in a large breached volcanic caldera on the north coast of New Britain (see Figure 7.4). The caldera, which measures 9 km by 14 km, is open to the sea (Blanche Bay) on the eastern side. The naturally sheltered Simpson Harbour is situated in the northern extent of the caldera. Several extinct, dormant and active volcanic vents are located along the northern and eastern rim of the caldera.

Rabaul township and the Port of Rabaul are located on a narrow, coastal fringe inside the caldera at the northern edge of Simpson Harbour. Rabaul was East New Britain's largest town and provincial capital before the 1994 volcanic eruptions of Vulcan and Tavurvur that buried it in volcanic ash. After these eruptions, the town was evacuated and the administrative centre for East New Britain moved to Kokopo, a small town 20 km southeast of Rabaul (Figure 1.1).

Today, the town of Rabaul is slowly rebuilding and the Port of Rabaul continues to act as the main port in the region for incoming and outgoing cargo, while Kokopo remains the administrative and provincial capital.

7.9.2 Marine Environment

Water Quality

Seawater sampling was undertaken in June 2008 to provide baseline water quality data for Port of Rabaul. Samples were collected from the surface at three sites adjacent to the port facilities within Simpson Harbour (see Figure 7.25). The results of the survey are consistent with an area already influenced by port activities. A summary of the results are provided in Table 7.7 and are discussed below.

Table 7.7 Marine water quality adjacent to the Port of Rabaul

Parameter	Sample Location			
	RH1	RH2	RH3	RH3 (duplicate)
pH	8.06	8.11	8.16	8.18
Salinity (ppt)	32	34	34	35
Total suspended solids (mg/L)	108	152	26	168
Total alkalinity as CaCO ₃ (mg/L)	114	115	118	118
Sulphate as SO ₄ (mg/L)	2,290	2,680	2,600	2,750
Chloride (mg/L)	20,100	19,500	22,400	20,500
Calcium (mg/L)	340	412	420	444
Magnesium (mg/L)	1,140	1,290	1,330	1,350
Sodium (mg/L)	9,980	11,000	11,300	11,400
Potassium (mg/L)	417	452	459	466
Aluminium (µg/L)	40	20	10	10
Selenium (µg/L)	10	5	<2	<2
Iron (µg/L)	31	8	5	7
Arsenic (µg/L)	2.1	2.2	2.2	2.4

Table 7.7 Marine water quality adjacent to the Port of Rabaul (cont'd)

Parameter	Sample Location			
	RH1	RH2	RH3	RH3 (duplicate)
Cadmium (µg/L)	<0.2	<0.2	<0.2	<0.2
Chromium (µg/L)	<0.5	<0.5	<0.5	<0.5
Cobalt (µg/L)	<0.2	<0.2	<0.2	<0.2
Copper (µg/L)	<1	<1	<1	<1
Lead (µg/L)	<0.2	<0.2	<0.2	<0.2
Manganese (µg/L)	12.3	7.7	6.4	5.2
Nickel (µg/L)	<0.5	<0.5	<0.5	<0.5
Silver (µg/L)	<0.1	0.1	<0.1	<0.1
Zinc (µg/L)	5	<5	<5	<5
Fluoride (mg/L)	0.8	0.8	0.8	0.8
Ammonia as N (mg/L)	<0.010	<0.010	<0.010	<0.010
Nitrite as N (mg/L)	<0.010	<0.010	<0.010	<0.010
Nitrate as N (mg/L)	<0.010	<0.010	<0.010	<0.010
Total Nitrogen as N (mg/L)	0.3	0.3	0.4	0.3
Total Phosphorus as P (mg/L)	0.1	0.12	0.08	0.07

Physico-chemical Parameters

Percent of hydrogen (pH) at the site ranged from 8.06 to 8.18 and was within the range normally expected for seawater. Electrical conductivity (49,300 to 52,900 µS/cm) and salinity (32 to 35 ppm) were within the ranges expected for seawater and indicated that there was no recent influx of freshwater from rivers or direct rainfall. Total suspended solids ranged from 108 to 168 mg/L (except for site RH3, which was 26 mg/L; however the duplicate result indicated a much higher value). These results are typical of an operating port site.

Major Ions

Four major cations (Ca²⁺, Mg²⁺, Na⁺ and K⁺) and four major anions (HCO₃⁻, CO₃⁻, Cl⁻ and SO₄²⁻) were analysed. The system is Na⁺/Cl⁻ dominated, as expected for seawater.

Nutrients

Total phosphorus ranged from 0.07 mg/L to 0.12 mg/L. These values are within the ANZECC/ARMCANZ (2000) guidelines for nearshore, tropical marine sites.

Total nitrogen ranged from 0.3 mg/L to 0.4 mg/L and are significantly greater than the ANZECC/ARMCANZ (2000) guidelines (0.1 mg/L), indicating a possible point source of organic nitrogen loads.

Total Metals

Although some metals exceeded detection limits (aluminium, selenium, iron, arsenic, manganese and zinc), all were within ANZECC/ARMCANZ (2000) guidelines for nearshore tropical marine sites.

Aquatic Fauna

There is a high diversity of marine species in and around Simpson Harbour. Munday (2000) reports that before the 1994 volcanic eruptions, coral reefs flourished with live coral cover typically around 50%. Following the eruptions, the fringing reefs within the harbour were buried by ash and mudflows however, by 1996, corals had extensively recolonised hard surfaces such as volcanic boulders and tree stumps (Maniwavie, 2001).

7.9.3 Terrestrial Flora and Fauna

The port area has been mostly cleared of original vegetation. A few patches of coconut trees remain close to the waters edge on the eastern side of the port; however, these are likely to have been planted rather than have grown naturally.

7.9.4 Landform, Soils and Geology

The Port of Rabaul has been operational for many years and soils and landforms have been altered by this continuous use. The geology of the coastal area around Simpson Harbour is typically basalt, which is a volcanic rock formed by the rapid cooling of lava (Greene *et al.*, 1985).

7.9.5 Air Quality and Noise

There is very little information currently available on the air quality of Rabaul. The World Health Organisation, in conjunction with the Rabaul Volcano Observatory, has recently completed an air quality study, however results from this study are not yet available.

The proximity of Tavurvur to Rabaul has a noticeable effect on the air quality. Prevailing winds often bring ash and volcanic gases to town as shown in Plate 7.25. Monthly reports from the Rabaul Volcanological Observatory indicate that Tavurvur emits almost continuous ash and vapour plumes that result in regular ashfalls on Rabaul. A hydrogen-sulfide (H₂S) odour is also regularly detected in Rabaul (Saunders and Patia, 2008).

During extreme eruptions, Tavurvur can produce large amounts of ash and gas. For example, Figure 7.26 shows concentrations of sulphur dioxide (SO₂) in the atmosphere in the days following a particularly strong eruption on 7 October 2006.

Existing noise levels are well above rural background levels at the port and are typical of an industrial, urban location.

7.9.6 Cultural Heritage

The Port of Rabaul is a developed industrial facility and any culturally significant materials will have been removed, disturbed or destroyed during initial port construction activities.

During World War II, Rabaul served as the main Japanese Naval base in the South Pacific. As a result, Simpson Harbour has a multitude of ships and aircraft wrecks, which are now popular diving sites for local tour operators.

7.9.7 Existing Use

The Port of Rabaul is the fourth largest port in PNG, behind Port Moresby, Lae and Kimbe and has an average throughput of approximately 300,000 tonnes per annum (World Bank, 1999). The port is crucial to East New Britain's economy for the export of agricultural products (mostly copra and cocoa) and the import of manufacturing and containerised goods. Ship movements by type of cargo at the port are set out in Table 7.8. On average, there are 12 scheduled vessels berth each

month at the port. Photos of some of the vessels currently using the port are shown in Plates 7.26, 7.27 and 7.28.

Table 7.8 Port of Rabaul Ship Movement 1993 to 1997

Vessel Type		Year					
		1993	1994 ¹	1995	1996	1997	1998 ²
Overseas	Container	69	49	37	32	43	34
	General Cargo	37	19	13	34	32	9
	Tanker	57	32	28	29	31	21
	Roll-on/Roll-off	24	17	9	11	17	16
	Cruise	11	8	2	0	1	3
	Log Ship	171	148	65	185	139	78
	Other	58	32	51	99	143	205
	Subtotal	427	305	205	390	406	366
Coastal	General Cargo	50	45	58	74	65	47
	Tanker	11	10	16	33	12	25
	Barge	4	28	30	41	63	20
	Passenger	16	26	22	27	6	4
	Other	13	66	35	48	11	59
	Subtotal	94	175	161	223	157	155
Total		521	480	366	613	563	521

¹ Volcanic eruption in Rabaul occurred September 19, 1994.

² January to September (inclusive).

Source: (World Bank, 1999).

The layout of Port of Rabaul is shown in Figure 5.3. It is approximately 4.5 hectares in size and is bordered by an oil tank farm to the west, Blanche Street to the north and private wharves and storage areas to the east. The port has two main berths, the dimensions of which are provided in Table 7.9. The largest and most used berth is Berth 2. The smaller Berth 1 is used as a back-up facility.

Table 7.9 Port of Rabaul Berth Dimensions

Berth	Length (m)	Width (m)	Maximum Draft (m)	Average Monthly Berth Occupancies (%)
Berth 1 (Blanche St)	122	12.1	7.9	25
Berth 2 (Bay Road)	152	15.2	10.2	40

The two main storage sheds at the port are Shed 1 and Shed 2, which are located at the back of Berths 1 and 2 respectively. Shed 2 has been recently maintained and renovated (Plate 7.29). There are plans to renovate Shed 1 in the near future (Plate 7.30).

Shed 1 (103.6 m by 30.4 m) has been leased to the following clients and port users:

- Copra buyer and exporter (40%).
- East New Britain Port Services as office space (10%).
- PNG Ports Corporation Limited (10%).
- Unavailable space due to condition of shed (40%).

Shed 2 (121.9 m by 30.4 m) usage is as follows:

- Cocoa storage (80%).
- Cargo storage (10%).
- Office space by other clients and port users (10%).

In addition to the sheds, there is approximately 20,000 m² of open storage area at the port. This area is currently unused.

7.9.8 Port Management

The Port of Rabaul is part of PNG Ports Corporation Limited (PPCL). PPCL operates 17 commercial ports in PNG and is responsible for:

- The regulation, management, operations and control of declared ports.
- The movement of shipping in such ports.
- The provision and maintenance of navigation aids, mooring, wharves, docks, landing facilities and platforms in such ports as well as equipment and installations used in connection with such ports.

East New Britain Port Services is the sole licensed stevedore for the Port of Rabaul.

PPCL does not currently have an environmental management plan or environmental monitoring program for the Port of Rabaul. However, it does police and report environmental incidents such as oil spills to the Department of Environment and Conservation who regulate environmental legislation in PNG. A waste management plan and emergency management plan is currently being drafted by the PPCL.

No industrial wastewater treatment facilities are available at the port. Waste from vessels is disposed of by National Agricultural Quarantine and Inspection Authority (NAQIA), who have a specialised waste disposal plant outside of the port area. The local waste from the port is disposed of by PPCL through the normal waste disposal process of the town authority.

Silt traps have been installed at the two-runoff water discharge points at the port to trap silt washed down from the hinterlands during wet seasons.

8. SOCIOECONOMIC ENVIRONMENT

8.1 Papua New Guinea in Brief

8.1.1 Population and Society

Papua New Guinea is located in Oceania and consists of a group of islands, including the eastern half of the island of New Guinea, between the Coral Sea and the South Pacific Ocean, east of Indonesia. The country's total land area is approximately 465,000 km². The country has a population of approximately 5.7 million people (in 2004), and the current population growth rate is 2.23% (UN, 2004). The capital is Port Moresby, with a population of about 255,000 (City population, 2008). Papua New Guinea is by far the largest and most populated of all Pacific island countries. While the overall population density in the country is low, there are pockets of high population density.

The spectrum of PNG society ranges from traditional village-based life dependent on subsistence production (sago cultivation, hunting and gathering, fishing and agriculture) and small-scale cash cropping to modern urban life in the main population centres of Port Moresby, Lae, Madang, Wewak, Goroka, Mt Hagen and Rabaul.

8.1.2 Sovereignty

The eastern half of the island of New Guinea was divided between Germany (north) and the United Kingdom (south) in 1885. The latter area was transferred to Australia in 1902. Australia occupied the northern portion during World War I and continued to administer the combined areas as a UN trusteeship until creation of the Independent State of Papua New Guinea in 1975.

8.1.3 Communities, Religion and Language

The population of Papua New Guinea is ethnically diverse (most people are of Melanesian origin, but some are of Micronesian or Polynesian origin) and one of the most heterogeneous in the world. Papua New Guinea has several thousand separate communities, most with only a few hundred people. Divided by language, customs, and tradition, some of these communities have engaged in low-scale tribal conflict with their neighbours for millennia. The three key elements of PNG's social environment are the traditional land tenure system, the 'wantok' system, and faith-based and community-based groups. The 'wantok' system is PNG's social safety net under which family and group members support each other under customary obligations defined by their shared language, culture, and kinship.

Migration from rural to urban areas is substantial. A considerable urban drift toward Port Moresby and other major centres has occurred in recent years. The trend toward urbanisation accelerated in the 1990s, bringing in its wake squatter settlements, ethnic disputes, unemployment, and attendant social problems.

According to the 2000 census, 96% of the population are Christian. Of these, 27% are Catholic, 19.5% are Lutheran, and the balance are members of other Protestant denominations (CIA, 2008). Although the major churches are under local leadership, a large number of missionaries

remain in the country. The non-Christian portion of the population as well as a portion of the nominal Christians, practice a wide variety of religions that are an integral part of traditional culture, mainly animism (spirit worship) and ancestor cults.

English, the official language, is spoken by only 1% to 2% of the population. Melanesian Pidgin is the lingua franca, and over 800 other languages are spoken. These languages are generally used by only a few hundred to a few thousand people, although Enga, a language used in the highlands, is spoken by some 130,000 people. Many of the languages used in Papua New Guinea are extremely complex grammatically.

8.1.4 Land Ownership

Underlying the Project's socio-cultural environment is perhaps the single most important feature of Papua New Guinean society: the customary system of land ownership. Land is Papua New Guinea's most important resource and is collectively owned via various forms of social organisation based on kinship and descent principles. Few social, economic or developmental issues can be described or assessed without reference to this system. Some 97% of the land of Papua New Guinea is held under customary tenure. This means that there are very few places outside urban areas where activities can be conducted without the consent of, and partnerships with, traditional landowners.

While any activities undertaken on the portion of the seafloor from the shoreline to 3 nm offshore require consultation with, and permission from, traditional owners of land immediately onshore, the seafloor further offshore is owned by the state.

8.1.5 Economy

Papua New Guinea has a dual economy, comprising a formal, corporate-based economy and a large informal economy in which subsistence production accounts for the bulk of economic activity. The formal sector provides a rather narrow employment base, consisting of workers engaged in exploitation of Papua New Guinea's vast natural resources, i.e., mineral and oil or gas production. Additional sectors include a relatively small manufacturing sector, the public sector, and service industries, including finance, construction, transportation and utilities. The bulk of the population is engaged in the informal sector, which provides a subsistence livelihood for 85% of the population (CIA, 2008).

In 2007, major exports were estimated to be worth PGK11.93 billion¹ (free on board), of which mineral resources accounted for nearly two-thirds of export earnings. Imports were estimated to cost the country PGK5.95 billion over the same period. The estimated 2007 gross domestic product (GDP) of Papua New Guinea is approximately PGK41.94 billion (PGK7,600 per capita), with an estimated growth rate of 4% (CIA, 2008).

¹ Based on an exchange rate of USD1 equal to PGK2.62.

8.1.6 United Nations Millennium Development

In 2000, the United Nations established eight Millennium Development Goals and set a target of 2015 to achieve those goals. PNG-gender-differentiated development indicators as of the year 2000 have been produced by the United Nations Millennium Development Goals and are presented in Table 8.1 (UN, 2004).

The population has been growing at an average rate over the past 20 years of almost 3% per year. Fertility remains high, with an estimated 3.96 children born per woman. Approximately 40% of the population is under the age of 15.

The rapid decline in mortality during the 1970s did not continue after 1980 and the level of infant, child and adult mortality remains high to this day.

Table 8.1 PNG development indicators at 2000

Indicator	Total	Male	Female
Population Size			
Total	5,171,548	2,679,769	2,491,779
Rural	4,496,145	2,314,236	2,181,909
Urban	675,403	365,533	309,870
Average population growth rate from 1980 to 2000 (% per year)	2.7	2.7	2.7
Crude population density (per km ²)	11.2	na	na
Age structure			
Population under 15 (%)	40	40.6	39.4
Population 15 to 59 (%)	55.9	55.1	56.8
Population 60 and over (%)	4.1	4.3	3.8
Adult (over 15) literacy rate (%)	49.2	55.2	43.9
Youth (age 15 to 24) literacy rate (%)	61.7	64.4	58.9
Cohort retention rate at primary level (%)	56.8	58.3	55.2
Infant mortality rate (per 1,000 live births)			
Total	64	67	61
Rural	69	72	65
Urban	29	31	26
Under age 5 mortality rate (per 1,000)	88	93	83
Attendance at antenatal clinic (%)	na	na	58
Supervised delivery (%)	na	na	41
Life expectancy at birth (years)			
Total	54.2	53.7	54.8
Rural	53.0	52.5	53.6
Urban	59.6	59.0	60.3
Proportion of children under age 5 with <80% weight for age (%)	24.9	na	na
Immunisation (%)			
Measles in children less than age 1	53	na	na
Triple antigen (3 rd dose) in children less than age 1	59	na	na

Source: UN (2004). N.A. Not available.

8.1.7 Government

National Government

Papua New Guinea is a constitutional monarchy with a parliamentary democracy. The head of state is Her Majesty Queen Elizabeth II, represented in Papua New Guinea by the Governor-General, who is appointed by the National Executive Council (cabinet).

The head of the government is the Prime Minister, who is appointed and dismissed by the Governor-General on the proposal of Parliament. The Prime Minister is usually the leader of the majority party (or majority coalition) in Parliament.

The nation is divided into 20 administrative units (19 provinces and the National Capital District of Port Moresby). Each province is subdivided into various districts that have a number of local-level governments (LLGs), with councils having elected ward representatives.

Provincial Government

The Department of Provincial and Local Government Affairs is charged with the responsibility for administering the Organic Law on Provincial and Local-level governments, which establishes the political, planning and financial management relationships between the national government and the provinces.

The Provincial Assembly is the paramount decision-making body in a province. It is composed of members of the National Parliament (MPs), heads of local-level governments and a limited number of appointed members representing women and other groups.

The onshore and offshore components for Phase 1 of the Solwara 1 Project are located in the East New Britain and New Ireland provinces, respectively.

Local-level Governments

Local-level governments are given certain legislative powers and, in principle, guaranteed funding.

Local-level governments only function in some parts of PNG's provinces. The provincial governments have included local-level government administration costs in forecast budgets but have done little to assist in their inauguration or to arrange for accounts into which funds, such as development levies, might flow.

The onshore component of the Solwara 1 Project is located in the Rabaul Urban local government area and it is envisaged that the offshore component of the project will be under the local jurisdiction of the Kavieng Urban local level government.

Provincial and Local-level Government Financing

Provincial and local-level governments are financed by grants from the national government and by 'internal' revenue, which is made up mainly of transfers of national taxation funds and a small amount of revenue that is generated by investments or under their own tax laws.

For provinces where mining and petroleum resources are present, the national government revenue transfers include royalty payments and development levies.

8.2 Project Impact Area

In land-based mining projects, impact areas defined in a social impact assessment are generally determined by reference to the areas associated with landowners who are entitled to benefits because their land lies within the area of project development. However, because the Solwara 1 mining area is located offshore (where the workforce will also be accommodated) and owing to the fact that the onshore Project components will utilise an existing commercial facility on alienated land, the social impact assessment Project impact area has been based on areas where:

- Employees will be recruited.
- Contractors and suppliers are located.
- Benefit streams, e.g., royalties and taxes, will be distributed.
- Offshore activities will take place, e.g., where fishing and marine traffic occur.

The main local areas, Kavieng and Rabaul, are discussed in the following sections. Fisheries, resource use and transportation are addressed in Sections 8.3 and 8.4.

8.2.1 Kavieng

Kavieng, the capital of the New Ireland Province (Figure 1.1), is the largest town on the island of New Ireland. The last census data (2000) recorded a town population of 11,560 (City population, 2008); however, informal information sources suggest that the population has increased to approximately 14,500 (ESM, 2008).

Kavieng is both a trading and tourist destination and is serviced by the main port for New Ireland and the Kavieng airport. Services provided in Kavieng include local government offices, shopping, hotels, hospital and a weekly market.

The PNG Millennium Development Goals rank province performance against the Papua New Guinea average and show that, in general, as for the other provinces in the islands region, New Ireland Province performs well above the national average (Table 8.2).

Table 8.2 New Ireland performance against millennium goals

Goal	New Ireland
Average life expectancy (years).	Far above national average
Average percentage for the years 1999 to 2003 for children under age 5 who have attended clinics and weighed less than 80% of that expected for their age.	Above national average
Cohort retention rates (%) at the primary level in 2000.	Above national average
Youth (15 to 24) literacy rates (%) in 2000.	Far above national average
Female labour force participation rates (%) in 2000.	Far below national average
Difference (%) between male and female youth (15 to 24) literacy rates in 2000.	Females performing above national average
Infant mortality rates (per thousand) in 2000.	Below national average
Average percentage for the years 1999 to 2003 of children under age 1 who received their 9 to 11 months dose of measles vaccine.	Above national average

Table 8.2 New Ireland performance against millennium goals (cont'd)

Goal	New Ireland
Average percentage for the years 1999 to 2003 of children under age 1 who received three doses of the triple antigen vaccine.	Above national average
Average percentage for the years 1999 to 2003 of pregnant women who had at least one antenatal visit.	Far above national average
Average percentage for the years 1999 to 2003 of births supervised in a health facility or by a trained village birth attendant.	Far above national average

Source: UN, 2004.

8.2.2 Rabaul

Rabaul is a township in East New Britain Province (see Figure 1.1) that was formally the provincial capital until it was destroyed by the falling ash from a volcanic eruption in 1994. The capital was moved to Kokopo approximately 20 km away. Consequently, the population of Rabaul has declined from 17,044 in 1990 to 3,885 in 2000.

Rabaul remains a tourist destination popular for diving and snorkelling but is no longer the premier commercial and travel destination that it was prior to the 1994 volcanic eruption.

The PNG Millennium Development Goals rank province performance against the Papua New Guinea average and show that, in general, East New Britain Province performs well above the national average (Table 8.3).

Table 8.3 East New Britain performance against millennium goals

Goal	East New Britain
Average life expectancy (years).	Above national average
Average percentage for the years 1999 to 2003 for children under age 5 who have attended clinics and weighed less than 80% of that expected for their age.	About national average
Cohort retention rates (%) at the primary level in 2000.	Far above national average
Youth (15 to 24) literacy rates (%) in 2000.	Far above national average
Female labour force participation rates (%) in 2000.	About national average
Difference (%) between male and female youth (15 to 24) literacy rates in 2000.	Females performing above national average
Infant mortality rates (per thousand) in 2000.	Below national average
Average percentage for the years 1999 to 2003 of children under age 1 who received their 9 to 11 months dose of measles vaccine.	Far above national average
Average percentage for the years 1999 to 2003 of children under age 1 who received three doses of the triple antigen vaccine.	Far above national average
Average percentage for the years 1999 to 2003 of pregnant women who had at least one antenatal visit.	Far above national average
Average percentage for the years 1999 to 2003 of births supervised in a health facility or by a trained village birth attendant.	Far above national average

Source: UN, 2004.

8.3 Fisheries

8.3.1 Commercial Fisheries

The primary commercial fisheries in PNG target tuna and prawn.

The tuna fishery is dominated by purse-seine and long-line fishing in the Bismarck Sea, Coral Sea and Pacific Ocean (Figure 8.1). In 2005, a total of 284,204 tonnes (t) of tuna was caught in the PNG Exclusive Economic Zone (EEZ), with the purse seine fleet catching 280,630 t or 99% and the long-line fishery catching the remaining 3,574 t or 1% of the total catch (Kumoru and Koren, 2006).

The main prawn fisheries are in the Gulf of Papua, Orangerie Bay, the Torres Strait and offshore Western Province. As there are no prawn fisheries in the Project area, they are not discussed further.

Domestic and Locally Based Foreign Purse Seine Tuna Fishery

The domestic and locally based foreign purse seine tuna fishery has a fleet of 41 boats (in 2006) fishing within the PNG EEZ. The domestic and locally based foreign fleet has steadily increased its catch over the last five years and exceeded 100,000 t/a in 2003, 2004 and 2005 (Table 8.4). The fleet now accounts for over 40% of the purse seine tuna catch in the PNG EEZ. In 2005, the domestic and locally based foreign catch comprised 65.1% skipjack, 33.7% yellowfin tuna, bigeye 0.9% and other species 0.3% (Kumoru and Koren, 2006).

Table 8.4 PNG domestic and locally based foreign fishing fleet catch composition

Year	Skipjack (t)	Catch (%)	Yellowfin (t)	Catch (%)	Bigeye (t)	Catch (%)	Other (t)	Catch (%)	Total (t)
2001	35,068	64.6	18,700	34.4	451	0.9	67	0.1	54,286
2002	46,686	67	22,634	32.5	122	0.2	287	0.3	69,728
2003	82,880	72.7	30,948	27.1	94	0.1	69	0.1	113,991
2004	92,328	84.3	17,101	15.6	100	0.1	47	0	109,577
2005	73,350	65.1	37,998	33.7	1,056	0.9	199	0.3	112,602

Source: Kumoru and Koren (2006).

International Purse Seine Tuna Fishery

PNG has bilateral fishing access agreements with China, Korea, Taiwan, Vanuatu, Japan and the Philippines. In 2006, the licensed international purse seine fishing vessels operating in the PNG EEZ totalled 155 vessels. The species catch composition from the international fishery is similar to that of the domestic fleet and is dominated by skipjack, which in 2005 accounted for 79% of the total catch (Table 8.5) (Kumoru and Koren, 2006).

Table 8.5 International fleet catch composition in the PNG EEZ

Year	Skipjack (t)	Catch (%)	Yellowfin (t)	Catch (%)	Bigeye (t)	Catch (%)	Other (t)	Catch (%)	Total (t)
2001	61,910	71	24,701	28	655	0.08	12	0.02	87,278
2002	75,152	80	18,473	20	863	0.09	18	0.01	94,525
2003	167,793	77	48,465	22	1,177	0.09	115	0.01	217,950
2004	184,035	89	21,372	10	751	0.09	54	0.01	206,211
2005	132,708	79	34,645	20	598	0.09	76	0.01	168,028

Source: Kumoru and Koren (2006).

Long-line Fishery

Since 1995, the PNG long-line fishery has been restricted to national or citizen companies resulting in a fleet of wholly owned PNG vessels. In 2005, the long-line fleet had a total catch of 3,450 t. This catch consisted of 61% albacore, 30% yellowfin, 6% bigeye and 3% other species (Kumoru and Koren, 2006).

Fishing Effort

Figure 8.1 shows the distribution of fishing effort in the PNG EEZ. The fishing effort of the domestic and locally based purse seine fleets is concentrated in the Bismarck Sea and along the northwest coast of PNG and is the only fishery near Solwara 1.

The foreign purse seine fleets focus their efforts further offshore, extending from the east coast of New Ireland to the eastern boundary of the PNG EEZ. The long line fleet focuses its effort in the southern portion of the EEZ in the Coral Sea (Kumoru and Koren, 2006).

8.3.2 Subsistence Fisheries

There are no subsistence fisheries at Solwara 1 as it is some 30 km from the New Ireland coast and 40 km from East New Britain; however, some interaction between ore transport and support vessel activities to and from Solwara 1 and subsistence fisheries may occur closer to shore, as discussed below in Section 8.3.3. However, nearer to the coast and reef areas, subsistence fishing is an important activity to provide food for daily needs and surplus sale at local markets. In addition, traditional activities, such as shark calling, are important, especially along the coast of New Ireland. The reported success (Post Courier of 16 August 2008) of the West Coast, Central New Ireland shark calling festival from 30 July to 1 August 2008 emphasises the importance of this activity and the need to avoid adverse impacts.

8.3.3 Simpson Harbour

A number of fishing charters operate in and around Simpson Harbour. These charters catch marlin, sail fish, Spanish mackerel, wahu, mahee mahee, barracoota and shark. Commercial fishing is banned in St. Georges Channel (Byrne, pers. com., 2008).

Very little subsistence fishing is conducted in Simpson Harbour.

8.4 Transportation

Marine traffic in the Bismarck Sea includes national and local cargo and passenger traffic moving between the main PNG ports of Port Moresby, Kimbe Bay, Rabaul, Madang and Lae. Generally, routes are poorly defined and companies operate largely without charts or nav aids and rely on the local knowledge and skill of their ships' masters.

There are some smaller local transportation boats (mostly motorised dinghies and banana boats) that move between New Ireland and East New Britain.

Environmental Impact Statement
Solwara 1 Project

9. ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

This chapter discusses the assessment of the potential environmental and social issues or impacts that may be associated with the Project; in this case, the operations of the Seafloor Mining Tool (SMT), mining support vessels, ore barging and activities within the Port of Rabaul. Identification of potential issues and impacts is based on knowledge of the existing environment, experience from equivalent operations in this or other areas, and issues of concern raised by local (in PNG) and international stakeholders.

These issues are identified and initially discussed without taking into consideration the mitigation measures that will be employed by Nautilus to reduce impacts. The proposed mitigation and management measures that are technically and economically feasible within the context of the Project's setting are then discussed and these reflect Nautilus' commitment to best practice environmental management. Being the first proposed developer of Seafloor Massive Sulphide (SMS) deposits, the consequences of mining in such areas of hydrothermal activity is an aspect of this EIS not yet addressed in PNG or elsewhere. Nautilus has acknowledged this responsibility and, since 2005, has undertaken extensive pioneering research to understand the characteristics of the seafloor environment and, with the help of international scientists, used this understanding to form the basis of plans that are put forward specifically to maintain biodiversity at Solwara 1 and enhance recovery during and after mining.

The final part of the assessment describes the residual risks or impacts, assuming effective implementation of the proposed mitigation measures. The risks and impacts are qualitatively evaluated according to the extent that they will occur, both in duration and distance from the particular project activity. In some cases, boundaries of expected impacts are calculated, based on, for example, dispersion of contaminants or attenuation of sound. Such boundaries that are described are conservative. No detectable adverse impacts would be expected outside these boundaries.

Impact assessment criteria are described (Section 9.1), followed by the identification of the environmental issues to be addressed, their proposed mitigation measures and residual impacts after the mitigation measures have been applied. The areas considered include:

- Air quality (Section 9.2).
- Oceanography (Section 9.3).
- Offshore water quality (Section 9.4).
- Sediment quality (Section 9.5).
- Biological environment (Section 9.6).
- Maritime safety and interaction with shipping (Section 9.7).
- Quarantine (Section 9.8).
- Waste management and emergency response (Section 9.9).
- Nearshore and onshore environment at the Port of Rabaul (Section 9.10).

9.1 Definitions and Impact Assessment Criteria

Over the course of the environmental assessment of the Project, several internal and external risk assessment workshops have been held to assess the hazards and potential consequences of each of the Project's activities; i.e., essentially those of the SMT, Riser and Lift System (RALS),

the Mining Support Vessel (MSV) and transfer of ore to the Port of Rabaul, temporary storage and final shipping.

Results of these workshops are summarised in tabular form in Attachment A. For each of the consequences (potential impacts), mitigation measures were determined in consultation with engineers and scientists and residual impacts assessed. However, being the first seafloor mining project, a true matrix-type assessment of risk, likelihood and consequence for the deep seabed environment is difficult given the limits of prior experience.

Instead, the precautionary and research approach has been followed in the development of mitigation measures and the assessment of residual impacts, based primarily on the observations and knowledge obtained from the studies undertaken by the scientists during the various research campaigns conducted by Nautilus (and its predecessors), as reported in this EIS.

Residual impact assessment assumes the successful implementation of appropriate mitigation measures. Criteria for assessing residual impacts in the marine environment are based (wherever practicable) on likely extent, duration and severity. The definitions for each criterion are provided below.

9.1.1 Extent

- Site scale – immediate area within 1 km of the project impact location.
- Local scale – extending between 1 km and 10 km from the project impact location.
- Regional scale – extending more than 10 km from the project impact location.

9.1.2 Duration

- Prolonged – impacts expected to last beyond one year from the completion of the project.
- Short duration – impacts not lasting beyond one year from completion of the project and are generally restricted in duration to the duration of the project itself.

9.1.3 Severity

- Negligible – impact unlikely to be detectable.
- Low – effect may be detectable but is small and highly unlikely to have any significance.
- Moderate – effect will be detectable but not severe; populations or the areal extent of communities may be reduced but unlikely to lead to major changes to population, community or ecosystem survival or health.
- High – effect likely to have severe negative impact on population, community or ecosystem survival or health.

9.2 Air Quality

The MSV, shuttle barges and the support vessels will operate 24 hours per day and operation of diesel engines and generators will emit exhaust emissions to the air.

Air quality modelling has not been conducted because mine operations are not expected to have an adverse impact on air quality as the nearest sensitive receptors to Solwara 1 are approximately 30 km to the east, comprising a number of villages along the southern coast of New Ireland. The tugs operating out of the Port of Rabaul will increase shipping movements by three to nine vessels per week, and this increase is unlikely to change the existing conditions at the port or contribute to significant changes in existing air quality.

Given these distances are so large and considering the dispersion affects from winds, no particular mitigation measures are practical or necessary as a result of operation of the mining vessels. The MSV will be a newly constructed vessel designed for worldwide deep-water operations, equipped with state-of-the-art propulsion systems with reduced emissions from fuel consumption. Routine maintenance of the mining vessel will be conducted to ensure engines are running as efficiently as possible, thus minimising exhaust emissions. A greenhouse gas assessment that considers the vessel emissions is presented in Chapter 12.

9.3 Oceanography and Deep-sea Sedimentation

Impacts of mine-related sediments in the mid and upper water column will be avoided by discharging return water close to the seafloor.

Deep-sea sedimentation rates will be affected by mining operations, with a predicted net increase resulting from the discharge of fine sediments from the return water, the mining plume created by SMT operations and the relocation of unconsolidated sediment and competent waste material away from the mineralised zones to the periphery of the Solwara 1 mound.

The potential impacts to sedimentation and the deep seafloor were assessed through hydrodynamic dispersion modelling for each scenario and the results are discussed in Section 9.5.

9.4 Offshore Water Quality

9.4.1 Issues to be Addressed

No construction is necessary at Solwara 1 prior to the commencement of mining operations; therefore this section considers impacts which may occur during operations.

Seafloor Mining Tool

The SMT may affect water quality via the generation of suspended plumes of sediment at Solwara 1 in a number of ways:

- Plumes may be generated when the SMT lands on the seafloor after being lowered from the surface and as it moves along the seafloor.
- As ore is cut during mining activities, finer fractions of the cut ore may escape the SMT cutter head and suction system and generate plumes.

Return Water Plumes

Ore mined by the SMT will be pumped as a slurry to the MSV via the RALS. Once on board the MSV, the ore will be dewatered and transferred to a shuttle barge as described in Chapter 5.

The seawater (and any solids <8 µm in diameter) component of the slurry that has been separated from the ore will be pumped to the seafloor to drive the subsea slurry lift pump (SSLP) and then discharged as return water between 25 and 50 m above the seafloor. The return water will be discharged at a rate of 0.3 m³/s and have a suspended solids concentration of approximately 6,000 mg/L.

During the dewatering process, ore will be exposed to some oxidation and an increase in temperature, and some geochemical changes could occur prior to discharge at depth.

Return water may impact water quality in receiving waters by:

- Causing plumes of suspended sediment due to the solids being discharged.
- Increasing concentrations of metals which may have leached from the ore during the mining and dewatering process.

Unconsolidated Sediment Disposal and Side Casting of Competent Waste Material

Prior to mining in new areas, pre-stripping of unconsolidated surface sediment will be required. Approximately 130,000 t of unconsolidated sediment will be moved across the five zones. Additionally, approximately 115,000 t of competent waste rock within the mining zones, which is below the mine cut-off grade, will be side cast during mining operations (Section 5.7.1).

The unconsolidated sediment will be disposed of, and competent waste material side cast, at a number of locations adjacent to the mining area as shown in Figure 5.11. Plumes of suspended sediment will likely be created during these activities, with resulting impacts on water quality near the seafloor.

While suspended sediment plumes may be created, no significant geochemical changes are expected to occur as the unconsolidated sediment and competent waste material will remain near the seafloor and not be exposed to any increases in temperature or oxidation.

Other Hazards Potentially Affecting Water Quality

Risk assessment workshops (Attachment A) identified other potential causes of impacts to water quality at Solwara 1, including small hydraulic fluid leaks, fuel spills during transfers at the site of the MSV, ore spills during transfer to barges and bulk ore carriers and accidental collisions resulting in loss of vessels.

Unexpected equipment malfunctions could result in the loss of material in the riser pipe through failure of the riser transfer pipe, subsea slurry lift pump or RALS. The maximum amount of mined ore in the riser pipe at any one time is approximately 11 m³, which could be lost to the seafloor, most likely via a dump valve at the base of RALS (Section 5.6.2). Any of these occurrences could cause localised impact to water quality near the seafloor or in surface waters, along with associated smothering of animals on the seafloor.

Although it is not a hazard, the MSV and associated mining equipment at Solwara 1 will become covered by marine growth, which, based on other observations of moored vessels, will act as a fish-attracting device, increasing marine life at the location.

9.4.2 Mitigation and Management Measures

Seafloor Mining Tool

When lowered to the seafloor, the SMT, assisted by an ROV, will be positioned as close as possible to the area to be mined. While plumes may be generated when the SMT lands on the seafloor, the distance required to travel over the seafloor prior to mining will be minimised and concomitantly the potential for plume generation during SMT travel will be reduced.

The SMT cutter and suction system has been designed such that all fine material (which has the potential to form plumes in the water column) will be collected by the system and pumped to the surface. Therefore, no plumes are expected to be generated at the cutter head.

While approximately 30% of cut material will be too large to be drawn into the collection system and instead fall to the seafloor, it will be too large to form plumes. The majority of this lost material will be recovered during subsequent sweeps of the cutter head.

Return Water Plumes

The ore dewatering system has been designed to retain all solid material greater than 8 µm, and only allow solids smaller than this to be discharged to the ocean. Additionally, from the time ore is mined to the time return water is discharged is expected to take 24 minutes, thereby reducing the time for any effects of oxidative changes of particulate material to occur, both from exposure to oxygen and an increase in temperature.

The return water system has been designed so that return water is discharged near to where it was collected, i.e., between 25 and 50 m above the seafloor, thereby removing any impacts on water quality in the mid and upper water column. To enhance plume dispersion, return water will be discharged upwards rather than downwards (where it would hit the seafloor as a jet and resuspend sediment, causing secondary plumes).

Unconsolidated Sediment Disposal and Side Casting of Competent Waste Material

During disposal of unconsolidated sediment and side casting of competent waste, all material will be discharged horizontally along the seafloor rather than into the water column to minimise plume formation and enhance the rate at which material settles to the seafloor.

Other Hazards Potentially Affecting Water Quality

All mining and support systems will be designed and constructed to appropriate international standards, thereby minimising the risk of an equipment malfunction discharging waste materials to the ocean.

Additionally, the development and implementation of environmental management plans, specifically covering waste minimisation and loss prevention will be implemented to minimise impacts on water quality. The plans will address, among other things, MSV deck drainage, non-process wastewater discharges, MSV waste management and ballast water.

Emergency response procedures will also be developed for all operations in the event of accidents leading to spills affecting water quality. These are described in Section 9.9.

9.4.3 Residual Impacts

Assessment of the residual impacts to water quality at Solwara 1 after the implementation of mitigation measures have been determined following investigations of reactivity and elutriate characteristics of representative ore material (Appendices 7 and 9) and hydrodynamic modelling of material discharged to the environment (Appendices 11 and 12).

Mineral Reactivity and Elutriate Tests

Ore that is mined at the seafloor will be transported to the surface and dewatered, and the return water will be discharged at the base of the RALS. During this process, the ore and water will be exposed to increased temperatures and oxygen. To understand how this process will affect the quality of return water (including ore <8 µm) being discharged to the environment, a comprehensive series of tests were undertaken.

Mineral samples were taken from active and inactive (weathered) chimneys and the seafloor within the mineralised zones to be mined in order to determine total and dilute acid-extractable metals (AEM) present within those materials.

Measurements of acid-volatile sulphide (AVS) and simultaneous extractable metals (SEM) were also undertaken to investigate sulphide-binding of metals; these providing a measure of reactivity and potential for metal release from the samples into dissolved and potentially bioavailable form.

As sulphide is a strong metal binding phase of many metals, the ratios of SEM to AVS provide some indication of potential release of metals:

- Where there is a molar excess of AVS over SEM, the metals silver, cadmium, chromium, copper, mercury, nickel, lead and zinc are predicted to be bound as sulphide phases that have a very low solubility in water.
- A molar excess of SEM over AVS indicates potential availability in dissolved form. Elutriate experiments were also conducted using the mineral samples in order to estimate rates of metal release.

The elutriate tests involved shaking the crushed sample in representative seawater to investigate metal release processes under various conditions of time, temperature, particle size and total suspended solids (TSS) concentration. The experiments were undertaken to determine if metals released from crushed ore could be an environmental issue either in water discharged from the dewatering process or from crushed particles side cast by the SMT. Methods and results of the reactivity and elutriate investigations are provided in Appendices 7 and 9.

The maximum strong acid-extractable (2:1 HCl:HNO₃) total metal concentrations measured in the sediment and chimney mineral samples and maximum weak-acid extractable (1-M HCl) metal concentrations in the mineral samples are shown in Table 9.1. Particulate metal concentrations are high, which is expected due to the high-grade ore in the proposed mining area.

Table 9.1 Maximum acid-extractable metal concentrations measured in samples

Metal	Strong Acid-extractable Metal Concentration (mg/kg)	Weak Acid-extractable Metal Concentration (mg/kg)
Ag	182	9
As	8,420	490
Cd	580	44
Co	670	20
Cr	4.9	1.4
Cu	147,000	2,400
Mn	108,000	1,700
Ni	20	11
Pb	9,570	1,400
Zn	76,700	1,000

The AVS concentrations of the mineral samples ranged from 0.1 to 18 µmol/g; however, many of the samples had a molar excess of SEM (ranging from 1.0 to 59 µmol/g), indicating that there was insufficient AVS to bind all of the SEM fraction should it dissolve.

Crushed chimney material and weathered chimney material had the highest metal concentrations and also the greatest excess of reactive metals (SEM) compared to AVS. While it is possible that some oxidation of the AVS material had occurred during handling (i.e., between collection and analysis), particulate metal concentrations were very high, and the excess of SEM is not likely to have been significantly affected.

Initial Elutriate Tests

Due to incorrect instructions being provided to the specialist consultant undertaking the testwork, incorrect procedures were used for collection, transportation, crushing and storage of the samples in the initial elutriate tests. This caused higher readings of the metals release than is likely to occur under operating conditions.

For example, water temperature during the initial tests was at room temperatures ($22\pm 3^{\circ}\text{C}$), which is significantly higher than the temperatures expected during the dewatering process. Rates of oxidation and dissolution were greater in the experimental set-up compared to actual operating conditions due to extended exposure of samples to air during storage and crushing. Furthermore, the individual samples from the chimneys are not likely to be representative of the ore as a whole as they represent the worst-case scenario.

Elutriate tests were repeated using correct procedures (and are presented further in this section). Regardless, results for Phase 1 tests are provided here for completeness.

Field and laboratory-based elutriate tests were undertaken on sample material crushed to form chips of approximately 25 mm diameter to simulate mining conditions. The test conditions were aimed to mimic the particle size (80% less than 25 mm) and dewatering time of approximately 12 minutes. Sample materials used in the laboratory tests were stored under refrigerated conditions at 4°C (Appendix 7).

The effects on metal release of elutriate times of 5 minutes, 6, 12 and 24 hours and at TSS concentrations of 10, 40 and 90 g/L were investigated. The results indicated that total suspended solids concentration and the resuspension time had the greatest effect on metal concentrations in the elutriate waters.

In general, metal release was high for arsenic, copper, manganese and zinc and relatively low for silver, cadmium, nickel and lead. The maximum concentrations of the metals measured (including results from elutriate tests performed for toxicity testing) are provided in Table 9.2.

Table 9.2 Maximum concentrations of the metals measured in Phase 1 elutriate tests

Metal	Metal Concentration ($\mu\text{g/L}$)
Mn	8,900
Zn	6,200
Cu	3,300
As	2,800
Pb	120
Cd	80
Ni	40
Ag	30

Based on the metals concentrations measured in the elutriate waters, dilutions of over 1,000 times may be necessary before the concentrations would meet the 95% protection levels of the ANZECC/ARMCANZ (2000) water quality guidelines.

Repeat Elutriate Tests

Due to the non-realistic experimental conditions used in the initial elutriate tests described above, repeat elutriate tests were undertaken to obtain results from material more reliably representative of actual ore and conditions of processing. Samples of representative run-of-mine materials were

obtained from the seafloor at Solwara 1, crushed to 25-mm-diameter chips and stored in nitrogen to prevent oxidation prior to testing.

The first round of repeat elutriate tests was carried out at 6°C, over times ranging from 5 to 1,440 minutes (Appendix 9) to investigate the effect that the holding time onboard the mining support vessel may have on the material. Under these conditions, the metal requiring the most dilutions to meet ANZECC/ARMCANZ (2000) guidelines was zinc, which would require a 300-fold dilution to achieve 95% protection levels.

A second round of repeat elutriate tests was carried out to investigate the possible effects that temperature change has on contaminant release from the material. Separate tests were carried out at 12 and 24°C over a period of 180 minutes. Results showed that the metal controlling the number of dilutions required to meet ANZECC/ARMCANZ (2000) guidelines was, again, zinc. To meet 95% protection levels, a 600-fold dilution would be required.

These reactivity and elutriate tests were undertaken in part to understand the risks of reactive changes taking place in the ore material when at the surface, and in part to assess the potential impacts if discharges from the dewatering were to occur at depths in the water column where these materials do not occur naturally.

However, the proposed use of the discharge water to drive the subsea slurry lift pump at the base of the RALS and its discharge close to the seafloor in the region of its source substantially reduces impacts to water quality, where there is already elevation from natural sources near to chimneys.

Hydrodynamic modelling of the return water discharge (Appendix 12) shows that a 600-fold dilution – required to meet ANZECC/ARMCANZ (2000) 95% protection limits – will be achieved within 85 m of the point of discharge (see Section 9.4.3.2, Suspended Sediment and Plume Formation, for details of modelling results).

Suspended Sediment and Plume Formation

The ANZECC/ARMCANZ (2000) target for total suspended solids (TSS) is 1.2 mg/L (note that baseline water column measurements at Solwara 1 location show a background range of 0.1 to 6.6 mg/L and maximum TSS concentrations of 14 mg/L (as described in Section 7.6).

Based on a return water discharge rate of 1,000 m³/h and an estimated 5,000 mg/L maximum fine sediment residual in this discharge, the dilutions required to meet the ANZECC/ARMCANZ (2000) target are approximately 4,200. For the purposes of this impact assessment, a conservative dilution of 5,000 has been adopted for return water discharge as being necessary to meet the ANZECC/ARMCANZ (2000) guidelines for all contaminants discharged to the environment in the return water stream.

Stochastic hydrodynamic modelling was undertaken to estimate the behaviour and fate of the return water and associated material <8 µm post-discharge (Appendix 12). Based on engineering data, two discharge temperature scenarios were modelled, namely a discharge temperature of 5.8°C and 11.4°C.

Modelling results show that:

- For both discharge temperatures, a subsurface plume will be formed which will initially exceed the ANZECC/ARMCANZ (2000) TSS target of 1.2 mg/L.

- Plumes will rapidly dissipate and achieve 5,000 dilutions a short distance from the point of discharge, at which time TSS concentrations will meet the ANZECC/ARMCANZ (2000) TSS target.
- During the time it takes for 5,000 dilutions to occur, plumes will be no more than 175 m thick and will stay between 1,300 and 1,475 m water depth.

Table 9.3 and Figure 9.1 show the probability of the return water plume exceeding the ANZECC/ARMCANZ (2000) TSS target a certain distance (and associated area) from the point of discharge over a 12-month period.

Table 9.3 Plume concentrations probability

Probability of Exceedance (%)	Area (km ²) from Point of Discharge	Distance from Point of Discharge (km)	Area (km ²) from Point of Discharge	Distance from Point of Discharge (km)
	<i>Discharge Temperature = 5.8°C</i>		<i>Discharge Temperature = 11.4°C</i>	
0-10	11.6	4.2	9.71	5.0
10-20	3.78	2.5	2.49	1.9
20-30	2.33	1.7	1.50	1.2
30-40	1.61	1.2	1.05	0.95
40-50	1.11	1.0	0.76	0.81
50-60	0.81	0.9	0.58	0.67
60-70	0.60	0.7	0.43	0.58
70-80	0.42	0.6	0.29	0.44
80-100	0.27	0.41	0.19	0.36

On average (i.e., for 183 days per year), at a discharge temperature of 5.8°C, plumes will not extend more than 900 m beyond the point of discharge (and cover an area of 0.81 km²) before meeting the target TSS concentration.

The maximum distance plumes will travel before meeting the TSS target is 4.2 km, at which point it will cover an area of 11.6 km²; however, this is expected to occur less than 37 days per year. Figure 9.1 shows that plumes will not affect North Su or South Su, but will generally occur above Solwara 1 and to the northwest.

Plumes will be formed during disposal of unconsolidated sediment and side casting of competent waste material. Modelling has shown that, due to material being discharged horizontally from pipes laying on the seafloor, plume formation will be minimal and all suspended material will deposit on the seafloor within 1 km of the point of discharge (Appendix 11).

Water quality monitoring will be undertaken at sampling sites around Solwara 1 during operations to monitor compliance with limits (or dilution amounts) in the event that TSS criteria are exceeded naturally.

Toxicity Tests (Elutriates)

Toxicity of initial elutriate test waters exposed to ore was assessed to understand the characteristics of the material and the potential impacts if return water discharges were to occur at shallower depths in the water column where organisms are not naturally exposed to (or tolerant of) elevated metals.

The toxicity of the elutriate waters was investigated using tests that determine inhibition of growth

rate of the alga *Nitzschia closterium* and inhibition of mobility of the marine copepod *Acartia sinjiensis* (as described in Appendix 7). The elutriate test water was prepared with a high solid:water ratio to provide high solids load and sufficient test water. Metal concentrations measured in the elutriate waters prepared for the toxicity tests were higher than those measured in the elutriate tests for the same sediment material.

Based on the metal concentrations measured in the elutriate waters prepared for the toxicity tests, copper requires the most dilutions at 4,000 to meet 95% protection levels of the ANZECC/ARMCANZ (2000) water quality guidelines.

The toxicity assessment used surrogate species, as no tests using local species from Solwara 1 were available or practicable, i.e., animals living at Solwara 1 do not survive for very long under conditions found at the surface. The philosophy of using surrogate species is that it is expected that species with similar exposure pathways and similar sensitivity will exist at the local sites. It is unlikely that this is the case, however, as species that exist at Solwara 1 have both differing exposure pathways (e.g., water versus food) and sensitivity to metals.

In the metal-enriched sediments and waters surrounding the active chimneys, it is likely that these vent-dependent species have specialised behaviour (e.g., chemotrophic feeding) adapted for the local conditions. Nevertheless, the tests were undertaken to provide some context of the likely toxicity that would be expected for typically used shallow water test organisms exposed to such water quality. Methods and detailed results are provided in Appendix 7).

The undiluted elutriate waters prepared from the cold sediment, and crushed active and weathered chimney mineral samples were found to be toxic to both the algae and copepods. Dilutions of up to 700 times would be required to result in no toxicity from the elutriate waters to these two species. These results are expected to be quite conservative for a number of reasons. They are indicative of responses of shallow water species, which will not come into contact or be exposed to such elutriate waters during normal operating conditions, and are not considered to be relevant to the vent-dependent species, which are naturally exposed and more tolerant to higher metal concentrations.

Summary of Residual Impacts

Overall, the water column mixing zone required to meet ANZECC/ARMCANZ (2000) water quality guidelines are limited to deep waters and are relatively small in extent. Fine sediment fall-out from the return water discharge is slow and the thickness on the seafloor less than the rate of natural deposition.

The results of the elutriate and toxicity tests to surface test species are not relevant given the proposed discharge from dewatering close to the seafloor, where natural discharges from vents are elevated in metals and the resident animals are evidently tolerant of highly mineralised habitats. Discharges from dewatering are therefore not expected to have any adverse toxicity effects to seafloor ecosystems and will have negligible overall effects.

9.5 Sediment Quality

9.5.1 Issues to be Addressed

The Project will not involve any construction phase at Solwara 1 prior to the commencement of mining operations; therefore, this section considers all activities and impacts occurring during the operational phase. During operations, impacts to seafloor sediment quality are likely to occur mainly through activities of the SMT, unconsolidated sediment disposal, competent waste

material side casting and, to a lesser degree, from the discharge of water from the dewatering process on the MSV.

Disposal of Unconsolidated Sediment and Competent Waste Material

During disposal unconsolidated sediment, the ROV will pump material from each mining zone and transport it through a weighted pipe for placement at designated disposal points (see Figure 5.11). Approximately 130,000 t of unconsolidated sediment and 115,000 t of competent waste material will be disposed of in this manner.

Seafloor Mining Tool

The SMT will mine a combined area of approximately 0.112 km² over the five target mineralised areas at Solwara 1 (Figure 5.10). The SMT will potentially affect sediment quality of areas adjacent to mining through disturbance to seafloor.

Dewatering Plumes

Recovery of the ore raised to the MSV via the RALS will involve onboard separation of solids from the seawater by means of a dewatering plant that is designed to retain all particles greater than 8 µm. This is expected to reduce significantly the quantities of sediment lost in the dewater discharge, where the proportion of ore below this size is estimated to be <5%. Discharge of this water, together with the residual entrained fine particles, will occur via a return discharge at a rate of approximately 1,000 m³/hr (during normal operations), at the base of the RALS, between 25 and 50 m from the seafloor.

Settling of fine particulates in the seawater discharge produced from dewatering the crushed ore is a source of potential impact to seafloor sediments. Material from dewatering will also be exposed to some oxidation and higher temperatures during the time of dewatering on the MSV and prior to discharge at depth.

Other Hazards

Potential malfunctions could result in the loss of material in the riser pipe through failure of the riser transfer pipe, subsea slurry lift pump or RALS. At any time, the volume of material in the riser pipe would be 11 m³, which could be lost to the seafloor via a dump valve.

9.5.2 Mitigation and Management Measures

Disposal of Unconsolidated Sediment and Competent Waste Material

Disposal of unconsolidated sediment and side casting of competent waste will not expose these materials to increased temperatures or oxidation; therefore, there will not be any physical changes that could cause significant geochemical changes to sediment quality.

Seafloor Mining Tool

The SMT cutter head and suction system has been designed to recover the maximum volume of ore and minimise the amount of cut material being lost to the surrounding environment. Initial loss at the cutter head in the order of 30% is possible although much will be recovered on subsequent sweeps of the cutter. It is estimated that 90% of mined ore will be recovered and up to 10% will remain on the seafloor.

Return Water Plumes

At the MSV, all ore will be retained and only fine material smaller than 8 µm will be discharged with the return water. The discharge will be oriented in an upward direction to maximise dispersion and avoid seafloor disturbance. The fine sediment will settle over a wide area at low

concentrations as described in Section 9.4.3. Furthermore, the expected time of transit from seafloor to MSV and back to seafloor is 24 minutes, with 12 minutes at the surface, with temperature at discharge to be limited to a range of 5.8 to 11.4°C.

Make-up seawater (for optimum RALS pumping) will be added pre-discharge to the return water leading to some oxidation and temperature increase; however, there will be a temperature decrease travelling the downwards route to discharge as the pipe will be specifically designed to accommodate temperature loss to ambient conditions. This proposed management of the dewatering process will reduce oxidation and temperatures thereby reducing the reactivity of particulate material discharged to the ocean which will eventually settle on the seafloor.

Other Hazards

Emergency response procedures will also be developed for all operations in the event of accidents leading to ore spills affecting seafloor quality. These are described in Section 9.9.

9.5.3 Residual Impacts

Assessment of the residual impacts to sediment quality after the implementation of the above mitigation measures has been determined following investigations of reactivity, sediment toxicity testing and dispersion.

Disposal of Unconsolidated Sediment and Competent Waste Material

A hydrodynamic model was created to predict the behaviour and fate of unconsolidated sediments discharged and competent waste rock side cast during operations at Solwara 1 (Appendix 11).

The coarser fraction of material disposed of will rapidly settle immediately downslope of the disposal point and form mounds slightly over 0.5 m deep (Figure 9.2). Lighter materials will travel further from the disposal points, and the lightest components of the disposed materials will form plumes near the seafloor.

Plumes will rapidly settle on the seafloor no further than 1 km from the point of discharge around Solwara 1. The resultant footprint depth will be between 0.18 and 500 mm as shown in Table 9.4 and on Figure 9.2 and cover an area just over 2.3 km². Some deposition will occur further afield, but at a thickness less than natural sedimentation rates.

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

Post-mining, the sediment depths due to material disposal outside the mining area will be a maximum of just over 500 mm greater than would naturally have occurred. Within the five

mineralised zones, additional sediment thickness will be 500 mm or less. This is considered to be a minor impact given existing sediment thicknesses at Solwara 1 are up to 6 m deep in some places (see Figure 5.11).

Seafloor Mining Tool

Although no plumes will be formed as the SMT cuts ore and competent waste material, approximately 10% of material mined will be lost to the seafloor. This material will not undergo any geochemical changes and will therefore not affect sediment quality. Additionally, this material will be confined to locations within the mining area.

Movement of the SMT will disturb sediment, but no impacts to sediment quality are expected. Impacts to sediment quality from SMT cutting and movement are therefore considered to be negligible.

Return Water Plumes

Plume dispersion modelling show that over the period of mining, sediment will flocculate and settle on the seafloor approximately 5 to 10 km to the west and northwest of Solwara 1. Maximum depositional thicknesses will not exceed 0.1 mm and rates of settling are less than existing deep-sea sedimentation rates as measured at Solwara 1 and South Su.

Impacts to sediment quality as return water plumes settle on the seafloor are therefore local scale but considered negligible as they are unlikely to be detectable.

Toxicity Tests (Sediments)

The toxicity of the sediments was investigated using the juvenile amphipod *Melita plumulosa* subjected to a 10-day whole sediment test (Appendix 8). The toxicity assessment used surrogate species, as no standard tests using local species from Solwara 1 are available or practicable for reasons described in Section 9.4.3.

A representative sample of crushed ore was progressively diluted with inert sand to determine the toxicity of varying concentrations of ore. Complete methods and detailed results are provided in Appendix 8.

The test show the median lethal concentration was found to be 4.3%, i.e., that 50% of amphipods survived the 10-day test period in materials comprising 4.3% ore. No observed effects on survivability were found when ore concentrations were less than 1%, i.e., a 100-fold dilution.

It is important to note that *Melita plumulosa* is a shallow water Australian species found in intertidal non-metalliferous sediments up to depths of 25 m. Therefore the high toxicity result is not surprising given the elevated natural metal content of the Solwara 1 sediments.

These tests were undertaken to understand the toxicity characteristics of the material in the event of dispersion and settlement in areas remote from hydrothermal vent activity, where animals may be less tolerant.

Regardless, dispersion modelling by APASA (Appendix 12) shows that to achieve the 95% protection level of the ANZECC/ARMCANZ (2000) water quality guidelines for suspended sediments, the required 5,000-fold dilution threshold occurs more than 50% of the time over an area of 0.8 km² at no more than 0.9 km from the point of discharge.

It is difficult to predict where the 100-fold dilution of settled sediments may occur (required for no toxicity to animals not naturally exposed to mineralised sediments). Conceivably, in the areas where return-water fine sediments are predicted to settle, some impacts could occur to resident

macrofauna and meiofauna in these areas. However, in the context of the natural sediment fallout from plumes of volcanic or hydrothermal origin, these impacts are not likely to be detectable, and overall regional scale of the impact would be low.

9.6 Biological Environment

This section describes the potential, Project-related sources of impacts to the biological environment of the Project area (offshore and ore barging operations), the mitigation measures that will be applied to reduce those impacts, and the residual impacts after those mitigation measures have been successfully applied. It is divided into two sections: firstly, the surface, water column and nearshore (which effectively includes everything from the surface to just above the seafloor) (Section 9.6.1), and secondly, the seafloor and the deepest water layers (Section 9.6.2). Issues associated with underwater light and noise, and water quality are discussed in Sections 9.6.3 and 9.4, respectively. Issues associated with operations at the Port of Rabaul are discussed in Section 9.10.

9.6.1 Surface, Water Column and Nearshore

This section describes the potential issues of:

- Interactions with marine animals, including endangered species.
- Discharges impacting on marine biota.
- Bioaccumulation of metals through the food chain.
- Increased turbidity effects on species reliant on bioluminescence.
- Electric and magnetic fields produced by cables to the SMT and ROV.

Issues to be Addressed

Interactions with Endangered Species

There are a number of protected and endangered species of whales, turtles and marine birds inhabiting the waters of the Bismarck Sea and, over the life of the project, these may pass through the Project area. There is the risk, albeit extremely low, that animals such as whales, turtles and dugongs could collide with the MSV or the vessels involved with the transportation of ore and supplies.

Discharges

Within PNG, the local coastal people have expressed most concern for the quality of the marine environments, and the protection of the reefs and fisheries upon which they depend, as well as on the wellbeing of the larger animals that are present such as whales, sharks and turtles. The maintenance of health of the marine environment is not a matter for negotiation and the project must demonstrate that the shallow water animals are not exposed to the mineralised materials of the seafloor to which they are not adapted, such that there is no risk to daily subsistence and traditional local activities, such as shark calling.

During operations at the MSV, the only discharge to surface waters will be the discharge of sewage, treated to meet MARPOL standards (see Section 9.9 for further detail). This may elevate nutrients locally and the resultant plankton productivity. Minor quantities of spills of ore may occur during transfer to and from barges. As discussed in Section 9.4, there will be no discharge of water from the dewatering process within the surface or mid-water (mesopelagic) depths in the ocean, therefore no thermal changes to these layers will occur.

Bioaccumulation – Potential Impact to Tuna Fisheries

The discharge from dewatering will contain some fines that pass through the dewatering of the ore and may contain elevated levels of some dissolved metals, depending on conditions, as indicated in the elutriate test studies by CSIRO (Appendix 7) and Charles Darwin University (Appendix 9). Many species of tuna occur in the project area, including skipjack, yellowfin and bigeye, and along with sharks they form the basis of a commercial fishery and important subsistence and traditional fisheries such as shark calling.

Although the project area is not within the most heavily fished area, these species would nevertheless be expected to pass through the area. Given that some species of tuna can also forage well into the mesopelagic layer, and the vertical migration of plankton can occur between the mesopelagic and epipelagic layers (Appendix 10), there is the potential for some bioaccumulation through the food chain via uptake by plankton and subsequent predation by small fish/crustaceans and larger fish. There are many other non-commercially exploited species that are also known to occur in the surface (epipelagic) and mid-water (mesopelagic) levels in the water column (Appendix 10) and these may also form part of the food chain. While there is some predation on bathypelagic species by mesopelagic species, this predation is not widespread and, as illustrated by Figure 7.21, there are limited pathways through the food chain upwards from deeper in the bathypelagic zone.

Bioluminescence and Surface Lighting

As described in Section 7.8.1 and Appendix 10, many species in the mesopelagic and bathypelagic zones are dependent on bioluminescence for functions such as catching prey, defence against predators and communication with others of the same species. Any sources of increased turbidity could potentially interfere with these processes by decreasing visibility through the water column.

Lighting on the MSV is required for night-time operations but can be a potential source of confusion or interference to animals, particularly turtles during nesting and hatching.

Electric and Magnetic Fields

The cables to the SMT and ROV will carry current at approximately 30 amps that will generate magnetic fields in addition to the Earth's natural magnetic field, in the same way as any power cable or the leads to any operating electrical appliance. This may be detectable by animals sensitive to electric fields (e.g., some species of sharks).

Mitigation and Management Measures

Interaction with Endangered Species

From time to time, species of whales and turtles may be in the project area and while these encounters are not expected to be frequent, effective mitigation measures will be needed to minimise the risk of injury from ship strike or collision. A study that modelled vessel speed highlighted the fact that speeds below 15 knots substantially reduced the chances of lethal injury to whales (Vanderlaan & Taggart, 2007). Once on location, the MSV will be virtually stationary and the tugs towing ore barges to and from the MSV will travel at speeds of around 4.5 knots minimising the likelihood of boat strike.

If any whales encounter the RALS or the SMT lift wire or control umbilicals, there is little to cause harm and no lines that would be loose or flexible enough to cause entanglement. In the case of turtles and dugongs, vessel speed is closely related to the number of strikes (Groom et al., undated) with boats travelling at higher speeds striking more animals.

The highest risk areas for encounter are most likely to be within Simpson Harbour and along shores of the Duke of York Islands (Figures 1.3 and 1.1 respectively). The supply vessel, tugs and barges travelling between the offshore location of the MSV and the Port of Rabaul will observe normal shipping speeds and channels in the approaches to the Port of Rabaul, as required by all other vessels using that port i.e., 10 knots.

During operations, a procedure will be established to record any whales, dugongs or turtles observed from the MSV (or other vessels), noting (where possible) species and any behavioural aspects such as direction of travel, resting or feeding. It will be an obligation of persons on watch to make such recordings in the event of a sighting, and forms for this purpose (already used during Nautilus exploration activities) will be employed. This will add to the knowledge base of the presence of whales and other endangered species in the area.

The endangered Beck's petrel is said not to be attracted to vessels (Shirihai, 2008) and hence the presence of the MSV is unlikely to interfere with their activities, nor to represent any significant threat to the birds, should they be attracted. Therefore, no specific mitigation measures for this species are proposed.

Discharges

On the MSV, sewage will be treated in an approved sewage treatment plant certified to meet operational requirements of Regulation 9.1.1, Annex IV of MARPOL such that operational discharges of treated effluent will not produce surface floating solids nor cause discolouration of the surrounding seawater (see Section 9.9 for further detail). There will be no normal discharge of oils, chemicals or garbage, which will all be returned to shore for treatment or disposal. Operational deck areas where hazardous chemicals and oils are used will have drainage to oil/water separators and treatment tanks. A shipboard marine pollution Emergency Response Plan will be implemented to combat accidental spills or non-routine discharges of pollutants (see Section 9.9 for further detail).

Leatherback turtles have the largest ranges of all reptiles in the world because they have the ability to control their body temperature (James & Mrosovsky, 2004). As they migrate from the tropics to arctic water, marginal and localised changes in the thermocline will have an effect on them, if such changes were to occur; however, as the Project will not discharge any cold water to the surface, no changes to the thermocline will occur.

Since the ore recovered from the seafloor is a highly valuable product, all systems will be in place during transfer from the MSV to the barges to avoid spillage. The MVS and handling equipment will be new and built to current international standards. Therefore, it is likely that only minor spills, if any, will occur.

Bioaccumulation – Potential Impact to Tuna Fisheries

The proposed depth of discharge of water from dewatering at depths between 25 to 50 m from the seafloor, was chosen primarily for reasons of pumping efficiency of the RALS, but effectively avoids any exposure or possible pathways of impacts back to surface ecosystems. Modelling shows that the plumes (and any dissolved/particulate metals) will not rise above 1,300 m water depth (see Section 9.4.3) and oceanographic data collected in this area does not reveal any upwelling below 400 m water depth (see Section 7.5.3). Hence, the main pathways potentially giving rise to risks of bioaccumulation have been engineered out of the project and risks to mid- and surface-water species such as tuna are assessed as low (Appendix 10). While there is confidence in this assessment for the mid- and shallow-water species, based on vertical separation, a ranking of 'moderate' confidence is given to the assessment in relation to potential

impacts to the bathypelagic (deep) species, which may be exposed to the return water (Appendix 10). The 'moderate' confidence level reflects general uncertainty about responses of bathypelagic species to metals, although the naturally high exposure to elevated metals in the bathypelagic environment of the project area suggests that any risks from returning the material to this deep environment would be extremely low. Species at the maximum depth that the return water plume is expected to rise to are naturally exposed to this type of material through naturally occurring particulate plumes (see Figure 7.14), which occur at water depths similar to those to which the return water plume is expected to rise.

Confidence in the assessment of low risks of uptake of metals via the food chain from mine wastes discharged at sea has previously been shown for an analogous case study of the disposal of jarosite (residue from zinc smelting containing high levels of metals, particularly zinc, cadmium, lead, arsenic and mercury), which was discharged at a rate of up to 240,000 tonnes per 12-month period by barge dumping off southeast Australia between 1972 and 1996. By combination of field sampling and modelling, CSIRO (1994) examined the likelihood of contact with plumes and uptake via marine animals at different trophic levels into a number of predatory species, including seasonally migrating bluefin tuna.

Even though the jarosite material was disposed at the surface and descended through the full 2,000 m of the water column, CSIRO concluded that, even under worst case scenarios, the predicted increases in heavy metal from the jarosite disposal were all relatively low, and the increase in heavy metal load predicted on the fish populations would not be expected to be detectable above natural sampling variability without extremely large numbers of samples. In the light of this example, it is unlikely that any effect could occur from a substantially lesser volume of solid material from the dewatering process, discharged at a depth of around 1,450 m.

Bioluminescence and Surface Lighting

Risks of interference of mid-water fish species and other invertebrates that use luminescence for functions of feeding, predator avoidance or communication are avoided by the proposed discharge at depths approximately 25 to 50 m from the seafloor, from where plumes are not expected to rise above 1,300 m depth (Appendix 12). Natural plumes also occur at these and shallower depths (1,100 m) from nearby hydrothermal and seafloor volcanic activity (Appendix 6), and within this context, project-related effects are not expected to be significant or detectable.

There is a risk that artificial lighting can be disruptive to hatchling turtles during times of new moon, and to minimise the risks of increases of the already high mortality rates during hatching, options that can be included are shielding or re-orientation of direction of lights or reductions in the heights of the source (APPEA, 2005). In the case of the MSV, it is well offshore so that height of source is effectively at the horizon and unlikely to cause disorientation that could increase risks of predation or mortality. There are few turtle nesting sites reported in the Bismarck Sea and none around the project area (Section 7.8.1).

Electric and Magnetic Fields

The umbilical cables connecting the MSV with the SMT and ROVs will be fully shielded and carry approximately 30 amps. At most, electric and magnetic fields created by the cables will be very small, and will dissipate within a few metres of the cable. These cables are frequently used for controlling ROVs and submersible vessels in deep-sea applications, and have been used during exploration activities by Nautilus and its predecessors, without adverse impacts to fauna.

Residual Impacts

Discharge of treated sewage will result in localised nutrient input that will be dissipated by currents and taken up by planktonic organisms, as per the intention of MARPOL. Impacts are negligible and localised to project scale.

The transfer of ore onto and off the barge and loading onto bulk carriers will be managed to reduce any spillage to a minimum, such that there will be no significant or sustained source of input to the offshore or inshore marine environment (see Section 9.9 for further detail) and no prolonged detectable impacts to biota.

As discussed in Section 9.4, by disposing of the return water from dewatering between 25 and 50 m from the seafloor, plumes are not anticipated to reach above 1,300 m water depth. From this depth, there will be no significant vertical migration pathways for bioaccumulation to affect any mid-water or surface-dwelling fish, including tunas or other important food species.

For the same reasons, there will be no risk of any adverse interference with species reliant on bioluminescence in the mesopelagic zone or bathypelagic zone shallower than 1,300 m.

The MSV is virtually stationary, and the barges move at slow enough speeds to minimise risks of collisions with whales or turtles. The operations present no threat or obstacle to normal migration that would be materially different from normal shipping and commercial fishing activities. Deck lighting at night is not likely to be a source of interference to turtle nesting and overall, impacts are assessed as occurring at the local scale, of short duration (time of presence of MSV) and of low severity.

9.6.2 Seafloor Habitat and Biodiversity

Issues to be Addressed

The Project will not involve any construction phase at the offshore mine site prior to the commencement of mining operations; hence, this EIS considers all activities and impacts as operational. The pre-operational activities are minor and involve locating six concrete bases and weights on the seafloor for the attachment of position fixing instruments and current meters. The MSV will be dynamically positioned and will therefore not require any anchors or preparatory layout for anchoring construction at the mining location.

Impacts to the seafloor and its biological communities will arise from a number of sources, as shown in Figure 9.3, and described below.

Seafloor Mining Tool

On the seafloor, the actions of the SMT will affect seafloor fauna in following ways.

The seafloor of most of the target area is hard, and initial access of the SMT to the ore will be on a hard pad area, from where it can commence cutting an access ramp and start mining. However, the exploration surveys have indicated that some accumulations of soft, unconsolidated sediments occur in the valleys, which in places might pose some risks of subsidence of the SMT. In these locations, the ROV will be fitted with skids and the material pumped laterally off the slope of the mound. The ROV will pump unconsolidated sediment from each mining zone and transport it for placement at designated tip head sites on the outer areas of the Solwara 1 mound away from mining. (see Figure 5.11). A total of approximately 130,000 m³ of unconsolidated sediment will be moved in this way over 30 months of mining. This process can run concurrently with the SMT operations where it is required.

The SMT will disturb the seafloor habitat as it is lowered onto the bottom and as it crawls along the seafloor, levelling chimneys and other irregularities in advance of mining and during the process of mining itself. These actions will destroy habitat and cause some loose sediments to become resuspended and affect water quality and deposition in the vicinity of the SMT. The actions of the SMT and of the cutter head will generate some resuspension of fine suspended material as described in Section 9.5. Sessile fauna the path of mining will be unavoidably entrained in the ore stream and pumped to the surface, resulting in an unavoidable loss of these animals.

Any fines that are resuspended directly or via relocation from the SMT will be subject to advection as suspended particles in the ambient seafloor currents, and settlement back on to the seafloor. The potential effects of these sediments will be mainly by smothering of nearby benthic organisms, for which modelling has been used in determining the potential extent of any effects.

It is expected that the majority of the mineralised zones indicated in Figure 5.10, including the venting areas, will be mined, subject to mitigation measures proposed to protect biodiversity (see below). Under the mine plan, the SMT will start at the Far West mineralised zone, then move in turn to the Central, West and then East and Far East zones.

Once the SMT leaves a zone, the mined area will then be left to rehabilitate. Mining will level off the chimneys and irregularities of the mound, creating a smoother and mainly hard final surface which for some 60% of the area will be to an expected depth of no more than 20 m below the existing seafloor.

Dewatering Plumes

Water and some residual entrained sediment remaining in suspension after separation of the ore during the de-watering process will be discharged (Section 9.4). Some geochemical changes may take place to this material through exposure to oxygenation and higher temperatures at the surface while on the MSV. Details of the nature and volumes of water discharged from the dewatering process are given in Section 9.5. The potential issues to be addressed from the de-watering plumes to the seafloor biological communities include:

- Impacts to free swimming and epi-benthic organisms within the predicted area of influence of altered water quality (based on results of elutriate tests and dilutions to meet water quality guidelines and conditions of no toxicity to animals).
- Smothering or burial by settlement of sediments, particularly on filter feeders in areas where sediments potentially settle.

Loss of Habitat, Biodiversity and Endemic Species

Overall, the main issues to be addressed from the effects of mining and dewatering are the potential loss of habitat and its associated biodiversity and endemic species from Solwara 1 and the pathways for recolonisation of the biological communities after cessation of mining. To the extent that the numbers and biomass of animals at Solwara 1 will decrease during the progress of mining at Solwara 1 and prior to its recovery, there may be potential effects by way of a reduction in spawning biomass of the Solwara 1 animals and reduced downstream larval recruitment that would otherwise naturally occur, for example at Solwara 8, which is 45 km down current of Solwara 1. Hence diminished recruitment may occur at equivalent habitats downstream of Solwara 1. However, relative impacts to Solwara 8 are likely to be diminished given the distance from the Solwara 1 and similar distance from the unaffected South Su. Samples of

animals from Solwara 8 will be taken as part of the completion of baseline studies to determine the genetic relationship between Solwara 1, South Su and Solwara 8.

Other Hazards Near Seafloor

In addition to the above, there are a number of other potential causes of impact that were identified in the December 2007 risk assessment workshop. These included circumstances ranging from small hydraulic leaks to accidental collisions resulting in loss of vessels. Other potential malfunctions could result in the loss of material in the riser pipe through failure of the riser transfer pipe, pump or RLS. It is estimated that at any time, the amount of material in the riser pipe would be 11m³, which could be lost to the seafloor beneath, causing localised smothering.

Noise from the SMT cutter head has not been modelled, in absence of details of likely source spectra and frequencies. However, low frequency sound is likely and would be expected to be audible for considerable distance. However, natural background noise from the erupting North Su volcano is likely to mask the sound of the SMT to a considerable extent and it is not considered further.

Mitigation and Management Measures

There are many mitigation approaches open to Nautilus, including design of the mine plan based around enhancing natural aspects of the prevailing environment and minimising impacts.

The proposed area to be mined is very small and the combined area of the five mineralised areas presently targeted for mining is only about 0.112 km².

The two main objectives of the proposed mitigation measures are:

- To maintain biodiversity and endemic species at the Solwara 1 hydrothermal area during and after mining.
- To determine the environmental impacts of mining at the mineralised active chimneys and adjacent inactive hard surfaces, and active/inactive sediments.

The mitigation measures that are outlined below to meet these objectives at Solwara 1 have been developed in consultation between the Nautilus project engineers and stakeholders represented by scientific experts in hydrothermal vent biology, PNG Government agencies, PNG academics and NGOs, via workshops (see Chapter 4) and made in the light of result from research studies completed during Nautilus' survey campaigns.

Natural Mitigation

There are a number of natural features of the environment of the project area that will reduce the scale of the potential impacts as described above. These are not direct actions taken by Nautilus, but nevertheless act to limit impacts and can be enhanced by the various mitigation measures proposed by Nautilus.

First, the mining cannot remove or exhaust the natural venting energy source at Solwara 1, which will continue until the underlying energy source naturally dissipates. The active venting field will remain, chimney structures will reform and the underlying hydrothermal energy basis will still exist for the potential re-establishment of vent-dependent and associated communities. The time sequence of recovery of fauna is not known but it is expected that, within 1 to 3 years, the major faunal elements will have re-established. It is also proposed to enhance this process by other mitigation plans summarised below. The vents may re-emerge in the same or different locations,

and vents in nearby unmined areas may alter in intensity or frequency of venting in response to adjacent disturbance. Fundamentally, however, the active venting field will remain, chimney structures will reform and the underlying hydrothermal energy basis will still exist for the potential re-establishment by vent-dependent and associated communities. There are a number of dependencies regarding the time scale and potential sources and sequences of faunal recovery that are not yet known, but which form subject matters for the mitigation and associated monitoring programs.

Second, the highly mineralised habitat of the vent-associated animals means that the predictions of the boundaries of impact to water quality that are based respectively on application of the numbers of dilutions to meet ANZECC/ARMCANZ (2000) water quality guidelines for dissolved metals, and to achieve no toxicity are relevant only to the protection of shallow water surrogate test species. These are likely to have quite different sensitivities to dissolved metals when compared with the vent-dependent deep sea species, which cannot survive away from such areas, beyond which the relevance of the standards may have little bearing on their survival. The mixing zone boundaries of expected effects on surface test organisms have nevertheless been applied, based on results of elutriate and toxicity tests from representative material at expected conditions of temperature and time of handling on the surface (Sections 9.4 and 9.5). There are no standard tests or established ways to allow for different tolerances of the deep-water species, particularly those adapted for life at hydrothermal vents. The results therefore give some representation of toxicity of the material in a shallow water context, but it is noted that the dilution boundaries presented are likely to be extremely conservative if applied to the fauna of deep-sea hydrothermal vents.

Furthermore, ambient baseline concentrations of some dissolved metals such as copper, lead and zinc already exceeded ANZECC/ARMCANZ (2000) guidelines (95% and 99% protection level) in some water samples that were taken in the vicinity of the vents (Appendix 7). These concentrations naturally dilute rapidly away from the vents, where metal concentrations were below detection or at trace levels typical of the ocean generally. However, it is at the vents where the animals are most exposed, including their larvae and juveniles at the point of release and settlement. It can be inferred from this that a high tolerance to metal concentrations on water and sediments would be of selective and survival value.

While the same logic cannot necessarily also apply to species located in sediments or hard surfaces away from direct influence of vents, the volcanic origins of sediments (Appendix 6) suggests that periodic episodes of sedimentation may be experienced. Certainly, extensive plumes have been observed emanating from North Su, blanketing visibility to the ROV on a number of occasions and, during the 1996 PACMANUS III and 1997 PACMANUS IV expeditions, there were two recognisable particulate plumes, both below 1,000 m, the fallout from which could have contributed to the seafloor sediments (Appendix 6).

Seafloor mineralised areas are often discovered initially by detection of plumes in near-bottom waters from vent or subsea volcanic activity; hence, settlement of sediment is likely to be a naturally intermittent activity to which benthic communities are tolerant, or in some stage of response after natural (volcanic) sediment deposition episodes. Conceivably, the very low numbers of benthic animals observed in sediments at Solwara 1 may reflect such stages after some recent event. Additionally, the low animal densities, presence of opportunistic genera and high dominance patterns suggest that settling is naturally subject to periodic disturbance. Either way, the assessments of the potential impacts of sediment from SMT disturbance or discharged in the dewatering are conservative when considered within this context.

SMT Limitations

Mining will not occur where water temperatures exceed SMT operating capabilities (Section 5.6.1). However, given the rapid thermal gradients between hot and cold water at Solwara 1, it is expected that this limitation will apply only within a metre or so from areas of elevated temperature.

It is uncertain whether or not the areas that cannot be mined for this reason will represent any significant refugia for animals, and whether or not the venting at such areas will vary as a result of adjacent mining. However, such areas may be an additional potential source of benthic macrofaunal communities to add to spawning and recolonisation potential.

Unmined Control Area at South Su

No mining is proposed at South Su, which will remain as an unmined control area about 2 km up current from Solwara 1. It will provide a potential source of recruitment to mined areas and provides a control location to set up transects to monitor natural variations in vent activity and communities over time. South Su and Solwara 1 are part of same hydrothermal system on the southeast and northwest flank of the North Su active seafloor volcano, respectively. The South Su mound is of a similar overall size to Solwara 1 although its active area is a single main central region of venting whereas Solwara 1 has more dispersed venting activity. Biological comparisons of the two areas have shown that the active sites at both areas share the same biomass-dominant species and generally similar indices of diversity and community structures. Where there are significant differences, South Su generally has higher abundances of secondary (i.e., less dominant) species and higher dominance of some groups. Some recruitment may also come from North Su, which will also not be mined. However, because of the actively erupting conditions and sediment-occluded visibility at North Su at the times of surveys, it has not been possible to characterise vent communities there to the same extent as at Solwara 1 and South Su.

Continued monitoring at South Su control site during mining will enable natural variations in indices to be assessed away from any influence of mining at Solwara 1. South Su lies approximately 2 km distant from Solwara 1 and is directly upstream of the prevailing seafloor currents. This is advantageous from the point of view of South Su providing a source of parent stock for recolonisation by larvae. Some recruitment may also come from North Su, which will also not be mined.

Temporary Refuge Areas within Solwara 1

Not all of the resource can be mined simultaneously; mining will be sequenced according to the mine plan, which currently proposes that mining of the mineralised East and Far East zones will be the last in the development of the Solwara 1. Hence these areas will remain for the longest time as an undisturbed source of parent fauna and supply of larvae within Solwara 1 (see Figure 5.5). However, it is difficult to prescribe which areas will be the last to be mined, or the size of any areas potentially set aside as refuge areas, while allowing for flexibility in the mine plan that may be required during the progress of mining. As the last areas to be mined are reached, recovery across the mined areas will represent various stages in the sequences of recolonisation, with the initially mined areas having had the longest recovery time before the majority of intact pre-mined communities are themselves removed, and the most recently mined areas the least. A temporary refuge area is proposed, which is effectively a representative area of unmined and unaffected seafloor in part or the entire final zone to be mined (depending on zone). It is referred to as 'temporary' on the expectation that, by then, it can be demonstrated by monitoring that recovery at active chimneys in the earliest mined out area meets specified criteria that the major community elements (i.e., the three biomass-dominant species) have re-established. However,

mining at the temporary refuge area will not commence until these recovery criteria have been met.

Transplant of Animals

The loss of animals in the path of the SMT is partially avoidable and it is proposed to remove the largest clumps and relocate them initially to unmined areas and ultimately to venting areas where mining is complete. The extent to which this will be done is a matter of practicality and will be undertaken opportunistically and during routine monitoring. Clearly a sweep of the entire mining area is not practical, but large clumps can be gathered by the ROV and repositioned away from mining initially, and when possible, to areas where mining is completed. The removal of clumps will include the biomass-dominant species and any other associated attached or sessile fauna.

Mobile animals such as crabs, squat lobsters and shrimps are likely to swim away but being mobile, are also more able to move from one area to another. It will not be practicable to confirm whether or not the rare species, or those only observed at Solwara 1, are amongst the clumps of animals transplanted, as this involves bringing the animals to the surface for analysis (from which they would not survive). However, even for the rarest species, (i.e., those only observed at Solwara 1), it is not likely that their real distribution could be geographically limited to such a small area as that represented by Solwara 1. The success of this relocation of clumps of animals to vents in mined areas will be observed periodically using the ROVs included in the mining set-up. Subject to testing during the baseline campaign in July 2008, artificial substrates may be placed over new vents to simulate and enhance habitat reformation. The success of this strategy will be routinely monitored.

Artificial Substrate

It is thought that rates of colonisation and growth of organisms such as the bamboo coral *Keratoisis* on hard inactive substrates are slow (Van Dover, 2000a) and hence, recovery of *Keratoisis* and its associated fauna may take longer than recovery of active vent communities. In order to enhance this process, hard settlement surfaces such as concrete blocks or various other settlement substrates will be located opportunistically in appropriate areas. If practical, representative stands of *Keratoisis* will also be removed from the path of mining (where these are encountered in dense enough stands, and repositioned in compartmentalised structures such as crates, where they might re-form attached colonies. The survival and growth of such transplants will be monitored, with continued relocation if successful.

SMT Plume Minimisation

The suction mouth, positioned within or below the cutting head (depending on final design) is designed so that during operation, there is minimal escape of suspended fine material during cutting. Removal of unconsolidated sediment and competent waste rock to tip head locations on the outer slopes of Solwara 1 will be achieved at the seafloor, with minimal risk of reactive changes to this material from oxidation or temperature change.

Dewatering Plume Minimisation

Minimisation of impacts from discharge of water and entrained sediments from the dewatering process on the MSV will be achieved by:

- Discharge between 25 and 50 m from the seafloor to confine all impacts to the bottom zones from where the water/sediment originated and animals are most adapted.

- Retention of all particles above 8 µm in size, which is expected to reduce significantly the quantities of sediment lost in the dewater discharge, where the proportion below this size is estimated to be <5%.
- Limiting the time of exposure to surface temperatures and oxygenation to approximately 12 minutes (once operational and after a period to develop equilibrium conditions), thereby reducing potential geochemical changes to occur. During this time, temperatures are not expected to exceed 13.5°C.

This depth of exit point location has been selected both for reasons of engineering and pumping efficiency, and for environmental benefits by returning the water and any entrained particles directly to their deep sea zone of origin. It eliminates risks of any adverse effects to water quality and biota of the shallow and middle levels of the oceanic water column.

Removal of Free-floating or Swimming Organisms by the SMT

Water pumped with ore from the SMT to the MSV will potentially contain some entrained organisms such as planktonic larvae or small fish that would not be able to escape or survive the subsequent rise to surface. However, the volume of water being pumped to the surface (24 ML/d) represents only 0.3% of the net volume of water moving over Solwara 1 (8,800 ML/d). Therefore the SMT will potentially remove 0.3% of free-floating or swimming organisms as they move over and past Solwara 1.

Lighting

Illumination of the SMT will potentially attract fish or other mobile species in the area and place these at some risk of being sucked into the cutter head and the RALS, from which they would not survive. The lighting must be aimed at illuminating the area of operation of the cutter head and the location of the lighting on the SMT is fixed, about 3 to 6 m distant from the suction system. Hence, there is limited flexibility to locate the lighting further from the suction area to reduce any incidental entrainment of fish in the pumped ore stream. Some accidental loss of fish may occur but this is not expected to be significant.

Other Hazards Near Seafloor

Risks of major losses of equipment or spills of ore or fuel oils due to accidental events will be extremely low with the implementation of vessel and equipment maintenance procedures, navigational procedures, safety plans, environmental management plans, and emergency response plans. Any ore that could be lost in the event of failure of the pumping or riser system (i.e., an estimated maximum of 11 m³ in the RALS at any time) would be recovered by mining once systems were repaired or replaced.

Residual Impacts

The residual impacts that are predicted after the implementation of the above mitigation measures are described as follows.

Venting

In areas where the SMT has completed mining, venting of fluids will continue at new or pre-existing locations. New chimney structures will start to reform as the vent fluids mix with the seawater causing metal sulphides to precipitate. Depending on temperatures, this can be quite rapid, with new chimneys forming within days to weeks (Van Dover, 2000a), which is consistent with observations made during exploration. Diffuse venting will also continue in any mined areas where soft sediments settle, although in the directly mined areas, the majority of the existing soft

sediments will have been mined. It is possible that the dynamics of venting activity in the areas adjacent to the mined areas may change because of alterations to the fluid flow or release of venting in newly cleared areas, resulting in some changes to the frequency and intensity of venting in the nearby undisturbed areas.

The extent of the impacts to vents and other seafloor habitats directly mined will inevitably be severe at the site scale (i.e., the area of mining). However, impacts are reversible, as vents and chimneys start to reform almost immediately, although it may be many years before development of chimneys returns to pre-mining conditions from a geological perspective.

Recolonisation of Fauna

Most of the animals and their existing habitat in the path of the SMT are likely to be removed by mining, hence the immediate loss at local scale will be severe. However, loss and recovery is progressive and risks of loss of species diversity at Solwara 1 will be reduced to levels as low as practicable, with recovery of communities facilitated through three principal means:

- By the survival of clumps of biomass-dominant animals (and other species) relocated to suitable unmined areas (using the ROV).
- By active migration of adults or settlement of larvae produced by those adults from the unmined areas or temporary refuge area to be located in the final unmined area of Solwara 1.
- From settlement of larvae produced from the unaffected communities of the South Su control area, and other locations.

After an area is mined and the SMT has been relocated to the next area, recolonisation of mined areas will begin. Around actively venting areas, this is expected to follow a succession, initiated by the formation of microbial mats on the newly exposed surfaces, followed by the establishment of the characteristic vent-dependent, zone-forming snail and barnacle species and their associated fauna respectively. This is equivalent to the dynamic succession processes described at other ocean vent systems (Van Dover, 2000a), although potentially with less complexity of assemblages at Solwara 1. The rates of recovery of communities equivalent in diversity or density to originals are expected to be faster at active vent and active sedimentary sites provided that the supply of recruits is not disrupted. With the measures to maintain spawning populations in the refuge area, it is expected that after a transition period of 1 to 3 years, post-mining, populations characteristic of active sulphide mounds will return and reorganise to a condition of biomass and diversity that resembles the pre mining state (Appendix 11). In the inactive hard (sulphidic) surfaces and sediments, it may take more years to return pre-mining conditions, due to presumed slower growth rates. The genetic structure of the recolonising animals is expected to be the same as the baseline, reflecting nearest sources of parent stock at Solwara 1 and South Su.

The actions to relocate species out of the path of the SMT are proposed in an effort to enhance recolonisation of mined areas. At the very least, these efforts will salvage some of the densest clumps of animals for continued survival and contribution to the genetic stock at Solwara 1. The extent to which this will result in the successful establishment of colonies will be a subject for monitoring by observation. It will be dependent on practicalities, availability of suitable venting sites nearby and the long-term viability of the venting at the translocated area. Some enhancement of recolonisation at inactive hard surface areas may be possible, for example, by the placement of artificial hard settlement surfaces, and/or by the relocation of some stands of

Keratoisis (where practicable). At the inactive sedimentary areas, natural recolonisation is expected to be slow, with no practical means of enhancement by relocation of benthic fauna.

Overall, the mitigation measures will significantly reduce or avoid any risks of loss of biodiversity and endemism at Solwara 1. The extent of the impacts to seafloor benthic faunas will be mainly at the site scale (i.e., the area of mining), with temporary reduction in larval production for recolonisation at down-current areas during mining. Impacts to fauna are reversible, but recovery of the main community elements is expected to take within 1 to 3 years at vents and longer at inactive areas. Overall, assuming successful outcomes of the mitigation measures proposed, the ecological impacts are expected to be moderate.

Sediment Re-suspension from the SMT

Impacts to benthic communities of both hard and sedimented surfaces in active and inactive areas is likely to be through physical settlement of particles released into the water column during operations.

Unconsolidated sediments that are removed during operations are the same materials that naturally occur at Solwara 1 and will not undergo any significant geochemical changes as they are relocated from the path of mining to the periphery of the Solwara 1 mound.

Unconsolidated sediment is likely to contain its complement of benthic infauna, the most robust of which (e.g., meiofauna) are likely to survive and establish communities, depending on comparative sediment conditions and frequency of exposure to hydrothermal influences between the old and new site.

Some faunal community changes could occur, for example, where sediments from active areas are relocated to inactive areas (or vice versa), or where sediments settle across existing heterogenous patches of surface sediments (described in Appendices 5 and 6).

However, given the generally low densities and variability between sediment samples (Appendix 6), such community changes are unlikely to be detectable without a large sampling effort. Settlement of sediments from the SMT may cause some smothering or changes in communities; however, this process is unlikely to be substantially different from the original settlement from its volcanic origins and impacts are expected to be low.

Suction of Entrained Organisms

The proportion of larvae entrained in water sucked up by the SMT is estimated at 0.3% of organisms passing over Solwara 1 at any one time; hence, impacts are not likely to be detectable, and considered as very low.

Plumes from Dewatering Discharge

Results of elutriate tests (Appendix 9) carried out on representative ore material at representative temperatures and durations of exposure indicate that at the point of discharge, 600 dilutions would be required to meet ANZECC/ARMCANZ (2000) guidelines for 95% protection level. Modelling of the dispersion of the discharge water plumes indicates that this protection level will be met within 85 m of the discharge (Appendix 12). The modelling has also shown that plumes from dewatering discharge will not rise above 1,300 m depth.

Over the 30-month life of the mining operation, most sediment will settle within 0.9 km from dewatering source. Fine sediments (<10 micron) are expected to fall out in patchy areas approximately 5 to 10 km to the west of the mining site and at thicknesses <0.1 mm (Appendix 12), where animals may be less exposed to mineralised sediments. Some impacts may

occur but, within the background of settlement of sediments from natural plumes from volcanic and hydrothermal activity, such impacts are not likely to be detectable.

Reduction of Recruitment at Solwara 8

Over the mining period, there will be a progressive reduction of larval production from Solwara 1, followed by a recovery as surviving adults and new recruitment enhanced by the mitigation measures at Solwara 1 and South Su. This may affect recruitment at any downstream areas dependent on Solwara 1 as a source. The nearest equivalent massive sulphide mound downstream of Solwara 1 with active venting is at Solwara 8, approximately 45 km to the northwest of Solwara 1.

To whatever extent Solwara 8 is dependent on recruitment from Solwara 1, the risks will be minimised to the same extent that the efforts to enhance recovery of communities at Solwara 1 are successful. The unaffected South Su is a similar distance upstream from Solwara 8 and likely to be as important a supply of larvae; hence, risks of impacts to Solwara 8 are likely to be low and reversible to any extent that they occur at all. Results of genetic studies underway will confirm this.

Modelling studies (Appendix 12) indicate patches of settlement of fine particles at distances of 5 to 10 km from the dewatering source. However, thicknesses are <0.1 mm, and it is not likely that any substantial volumes of sediment from disturbance at Solwara 1 could reach Solwara 8.

9.6.3 Light and Underwater Noise

This section addresses the potential impacts of underwater light and noise derived from the offshore vessels and seafloor mining activities on marine animals. It presents the principal issues, proposed mitigation measures and residual environmental impacts of the project during the operations phase. In particular, the project has the potential to interact with large marine animals such as whales, dolphins and turtles and their environment, and this section considers their behavioural response.

Issues to be Addressed

The primary issue associated with the proposed offshore vessels and seafloor mining is the additional light and noise over ambient levels and above that of regular natural processes and commercial (shipping and fishing) traffic to any extent that might be significant. The offshore vessels and seafloor mining tool will operate 24 hours per day using artificial lighting at both the surface (at night) and seafloor, which will have the potential to attract marine fauna including seabirds, fish, squid and larger predatory species.

The operations of the SMT and the MSV will add to the natural existing noise levels of the ocean. An assessment of the underwater noise characteristics of the project and results of numerical modelling of underwater sound levels from operational activities are given in the Curtin University Report (Appendix 13), and summarised here.

Of the sound sources involved in the project, the most significant will be the cavitation noise produced by the thrusters on the MSV. Cavitation noise is well understood and predictable with confidence from the size and power characteristics of the vessel. The exact characteristics of the SMT are not known but likely to be low frequency sounds related to the rate that the cutting teeth strike the rock face. Details of this source and likely decay rates are not known well enough to model at this stage but will be modelled during prior to operations.

Mitigation and Management Measures

Surface Lighting

Decking lights on the surface vessels will be kept to the lowest levels needed to maintain safe working conditions. In principle, this will be not materially different from lighting associated with other vessels traversing the area and no adverse impacts to flora and fauna are therefore predicted.

Seafloor Lighting

Illumination of the SMT will potentially attract fish or other mobile species in the area and place these at risk of being sucked into the cutter head and the riser and lifting system, from which they would not survive. Lighting must be aimed at illuminating the cutter head and there is limited scope for altering its position or intensity. Most fish life will be attracted to the lights which will be some metres away from the suction mouth and unlikely to place them at risk. Some accidental entrainment of fish in the pumped ore stream may occur.

Underwater Noise

Noises associated with operations will likely to be generated by the SMT, surface support vessels and the MSV principally when using its dynamic positioning thrusters. This is mostly unavoidable during the normal course of operations. The implementation of a whale observing procedure will require all observations and encounters with marine mammals to be documented in a log, which will then be used to alert all other vessels. In the event of marine mammals approaching within 1 km of the MSV, the level of power to the thrusters will be reduced as far as practicable while maintaining safety of the operation. The predicted broadband noise levels from the mining vessel are less than 180 dB re 1 μ Pa at close range and therefore it is unlikely that these levels will cause significant physiological effects to marine mammals unless they are immediately adjacent to the vessel.

Residual Impacts

Subsequent to the implementation of the above mitigation measures, the predicted residual impacts of this project are described as follows.

Lighting on the MSV at night will attract fish and other marine animals, although without substantial adverse effects. Being so far offshore (30 km from New Ireland) the light is not likely to affect orientation of turtles moving to or from nesting beaches. Lighting around the cutter head may attract some fish and some individuals may be sucked into the riser system. Most suction at the cutter head will be directed towards the rock face and the extent of the potential entrapment area is small so that no impact to populations is likely.

Modelling of predicted noise associated with the project has assumed a basaltic, sound-reflective seafloor surface and although softer and more sound-absorbing seafloor sediments occur, these results give worst-case predictions (Appendix 13). Propagation of cavitation noise from the MSV's thrusters will be the most significant source of noise; however, modelling indicates that received levels will drop rapidly within the first 2 km, and more slowly thereafter. The sound may be audible (e.g., to whales) at up to 600 km (a similar range as with other large ocean going vessels), but at long ranges, the sound will not be greatly above that of background ocean noise depending on sea surface conditions.

The maximum distances for specific received level thresholds being exceeded show that it would not be until an animal approached closer than 1.1 km from the source that the levels would be greater than 140 dB re 1 μ Pa (considered 'loud'). Received levels are less than 180 dB re 1 μ Pa

(sufficient to cause detectable physiological effects) at very close range and drop to 160 dB re 1 μ Pa within 70 m; hence, harmful effect to whales is unlikely.

Responses of whales, based on worldwide literature, suggests behavioural avoidance at received levels generally between 140 to 130 dB re 1 μ Pa, which is equivalent to distances ranging from 1.1 to around 15 km, although distances and responses varies on species and behaviour of the whales at the time. These results are typical of modelled received level sounds with distance from other applications such as offshore drilling (APPEA, 2005). Masking of marine animal calls (signals) may occur if the mining vessel noise interrupts or prevents the listener from detecting the communicative signal.

The operational noise associated with dynamic positioning of the mining vessel is continuous over a wide frequency bandwidth. Animals may suffer signal-masking effects at similar ranges up to approximately 15 km.

Actual risks to whales and other animals are reduced by a number of factors (Appendix 13). The MSV is effectively static, which reduces risks of collisions and favours marine animals readily acclimatising to them after a period of time. Sudden exposure to sound will not occur as the MSV will be audible for considerable distance, and rapid changes of speed and direction of the MSV will not occur. It is possible that some animals (including fish and whales) may be attracted to the sound out of curiosity and through time the vessel may be treated as a landmark (Appendix 13).

The Project is effectively a single ship on the surface, with attendant barges and supply vessels and, in that respect, has analogues in offshore oil and gas production and dredging projects in many part of the world. The annual humpback whale migrations have continued off the east and west coasts of Australia notwithstanding the extensive development of oil and gas facilities and shipping that has developed off the west and east coasts of Australia respectively. Much has been learnt from the interactions between these offshore structures and whale behaviour (APPEA, 2005), none of which has indicated adverse impacts to whale populations or annual migrations from these offshore structures and associated operations.

Consequently, seismic surveys in areas of potential activity of whales, turtle, dugongs or whale sharks, such as off the Northwest shelf of Australia, are routinely approved provided means such as onboard observations, minimisation of lights to the level necessary for safety of operations and reduction of sound (in case of seismic) reduction (e.g., Enfield marine seismic survey proposed by Woodside [DEWHA, 2008]). In principle and as applicable, these measures are also incorporated into the operations of the MSV.

To a great extent, the exploration activities that have occurred over the past few years from vessels such as the *DP Hunter* (December 2005 to February 2006), *Wave Mercury* (March 2007 to October 2007) and the *Norsky* (June 2008 and still in progress) represent similar aspects and magnitudes of vessel presence, lighting, underwater sound and discharge of treated and macerated food waste/sewage as expected for the MSV. The *Wave Mercury* is of very similar dimensions and power as the MSV; hence, the impacts of the activities of surface vessel have been experienced already over protracted periods, albeit without the SMT or the ore barging operations.

Concern that underwater noise may affect other species such as sharks has also been expressed by local people. The reported success (Tiden, 2008) of the West Coast, Central New Ireland shark calling festival from 30 July to 1 August 2008 coincided with active survey by the *Norsky* in the area, which suggests that the surface vessel's activities or its underwater noise spectrum did not negatively affect the reef sharks or shark calling.

9.7 Maritime Safety and Interactions with Shipping

9.7.1 Issues to be Addressed

Operation of the offshore phase of the project must meet company, national and international standards of safety.

Weather and sea conditions present safety issues for the vessels engaged in offshore operation activities. Strong winds and strong currents may periodically generate difficult sea states, especially during the southeast trade wind season, and in the event of cyclones.

Installation of the MSV, from which the mining seafloor mining machine will be launched, the operation of the shuttle barges, which will transfer ore to the storage facility in the Port of Rabaul, and the bulk carriers that will export the ore, give rise to the following issues:

- The stationary MSV will create a long-term obstacle, and the shuttle barges and bulk carriers will add to offshore traffic, creating a short-term obstacle for other vessels.
- MSV, shuttle barge vessels and bulk carriers will pose a hazard to small boats and sea-going canoes if the latter approach too closely, especially when approaching and departing the Port of Rabaul.

9.7.2 Mitigation and Management Measures

Project Safety

Offshore operations will be carried out to comply with:

- Safety, health, and environment policies and plans for all offshore operations to be developed by Nautilus and its contractors.
- Applicable PNG occupational health and safety legislation.
- Various DNV Offshore Standards (DNV, 2005), including:
 - DNV-OS-A101 Safety Principles and Arrangements, 2005.
 - DNV-OS-D101 Marine and Machinery Systems and Equipment, 2005.
 - DVN-OS-D301 Fire Protection, 2005.

Matching safety performance expectations to give effect to PNG legislation and international standards will be established between Nautilus and its contractors, and these will be documented in the EMP.

The MSV and shuttle barges will also be regularly inspected to assess their ability to work safely, and to ensure the MSV can maintain its position in the sea conditions likely to be encountered.

Interaction with Other Vessels

The operations of the MSV are outside the main commercial tuna fishing grounds (see Section 10.3.5), but the ore barge transit routes to the Port of Rabaul, are likely to intersect the routes of the fishing vessels and other commercial vessels using the port. The physical presence of the MSV and barges will be an unavoidable but minor obstacle to fishing and movement of fishing vessels, as will be the case for other shipping in the region. The unlikely risk also has to be considered that ghost fishing gear (fishing gear that has been accidentally lost or discarded from fishing boats, including drift nets and long lines etc.) may be present and become tangled with the

RALS or umbilicals. The RALS and umbilicals will be regularly inspected to ensure that ghost fishing gear, if entangled, is removed as soon as reasonably practical.

A buffer zone of 500 m will be established around the MSV for observance of all vessels. Normal maritime navigational and communication systems and procedures are to be followed by the MSV, shuttle barges and bulk carriers to ensure safety at sea. Where possible, the shuttle barges will utilise existing shipping routes, limiting the possibility of collisions or interrupting the course of other vessels. This exclusion zone will be communicated via notices to mariners in advance of the MSV taking up its position. The MSV will have officers on watch at all times and to advise of any specific activities or to warn ships potentially approaching within the exclusion zone. The small area of ocean alienated to fishing around the MSV is not significant for highly migratory species such as tuna.

A hazard may apply to villagers if, out of curiosity, their boats or canoes approach too close to the offshore vessels. Such encounters are not likely to be frequent near the MSV, being 50 km offshore from Rabaul, but they may occur for the shorter period when the shuttle barges, and to a lesser degree, bulk carriers are closer to shore en route to the Port of Rabaul and within access of the small boats. This is unlikely to be a new source of risk to local canoe movements, given the current use of the Port of Rabaul for shipping. Nevertheless, villagers will be informed about the presence and potential hazards of vessels.

9.7.3 Residual Impacts

The implementation of the mitigation measures described above will ensure that the risk of safety hazards from operation activities will be reduced to be as low as practicable and consistent with normal maritime operations.

9.8 Quarantine

9.8.1 Issues to be Addressed

A potential pathway for the introduction of non-native marine flora and fauna into PNG waters is the presence of non-native organisms in ballast water or on the hulls of the vessels associated with transporting ore or consumables (including packaging) and equipment to the Port of Rabaul and to the offshore mine location.

9.8.2 Mitigation and Management Measures

Vessels entering the Bismarck Sea for project purposes may arrive under full ballast so there will be a need to discharge ballast sourced from overseas ports. To minimise the impacts of introducing foreign ballast water, vessels will adhere to MARPOL requirements (IMO, 1973/1978) to exchange ballast in mid ocean. Additional guidelines, developed as a basis for a new annex to the MARPOL requirements, are included in Guidelines for the Control and Management of Ships' Ballast Water to Minimise the Transfer of Harmful Aquatic Organisms and Pathogens (IMO, 1997), which are being implemented under the Global Ballast Water Management Program to help developing countries understand the problem and monitor the situation. Another international convention, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO, 2004) requires that new ships implement a Ballast Water Management Plan.

Antifouling refers to substances applied to the hulls of vessels to prevent attachment and growth of marine organisms that could affect the performance of the vessels and introduce exotic marine organisms. The International Convention on the Control of Harmful Antifouling Systems on Ships

(IMO, 2001) contains protocols measures to minimise antifouling. However, the use of organotin compounds in antifouling systems is being phased out because of its adverse environmental effects and Nautilus will comply with proposed changes to Marine Pollution (Ships and Installations) legislation in PNG in this regard. Alternative antifouling paint systems must therefore be used to prevent introduction of exotic organisms and hull-antifouling records of vessels entering PNG waters can be inspected by State authorities.

The carriers contracted by Nautilus must comply with the relevant conventions and guidelines, along with consultation with PNG Ports in regards to PNG requirements including water exchange locations and treatments. Information on vessel operators, destinations, routes and origin of ballast water will be determined closer to mining; however, Nautilus will ensure that reputable carriers that are aware of IMO guidelines and practice satisfactory ballast water and antifouling management procedures during operations and that management plans are in place to address the issues of introduction of exotic organisms in ballast or on cargo, and that antifouling systems conform to PNG requirements and form part of contractual requirements.

Cargo and packaging (e.g., pallets) will be inspected for the presence of stray organisms (e.g., African land snails) to prevent unintended introduction of such pest animals. Any such animals detected will be dispatched humanely.

9.8.3 Residual Impacts

To meet mining rates, between three and six bulk carriers will be required each month to export to existing overseas concentrators. Typical ballast water tanks capacity for contemplated bulk carriers would be in the range of 10,000 to 20,000 cum. Table 9.5 shows that approximations of the minimum and maximum volume of ballast water to be discharged per year of operation are 360,000 m³ and 1,440,000 m³, respectively.

Table 9.5 Estimates of ballast water discharge

Bulk Carrier Trips Per Month	Ballast Water Volume (cum)	Ballast Discharge Per Year (cum)
3	10,000	360,000
	20,000	720,000
6	10,000	720,000
	20,000	1,440,000

With implementation of ballast water treatment, antifouling systems and adherence to the relevant guidelines and the conventions, low residual impacts are predicted in relation to the introduction of non-native marine species from the discharge of ballast water, on the hulls of vessels or with cargo involved in the operation the Project.

9.9 Waste Management and Emergency Response

This section describes how the Solwara 1 Project will manage wastes produced during operation of both offshore and onshore aspects of the project.

9.9.1 Issues to be Addressed

Activities on the MSV, shuttle barges and bulk carriers include the handling and storage of wastes, including domestic wastes and small quantities of wastes with hazardous properties that could impact the marine environment. The description of the waste management strategy and expected waste types is presented below.

Offshore Wastes

The types of wastes potentially generated by the offshore component of the project during operation are listed below:

- Used lubricating oils.
- Oily debris, e.g., oil filters, oily rags from vehicle and equipment maintenance.
- Accidental contamination, small-volume releases, spills or leaks of hydrocarbons and chemicals.
- Drilling fluids and cuttings.
- Domestic waste or trash.
- Domestic wastewater, sewage and sludge.
- Empty barrels, drums, containers, and gas cylinders.
- Batteries (lead acid and other types).
- Construction debris, e.g., wood, metal, glass, insulation.
- Ash from waste incinerators.
- Unused, spent, expired and contaminated solvents, chemicals, and additives.
- Medical wastes.
- Scrap metal.

Onshore Wastes

In order to accommodate the anticipated production rates, on-land storage and export facilities are envisaged for the project, consisting of ore storage and berthing and loading of export vessels at the Port of Rabaul. Waste management at the port will be coordinated by PNG Ports Corporation Limited. The types of wastes potentially generated by the onshore component of the project during operation are listed below:

- Used lubricating oils.
- Oily debris, e.g., oil filters, oily rags from vehicle and equipment maintenance.
- Contaminated soil as a result of accidental, small-volume releases, spills or leaks of hydrocarbons and chemicals.
- Domestic waste or trash.
- Domestic wastewater, sewage and sludge.
- Empty barrels, drums, containers, and gas cylinders.
- Batteries (lead acid and other types).
- Construction debris, e.g., wood, metal, glass, insulation.
- Ash from waste incinerators.

- Unused, spent, expired and contaminated solvents, chemicals, and additives.
- Medical wastes.
- Stormwater from under or around operating equipment (potentially contaminated with hydrocarbons).
- Paint.
- Plastic.
- Scrap metal.
- Tyres.

9.9.2 Mitigation and Management Measures

Conventions, Legislation and Principles

Conventions, legislation and principles (see Chapter 3) relevant to the Project's waste management strategy are listed below. Nautilus is committed to developing a waste management plan for the generation of offshore and onshore waste that is consistent with the documents below, and in line with current leading practices.

International Maritime Conventions

United Nations Convention on the Law of the Sea (UNCLOS)

UNCLOS is a multilateral agreement on the law of the sea, in particular, the protection and preservation of the marine environment.

International Convention for the Safety of Life at Sea (SOLAS)

International Maritime Organisation (IMO) has developed the International Convention for the Safety of Life at Sea (SOLAS), a treaty that deals with maritime safety.

IMO has also developed and adopted international collision regulations and global standards for seafarers, as well as international conventions and codes relating to search and rescue, the facilitation of international maritime traffic, load lines, the carriage of dangerous goods and tonnage measurement.

MARPOL 1973/1978 Convention

The MARPOL convention is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. Currently the convention includes six technical annexes:

- Annex I Regulations for the Prevention of Pollution by Oil.
- Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk.
- Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form.
- Annex IV Prevention of Pollution by Sewage from Ships.
- Annex V Prevention of Pollution by Garbage from Ships.
- Annex VI Prevention of Air Pollution from Ships.

Papua New Guinea has ratified annexes I, II, III, IV, and VI of the MARPOL Convention, which include regulations aimed at preventing and minimising pollution from vessels, including dumping, oil, exhaust pollution and both accidental pollution and from routine operations.

PNG Legislation

Papua New Guinea National Maritime Safety Authority

Existing legislation relevant to waste management of the Project includes:

- *Dumping of Wastes at Sea Act 1979* – places restrictions on the dumping of waste at sea.
- *Prevention of Pollution at Sea Act 1979* (Chapter 369) – provides standard offshore operating requirements.

Drafts of two new bills relevant to the Project, designed to bring PNG into line with international standards, are currently available for public comment. The bills were developed by the National Maritime Safety Authority (NMSA) in PNG for the prevention and control of marine pollution from vessels, offshore installations and other maritime sources.

Descriptions of the two new bills are detailed below:

- Marine Pollution (Ships and Installations) Bill – designed to regulate all forms of marine pollution from ships and offshore installations, and implements the MARPOL Convention and Anti-Fouling Systems (AFS) Convention. This Bill is designed to repeal the *Dumping of Wastes at Sea Act 1979*.
- Marine Pollution (Sea Dumping) Bill – designed to regulate the dumping of wastes at sea and implements the London Dumping Protocol. This Bill is designed to repeal the *Prevention of Pollution at Sea Act 1979* and Prevention of Pollution at Sea Regulation.

Another new act may also be developed to implement the IMO Ballast Water Convention in PNG. Nevertheless, Nautilus intend to take measures to ensure that the risk of marine pest introductions via ballast water from ships entering the Bismarck Sea is minimised and that comprehensive risk-based ballast water management arrangements are in place (see Section 9.8).

Equator Principles

Equator principles that apply to the waste management strategy adopted by the Solwara 1 Project are as follows:

- Waste management.
- Wastewater and ambient water quality.
- Hazardous materials management.

Waste Management

A waste management procedure will be developed to ensure that all hazardous and dangerous goods that will be used on the vessels, including diesel fuel, oxy-acetylene gas (for welding), lubricants, hydraulic fluids, solvents, corrosion inhibitors are used in areas where deck drainage is directed to oil/water separators and treatment tanks, and waste products are transported to shore and disposed of in accordance with the MARPOL international standards (IMO, 1973/1978) governing the transport, handling and disposal of hazardous and dangerous goods.

Domestic wastes (i.e., kitchen scraps) will be treated by maceration before discharge (into international waters >3 nautical miles from shore). Sewage and grey water are to treated in accordance with MARPOL requirements by comminution and disinfection (via a certified

treatment plant onboard) prior to being discharged, and will not cause visible floating solids or discolouration of the surrounding waters.

Discharge of garbage, including victual, domestic and operational waste, including all forms of plastic waste, packaging, scrap wood and cargo lining is prohibited under MARPOL (1973/1978) and all such material will be brought to shore for appropriate disposal at the Port of Rabaul, where suitable waste disposal facilities exist. Waste from the vessels will be disposed of by the PNG National Agricultural Quarantine and Inspection Authority, who have a specialised waste disposal plant outside of the port area. Solids waste from the port will be disposed of by the town authority's existing waste disposal process.

The vessels employed in the offshore operations of the Project are to store, use and handle all hazardous chemicals and materials in accordance with MARPOL (1973/1978) requirements. This will include:

- The development of a hazardous materials register.
- Separate storage of paints and other flammable materials.
- Wastes produced by the MSV, shuttle barges and bulk carriers will be stored on board and then transferred to approved onshore facilities for treatment, reuse, recycling or disposal.

Waste Management Strategy

The project and its contractors will comply with applicable PNG legislative requirements, including the proposed marine pollution bills, related to the management of wastes (see above), and appropriate industry waste management standards and practices will be implemented in the absence of such requirements.

The project's waste management objectives, which apply to both offshore and onshore components, are as follows:

- Where possible, utilise to the maximum extent the waste management facilities or capabilities.
- Establish and operate new fit-for-purpose waste management facilities or capabilities to augment the existing facilities and capabilities.
- Optimise the selection and use of materials in order to avoid or reduce the production of wastes.
- Reuse or recycle certain waste materials to the extent practical.
- Properly and prudently treat or dispose of non-reusable or non-recyclable wastes and waste treatment residues.
- Classify or characterise wastes, and then store, handle, transport, and track wastes appropriately.

This waste management strategy will evolve into waste management plans that will be incorporated into the Environmental Management Plan. These waste management plans will feature the following:

- Waste characterisation criteria.
- Overall waste storage, inventory, transportation, and tracking requirements. A waste-by-waste listing including:
 - Definition of the waste type and source.
 - Waste-specific storage, handling, and transportation requirements, including safety considerations.
 - Reuse or recycling and treatment options (if appropriate).
 - Waste disposal options.

Emergency Response Spill Contingency Planning

Personnel on the offshore vessels are to be inducted into the relevant contractor's environment, health and safety policies, and emergency response procedures (approved by Nautilus) pertaining to the offshore activities.

Emergency (spill) response procedures will be developed and implemented in the event of a spill and these will include:

- Spill prevention procedures for the most likely situations (refuelling, routine operations).
- An active spill trajectory model to estimate direction of travel, distance, time and weathered fate of under ambient conditions of any fuel or other oils that may be spilled, such that application of retaining and clean-up equipment can be most effective.
- Allocated responsibilities and lines of communication in the event of any spills.
- Booms will be available for oil spills.
- Inductions (for all on-board personnel) regarding responsibilities and lines of communication related to spill response.
- Availability of appropriate containment and clean-up equipment (on board MSV and in Port of Rabaul, as appropriate) to prevent and respond to spills.
- Training for those workers responsible for implementing emergency procedures.
- Details related to emergency response and spill contingency planning and capabilities will be provided in the offshore Environmental Management Plan.

Cleaner Production and Energy Balance

The MSV is brand new and offers a 'state of the art' design for the project, as is all mining equipment to be used. The latest and best technologies for energy efficiency will therefore be incorporated into the vessel's design.

The shuttle barges and bulk carriers will be surveyed prior to use in the Project, as will all onshore infrastructure, to ensure that energy efficiencies are in line with leading practice standards.

9.9.3 Residual Impacts

Residual impacts after implementation of the waste management procedures for wastes generated during offshore operations will be limited to the discharge of treated sewage and macerated kitchen wastes into offshore waters. These discharges will be rapidly diluted and will

result in only extremely localised and very short-duration impacts to water quality. Nutrients will cause some localised increase of phytoplankton and zooplankton and organisms feeding on these but this is not likely to have any detectable effect on the pelagic ecosystem of the Project area.

9.10 Port of Rabaul

Nautilus will enter a Heads of Agreement (HOA) with the PNG Ports Corporation Ltd (Ports Corporation) to manage all Project-related activities proposed for the Port of Rabaul. Nautilus will, however, undertake regular audits of the port to ensure that onshore infrastructure is designed, constructed and operated in accordance with appropriate standards (see Chapter 3) and the environmental management measures provided in this section are implemented.

9.10.1 Marine Environment

Issues to be Addressed

Pollution of the marine environment can arise from hydrocarbon and chemical spills or inappropriate disposal of waste. The risk of pollution and product spillage is likely to be greater around areas such as refuelling stations and loading/unloading areas.

Increased water turbidity may result from water runoff from the stockpile escaping into the environment, increased shipping movements and any berth upgrades or dredging that may be required in the future. Water turbidity can decrease light penetration through the water column and decrease phytoplankton and zooplankton productivity.

There is the potential for acid generation through the oxidation of any sulphidic materials in stockpiled ore. This can result in runoff of low pH (acidic) water from the stockpile. Acid generation increases the potential for heavy metals to leach from the ore and the runoff often carries dissolved heavy metals, such as copper and zinc, which can be toxic to many marine organisms.

Mitigation and Management Measures

To prevent discharge of hydrocarbons or contaminated water, fuel and other hydrocarbons will be stored in appropriately sized, lined and bunded areas. A designated refuelling area will be established in order to contain potential hydrocarbon spillages. A spill response procedure will be developed and spill containment and recovery spill equipment will be kept at the port.

Waste from ships will be managed in accordance with MARPOL 73/78 Convention and the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*, which states that no disposal of food wastes or untreated sanitary wastes shall take place within 12 nautical miles of land and no disposal of treated sewage shall take place within 3 nautical miles of land (see Section 9.9 for more information).

To prevent acid generation, stockpiles will be covered to limit exposure to wind and rainfall (see Plate 5.4 and Section 5.7.2). Clean water runoff will be diverted away from the stockpiles and drainage from the stockpiles will be directed into a bund and channel to enable monitoring and treatment, if necessary. Any contaminated runoff will be neutralised (most likely via lime dosing) and solids returned to stockpiles. Water will be discharged to Simpson Harbour after being treated to applicable water quality standards (i.e., ANZECC/ARMCANZ (2000)) or returned to the MSV for combination with the dewatering plant discharge at depth after treatment.

Baseline monitoring of marine water and sediment quality will be undertaken for a minimum of 12 months before operations. Regular marine water and sediment quality monitoring will be undertaken during operations and records kept of any contaminant releases to the marine environment.

Residual Impacts

Given the management measures described above, it is considered unlikely that a hydrocarbon or chemical spill will occur. The consequence of such an event, if it were to occur, is expected to be minor, since it would most likely be localised, small in size and of negligible significance beyond the immediate environs of the port area.

Given that the maximum period ore will be stockpiled at the port is approximately four weeks, it is likely that management of the covered stockpiles will avoid the generation of acid. In the event that acid generation does occur and report to the marine environment, the severity of the impact is expected to be low due to the low volumes likely to be generated.

9.10.2 Landform, Soils and Geology

Issues to be Addressed

The stockpiled ore has the potential to leach heavy metals, which could result in soil and groundwater contamination.

Management Measures

Before the commencement of operations, geochemical characterisation of the ore will be undertaken to assess the risk of impacts associated with acidification of the stockpiled ore. All stockpile areas will be constructed from compacted clay or other low-permeability, non-acid-generating or acid-consuming materials to minimise infiltration into the underlying substrate.

Residual Impacts

Residual impacts on landforms, soils and geology are anticipated to be negligible.

9.10.3 Noise

Issues to be Addressed

Noise impacts from handling and loading activities at the port have the potential to disrupt the amenity of surrounding sensitive receptors. The closest sensitive receptor to the port has been identified as a house approximately 60 m from the ore stockpile area.

Mitigation and Management Measures

The equipment associated with the most dominant Project-related noise sources at the port (conveyor drives on the shiploader and shiploader compressor) will be carefully designed to reduce operational noise.

Non-Project shiploading and unloading activities currently occur 24 hours/day and the incremental increase to night-time activities at the port due to the Project is not expected to be detectable. However, a complaints register will be implemented and any noise-related complaints will be investigated and, if deemed to be valid and caused by Project activities, operation procedures will be reviewed.

Residual Impacts

Noise impacts from construction activities at the port are expected to be moderate. Equipment when operating may be heard by nearby residents; however, as there are already industrial noise sources in the area, the level of disruption to local residents is not anticipated to be noticeable.

9.10.4 Air Quality

Issues to be Addressed

Dust may be generated during ore handling and storage at the Port of Rabaul. Additionally, ore transport vessels and onshore ore handling equipment will release both sulphur dioxide (SO₂) and oxides of nitrogen (NO_x) into the atmosphere.

The potential exists for dust and air emissions to impact health and amenity, particularly at the nearest sensitive receiver, located 60 m from onshore activities.

Management Measures

A Dust Management Plan will be included in the Operations EMP and will outline all mitigation measures to be undertaken to control dust emissions. Measures will include:

- Covers on all stockpiles to prevent entrainment by wind.
- If necessary, water-spray dust suppression at transfer points, including shiploading. However, it is not envisaged that this will be required as the ore will remain moist from the time it is transferred to shore until the time it is exported on bulk carriers.
- Limiting activities generating high dust levels (e.g., ore transfer) in adverse wind conditions.

All vessels, vehicles and machinery involved in Project-related activities at the Port of Rabaul will be regularly serviced and fitted with appropriate exhaust systems to minimise the volumes of SO₂ and NO_x emitted to the atmosphere.

Residual Impacts

The increased dust associated with the port operations is expected to have a negligible impact on nearby receptors due to the existing high background particulate matter associated with the nearby volcanic activity, the small amounts of ore being stored at any one time and the management measures that will be put in place.

While not quantified, onshore activities are not expected to increase levels of SO₂ and NO_x at the port above existing levels.

10. SOCIOECONOMIC IMPACTS AND MITIGATION AND MANAGEMENT

This chapter provides a summary of the socioeconomic impacts (both positive and negative) of the first phase of the Solwara 1 Project. Mitigation measures proposed by the Project are also described.

Due to the majority of Phase 1 Project activities being located offshore, few direct socioeconomic impacts are expected. Onshore components of the Project will be associated with existing commercial facilities at the Port of Rabaul. No components of the Project will be located on customary or alienated land that is occupied or used by descendents of the former customary owners.

Impacts for the Project are centred on:

- Employment and training opportunities (for both genders).
- Opportunities to support the Project through the provision of goods and services.
- The potential for employees to interact with the community during crew shift changeover.
- The distribution of beneficial streams, i.e., taxes and royalties.
- Resource use (both nearshore and offshore) in the Bismarck Sea.

The Papua New Guinea Millennium Goals Progress Report (UN, 2004) highlights that, while the New Ireland and East New Britain provinces are performing reasonably well with respect to the goals (Section 8.1.6), there is large disparity between provinces and overall Papua New Guinea is unlikely to achieve the millennium goals by the target date of 2015. The country, therefore, faces development challenges, especially since the population is growing quickly and there are limited resources to invest in health, education and job creation to support the increasing population. External financing provides a very large proportion of financial resources available for the support and facilitation of the government's development program.

The Project will provide the government revenue through royalties and taxes (Section 10.3.1) and establishment of the Community Development Fund that will support existing provincial development projects in New Ireland and the island provinces (Section 10.3.2).

10.1 Issues to be Addressed

Many socioeconomic and sociocultural issues that are normally associated with terrestrial mining projects are absent from the Solwara 1 Project as the majority of Project activities will occur at sea and not be located on occupied land. Additionally, land-based Project activities in Rabaul will be limited within the confines of the Port of Rabaul, which is an existing development located on alienated land and is not accessible by the public. Therefore, the Project will not cause the displacement of people from their land or alter existing land use practices.

The positive socioeconomic aspects of the Solwara 1 Project relate to the income, services and personal opportunities that development brings. On the negative side are the effects that these changes can bring to social organisation, in terms of conflicts over the distribution of benefits or between people in the areas adjacent to the Project and those living outside.

Positive socioeconomic aspects of the Solwara 1 Project include:

- Economic benefits to the national and provincial economies through the payment of royalties and taxes.
- Economic benefits to local business that support the Project through the provision of goods and services.
- Community development through company support of community programs in the health and education sectors.
- Increased industry diversity for PNG and development of specialised knowledge and skills that can be shared with other Pacific Nations where future seafloor mining projects may occur.
- Training associated with employment of PNG nationals on the Project.

Potential negatives relevant throughout the Project include:

- Ineffective distribution of benefits.
- Conflict between employees from areas outside the immediately adjacent Project area and the local community at shift changeovers. Conflict would potentially result from a lack of awareness of environmental and social sensitivities in the area.
- In-migration of people from other parts of New Ireland, East New Britain and other parts of PNG to Rabaul and Kavieng seeking employment (either directly with Nautilus or indirectly through service providers). Increased in-migration has the potential to:
 - Reduce the opportunity for local people to gain employment.
 - Cause disruptive social tensions.
 - Overwhelm existing social and economic infrastructure.
- Disruption to fishing activities and other vessels operating in the vicinity of Solwara 1 and Project marine transport corridors.
- Danger to local peoples fishing around mining vessels.
- Disruption to local customs (for example, shark calling).

As the major components for Phase 1 of the Project are located offshore, minimal socioeconomic impacts are expected to result from the Project. However, based on other larger projects in PNG, local impacts are expected to arise from:

- Employment created during the operational phase of the Project.
- Business opportunities generated by the supply of goods and services, such as fuel, security and catering services.
- Subsidiary employment and business opportunities arising from expenditure of incomes earned from Project employees.

10.2 Mitigation and Management Measures

10.2.1 Optimisation of Benefits

Nautilus will aim to optimise the socioeconomic benefits resulting from the Project by:

- Establishing a Community Development Fund to support existing and proposed provincial government health and education projects in New Ireland and other island provinces (see Section 10.3.2).
- Continue to put a high emphasis on stakeholder consultation to foster and maintain good relationships with stakeholders.
- Continue to offer skills development-based scholarships to people from PNG organisations such as universities and government agencies (see Section 10.3.3).

Indirect benefits to the PNG economy may arise from the multiplier effects of money spent within the local economy by various Project income recipients. An unpublished and confidential socio-economic impact assessment for another project in PNG estimated that, for every one Kina increase in spending in the local economy, total income might increase by an additional 0.7 Kina.

10.2.2 Management and Mitigation

Mitigation and management measures will include:

- The development and implementation of a cultural awareness program for employees. The program will include a formal community awareness program induction on arrival at the workplace and distribution of a community awareness booklet that emphasises the rules for employees and contractors. This booklet will be available in both English and Tok Pisin and will provide descriptions of:
 - The Project and its environmental and social setting.
 - The Company's environmental policy.
 - The local culture, beliefs and customs.
 - The rules for employees, and the consequences of breaching these rules.
- Direct transfer of fly in/fly out employees from airports to the crew boat or vessel to eliminate the need for overnight accommodation in Rabaul or Kavieng. This will minimise the potential for interaction between outsider employees and the local communities.
- Preparation of a Training Associated Plan that provides general principles for employment and training. The plan will seek to maximise employment opportunities for local labour, i.e., New Ireland Province, before looking at others from further afield.

Measures to manage possible interactions between fishing and other vessels operating near the Project area will include:

- Establishment of a 500-m-radius exclusion zone around the MSV¹.

¹ Various acts (e.g., the *Australian Offshore Petroleum Act 2006* and *United Kingdom Petroleum Act 1987*) suggest a minimum 500-m exclusion zone around permanent offshore oil and gas facilities to avoid ship collision.

- Installation of appropriate devices on the MSV to allow monitoring of and communication with approaching vessels.
- Regular communication with PNG's National Maritime Safety Authority and National Fisheries Authority to advise on Project activities and planned vessel movements.
- Revision of nautical charts (in consultation with PNG's National Maritime Safety Authority) to include the location of the MSV, the mining leases, associated exclusion zones around these two locations, and routine shipping routes to be used by the Project.

10.3 Residual Impacts

10.3.1 Economic

Benefit streams generated by the Project have the potential to enhance the quality of life of the general populace of PNG, particularly in New Ireland and East New Britain. The State will capture a share of profit and labour income via royalties and taxes. Total tax, duties and royalty receipts are estimated at approximately US\$40.8 million over the nominal life of the Project. The New Ireland and other island provincial governments will receive funding for health and education projects from a voluntary Community Development Fund to be established by Nautilus (Section 10.3.2). The major government benefit streams are described below.

Royalties: Royalties are paid at 2% of the net smelter returns of mine products exported from PNG. This is estimated at US\$23.2 million over the life of the Project. The royalty is shared between the national and provincial governments according to negotiated agreements, usually agreed upon during the Development Forum.

Taxes: Company tax will be paid on the profits of the company at a rate of 30%. However, as the Project is largely seen as a proof of concept and taking into account the current carried losses, it is expected that no company tax will be payable during the life of the Project.

Salary tax will be levied on the wages paid during operations. Gross wages expected to be paid to PNG citizens over the the Project are US\$6 million. Assuming a tax rate of 30%, a total of US\$1.8 million will be paid in salary and wages tax.

Taxes paid by expatriate and company withholding taxes have not been modelled at present, and are awaiting Treasury input.

Production Levy: Under the *Mining Act 1992* (Section 3.1.1), mineral producers are required to pay a Production Levy of 0.25% of assessable income. This levy is the principal funding for the Mineral Resources Authority (MRA). The MRA manages and implements mining sector related Public Investment Programme (PIP) projects approved by the State (MRA, 2007).

Fuel Excise Tax: Nautilus expects to pay approximately PGK500,000 in fuel excise taxes every year.

Value Added Tax: PNG has a single rate value added tax (VAT) of 10% that is collected by customs when goods are imported into the country.

Community Development Fund: Two kina for every tonne of ore mined will be paid into a community development fund. This is a voluntary fund being established by Nautilus, and will be used to support health and education projects in New Ireland and other island provinces (see Section 10.3.2). Nautilus will administer the fund, with advice provided from an independent committee.

Total direct economic benefits to PNG associated with the Solwara 1 Project are projected to be approximately US\$142 million over the anticipated life of the Project. This income has the potential to improve social and economic welfare in PNG.

Due to the fact that key Project workforce and activities will be located offshore, the potential for local people to develop Project-associated businesses is considered to be limited in the first instance. However, some opportunities for commercial development in towns such as Kaiveng and Rabaul (where support services such as catering, laundry and accommodation are likely to be sought) are expected to result from the Project.

Import Duties: The Company's operations will primarily be related to mining operations and as such the impact of import duties is expected to be minimal.

10.3.2 Community Development Fund

Nautilus has evolved a Community Development Fund under which it will work with the provincial governments of New Ireland and other island provinces to identify community priorities, and to create opportunities for improved quality of life through the provision of health and education services. To this end Nautilus will pay PGK2 per tonne of ore mined into the trust, which will be managed by Nautilus.

Requests for funding of projects will be reviewed by an independent committee established by Nautilus, namely the Community Development Advisory Committee (CDAC). Committee members will consist of provincial government, church, industry and PNG-based NGO groups. Funding recommendations will be submitted to Nautilus for consideration.

Preference will be given to projects which are:

- Based in New Ireland Province.
- Based in island provinces, i.e., East New Britain and thereafter other selected islands.
- Part of existing provincial government development projects and leveraging funding from other sources (e.g., provincial or national government or international aid organisations).

It is anticipated that a total of PGK5.8 million will be paid into the fund over the Project life and be available for development projects.

10.3.3 Industry Diversity and Skills Development

It is anticipated that PNG nationals will be trained and receive skills development, with an expectation that the number of PNG nationals employed by the Project will increase over time.

Nautilus is committed to an active training program for the Solwara 1 Project. This program will be focused on enhancing the employment benefits for PNG and providing training for the people of

PNG in this new industry, whilst maintaining the long-term international competitiveness and success of the Project.

10.3.4 In-migration and Community Conflicts

When the Project proceeds, some in-migration to Kavieng and Rabaul will likely occur, even if the strategies proposed in the Training Associated Plan are effective. This has the potential to create added pressures on social and economic infrastructure and to cause disruptive social tensions, especially if migrants fail to procure employment with Nautilus.

Nautilus' recruitment policy will assist in deterring non-local people moving to Rabaul and Kavieng with the expectation of employment with the Project. Therefore, it is not expected that migrants will reduce the opportunity for local people to gain employment. Nautilus will work with local and district authorities to monitor in-migration and, if required, seek ways of improving its management.

Interaction between outside employees and local communities is inevitable. However, implementation of the above measures will minimise the potential for conflict.

10.3.5 Fisheries and Marine Traffic

Commercial Fisheries

The long-term presence of the MSV at Solwara 1, and the associated 500-m exclusion zone, may cause some inconvenience to the PNG local purse seine fishery (as it focuses its fishing efforts in the Bismarck Sea). However, the exclusion zone is negligible in size when compared to existing Bismarck Sea purse seine fishing grounds. Therefore, any inconvenience experienced by the commercial fleets operating in the Bismarck Sea relating to restriction of movement and fishing areas is also expected to be negligible.

Other fishing fleets operating in PNG, i.e., international purse seine and the PNG long-line fleets, do not focus their fishing effort in the eastern extent of the Bismarck Sea and the Project is not expected to have any impact on their operations.

Subsistence Fisheries

When operating at Solwara 1, the MSV will be located some 30 km from New Ireland landfall and 40 km from East New Britain landfall (the Duke of York Islands are approximately 50 km distance from Solwara 1). Subsistence and small-scale coastal fishing activities are restricted to waters close to shore and no fishing is expected to occur at Solwara 1. Therefore no adverse effects due to interference with subsistence fishing vessels is anticipated.

Modelling has shown that plumes from the return seawater will not rise above than 1,300 m in the water column (see Chapter 9). The processes of mining and dewatering will therefore not affect the pelagic tunas, tuna fisheries or nearshore coral reefs, including traditional reef fishing activities such as shark calling.

Marine Traffic

The implementation of the mitigation measures described above will ensure that the disruption to marine traffic from Project activities will be kept to a minimum. Overall impact on marine traffic from the Project is anticipated to be low.

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11. ACCIDENTAL EVENTS AND NATURAL HAZARDS

11.1 General

Environmentally hazardous discharges resulting from accidental and extreme natural events are fundamentally different from normal operational discharges of wastes and waste waters described previously in Chapter 9. The probability of accidental events is low, given that the design, which factors in the requirements of relevant technical codes and operating and control measures adopted by Nautilus, will have the specific aim of their prevention. Similarly, natural occurrences of sufficient magnitude to cause significant damage to Project infrastructure have a low probability of occurrence over the life of the Project.

Nevertheless, both accidental and natural events can occur and the main risks have been assessed. Should accidental events and natural hazards occur, Nautilus resources will be mobilised in accordance with their emergency plans to respond to the event. Other general safeguards that will be adopted by Nautilus include:

- Induction training and regular refresher courses that address site safety and emergency procedures in the event of an accident or natural hazard.
- Government notification and liaison procedures in the event of an accidental event or natural hazard.

The following sections provide an initial assessment of specific events and their associated main risks, mitigation and management measures and emergency control procedures, drawing predominantly on Appendix 14.

Note that occupational, health and safety issues associated with accidental events and natural hazards are not addressed in this chapter.

11.2 Extreme Weather

11.2.1 Issues to be Addressed

Gale force winds and rough seas associated with extreme weather increase the risks associated with the offshore component of the Solwara 1 Project. Operating during such conditions adds another level of difficulty to standard operating procedures and increases the potential for injury, damage to vessels and equipment and spillage of hydrocarbons and ore during transfer.

11.2.2 Mitigation and Management Measures

Equipment has been designed such that mining activities at Solwara 1 can be undertaken in conditions up to sea state 5 (see Section 5.6.3), but not in conditions exceeding this state.

The main mitigation measure during extreme weather will be to suspend operations, a decision that will be made in conjunction with the Nautilus site representative and the Mining Superintendent based on weather reports, alerts and the prevailing conditions. Other mitigation measures will include:

- Depending on the duration and severity of the event, recovery of all seafloor equipment for safe storage on the MSV.
- Turning the MSV, shuttle barges and tugs toward oncoming weather to minimise the cross-sectional hull area exposed to prevailing conditions, thereby minimising movement and protecting vessels.
- Securing the vessels and waiting for the event to pass. The vessels will either sail to the nearest safe port or stand by at Solwara 1.
- Maintaining safe distances between vessels during extreme weather conditions.

11.2.3 Residual Impacts

The suspension of operations and implementation of the measures described in Section 11.2.2 will minimise the potential for uncontrolled releases of contaminants, such as hydrocarbons, into the marine environment.

11.3 Seismicity, Volcanism and Tsunamis

11.3.1 Issues to be Addressed

The greatest potential environmental implications for the Project – specifically the onshore component – following a major earthquake would likely arise from an associated tsunami or from infrastructure damage at the Port of Rabaul, e.g., to roads, the wharf, ore handling systems and hydrocarbon storages, with possible disruptions to operations. Similarly, volcanic eruptions have the potential to cause damage to onshore infrastructure (and, to a much lesser extent, Project components at Solwara 1) and may disrupt port operations due to lava flows, through the accumulation of ash that, due to a high sulphur content, can be corrosive when wet and as hard as cement when dry, or pumice floating in the harbour preventing vessel access. Specific environmental impacts to downstream water quality due to an adverse release of trace metals and hydrocarbons include:

- Uncontrolled releases of hydrocarbons due to the failure or flooding of storages.
- Formation of acidic runoff from the exposure of oxidised ore to water (either through damage to, or failure of, ore storage areas or transport system).

The primary issue associated with trace metals and hydrocarbons is a toxicological one, i.e., impacts on water quality and to marine fauna.

Some local communities around the Bismarck Sea have expressed concern that the extraction of minerals could trigger volcanic activity, earthquakes and tsunamis. These concerns relate to the possibility of extraction uncovering a shallow magma body or destabilising the local stress regime causing the depression (the weakening of pressures) of a deeper magma body or activating faults leading to seismic activity. It is perceived that any of these events could then cause a tsunami.

11.3.2 Mitigation and Management Measures

Seismicity

Nautilus will enter a Heads of Agreement (HOA) with the PNG Ports Corporation Ltd (Ports Corporation) for activities at the Port of Rabaul. While the Ports Corporation will be responsible for infrastructure, operations and maintenance at the port, Nautilus will undertake a facility due diligence to ensure that short- and long-term stability analyses under static and earthquake conditions have been undertaken and that onshore infrastructure are designed, constructed and operated in accordance with appropriate standards, e.g., bunding, and suggested methods for the structural design of the relevant seismic zone as defined in Section 7.1.1.

The Nautilus review will also address the port's operating plans for the transport, storage and handling of hazardous (hydrocarbons and chemicals) materials and management of site drainage to ensure that any off-site release of water is not contaminated and meets Schedule 1 of the Environment (Water Quality Criteria) Regulation 2002 (Independent State of Papua New Guinea, 2002) for the protection of ambient water quality.

Volcanism

Nautilus will review the Ports Corporation's operating procedures and management plans to check that the management of sediment, drainage and air quality are in accordance with relevant guidelines and standards adopted by the Project that are set out in Chapter 3. The review will specifically include the port's maintenance schedule to ensure that volcanic ash is regularly cleaned off infrastructure, especially that which has moving parts, e.g., conveyors, and that storages are regularly inspected for corrosion. The due diligence will also ensure that there is an adequate system for managing maintenance work identified from inspections.

A rise in water level associated with volcanic lava flows will be managed the same way as inundation from a tsunami (see 'Tsunamis' below).

Tsunamis

Emergency procedures will be implemented at Solwara 1 and the Port of Rabaul in the event of a tsunami.

The depth of water at Solwara 1 is expected to mitigate the effect of a tsunami offshore; however, depending on the tsunami alert level, Nautilus will implement emergency procedures, based on the emergency response plan, in the event that the Vessel Master decides to suspend operations, and possibly cut the SMT umbilical and steer the MSV out into deeper water. The procedures will also address hydrocarbon spills that may result from a collision between the MSV, shuttle barges or tugs, caused by a tsunami or extreme weather (see Section 11.2 and Section 11.4).

As described in 'Seismicity' above, a due diligence will be completed to assess the adequacy of the port's infrastructure and operating procedures, especially secondary containment capacity in the event of flooding, the extent of which has varied at Rabaul with past tsunami events (see Section 7.1.3). A similar exercise will be completed for the Ports Corporation's emergency response plan with which Nautilus will comply when operating within Simpson Harbour. Nautilus' own emergency response plan will be implemented in the event of a tsunami when the shuttle barges and tugs are operating in shallow water beyond the harbour.

11.3.3 Residual Impacts

Seismicity

There are various sites around the world where subaerial mining has induced seismic events, e.g., Book Cliffs coal mines, Utah. These occur when the local elastic stress regime has been changed by the loading or unloading of large volumes of rock or changing hydrostatic pore-pressures and are not related to seismic activity associated with volcanism or faulting. It is unlikely that seafloor mining at Solwara 1 will induce a seismic event as:

- The area is naturally very seismically active so stresses have not built up in the rocks.
- There are favourable unloading differentials in an aqueous environment. Material will only be removed in 1-m-thick swathes at a time (to a maximum depth of 220 m), where 1 m³ of material is replaced by 1,000 kg of water resulting in a density differential of less than 2:1, which is stable compared to a subaerial differential of 1,500:1, where air replaces the material.
- Changes in hydrostatic pore-pressure are not going to occur at depths of 1,500 m. No dewatering is required at the point of extraction and the mining equipment is designed to operate submerged with the ambient pressures encountered at the seafloor.

The mitigation and management measures described in Section 11.3.2, 'Seismicity', for normal operating conditions, will help to minimise onshore, and consequent offshore, environmental impacts associated with an earthquake, e.g., release of non-compliant water containing hydrocarbons or elevated metals (Section 11.4.3).

Volcanism

Volcanic activity is caused by the rise of molten rock and gases from depth to the earth's surface. The violence of these eruptions is controlled by the decompression of dissolved gases and the ease with which these gases escape from the magma. It is possible to calculate the volume of gas in magmas for submarine eruptions by applying Boyle's Law that states gas volume will halve with each 10-m increase in water depth.

The volume of bubbles naturally released from magma on the seafloor at Solwara 1 would be infinitesimal and would not result in violent explosions/eruptions. Instead, gentle lava outpourings onto the seafloor would occur and be unnoticed by, and pose no hazard to, coastal populations and marine traffic.

At Solwara 1, magma is located at least 1 km below the seafloor and concomitantly any seafloor mining activities. It is unlikely that the gradual removal of low-density porous material to a depth of 20 m below the seafloor will depress magma at 1 km. Should extraction uncover a shallow magma body or alter the stress regime causing dilation of faults through which magma could flow, as described above, there would be no noticeable effects at the surface.

Fine dust (ash), from 'normal'¹ volcanic eruptions within the Rabaul Caldera, could be transported the distance of 50 km to where the Solwara 1 Project MSV, shuttle barges and tugs will be

¹ Normal refers to the regular eruptions that are occurring at the time this EIS was being prepared, i.e., May to June 2008.

operating, but this would not be at nuisance levels. At this location, larger debris such as gravel-sized pumice could only be expected from caldera-forming volcanic events (the probability of occurrence is 1 in 4,000 years and the last one occurred 1,400 years ago (see Section 7.1.2)). Such debris would behave in much the same manner as hail and float on the sea surface, and is not expected to result in any environmental impacts (Saunders, pers. comm., 2008a). It is certain that volcanic ash, and possibly larger debris, would effect port operations (Plates 7.25, 11.1 and 11.2), but the port's operating procedures and management plans will ensure that any Project-derived off-site releases will comply with Schedule 1 of the Environment (Water Quality Criteria) Regulation 2002 (Independent State of Papua New Guinea, 2002) to provide the required protection to the marine environment.

Tsunamis

Mining operations at Solwara 1 are located where water depths are approximately 1,600 m; therefore, it is unlikely that the large swells associated with tsunami waves will be felt by the MSV, shuttle barges and tugs positioned above the mining equipment. During the *Wave Mercury 07* Campaign, the Nautilus-chartered, 140-m-long vessel, the *Wave Mercury* was undertaking exploration activities at Solwara 1 (see Section 2.2) when the 2 April 2007 Solomon earthquake occurred. Wave surges of up to 2.5 m were recorded around the region and a maximum peak to trough surge of 1.68 m was recorded at the Port of Rabaul. However, no tsunami-derived wave surges were observed at Solwara 1 on the *Wave Mercury* (Saunders, pers. comm., 2008b and Smith, per. comm., 2008b). The potential for consequent environmental impacts is, therefore, low. Emergency procedures, implemented by the Vessel Master, will further reduce the potential for environmental impacts during a tsunami event in the Bismarck Sea.

It is possible, however, that onshore facilities at the Port of Rabaul could be inundated by a tsunami wave should one hit the coast. While the return period of tsunamis, such as the Aitape Tsunami (see Section 7.1.3), is unknown, a tsunami of this magnitude is likely to be a very low probability event, particularly over the life of the Project. In such an event, it would be difficult or impossible to defend most coastal areas.

Potential environmental impacts caused by tsunami damage to the onshore facilities and to shuttle barges and tugs operating outside Simpson Harbour will be minimised by the implementation of appropriate operating, maintenance and emergency response plans.

Onshore inundation would likely result in extensive flooding that would disrupt operations. Good port operating and maintenance procedures will reduce the potential for metals and hydrocarbon contamination; however, there will be elevated sediment in floodwater runoff from ore stockpiles and the remobilisation of volcanic ash. This sediment may be deposited inland as the tsunami wave retreats or may be washed into the harbour, along with large amounts of other debris and contaminants mobilised from coastal areas during the tsunami. Wetting of the high-sulphide-content oxidised ore by a tsunami wave may result in acidic runoff with elevated metal concentrations, i.e., acid rock drainage, which may damage vegetation and contaminate soils.

11.4 Hazardous Material Leakage or Spillage

11.4.1 Issues to be Addressed

There is the potential that hazardous materials, such as fuel, may leak or spill from their containment vessels, especially during transport and transfer, with the associated hydrocarbon contamination impacting water quality or marine fauna.

This section focuses on hydrocarbons as no process chemicals are required for Phase 1 of the Project.

11.4.2 Mitigation and Management Measures

Section 5.6 describes the management measures Nautilus will, and expect the Ports Corporation to, implement for the transport, handling, storage and disposal of hydrocarbons. Nautilus will also ensure that the fuel supply boats that service the MSV have management plans that meet their requirements and standards required.

Of particular importance are the fuel transfer and spill contingency procedures for the offshore operation that include the following mitigation measures:

- The MSV has a fuel storage capacity of 2,000 m³ (1,840 t assuming a density of 920 kg/m³) and operations at Solwara 1 will use up to 40 t/day of fuel. Fuel deliveries will be required at least monthly thereby reducing the risks associated with the transport and transfer of fuel at sea.
- Shuttle barges do not require fuel, and tugs and support vessels will refuel while they are at port in Rabaul.
- Stocks of hydrocarbon spill response equipment will be regularly checked and replenished to ensure appropriate supply quantities are on hand at all times.
- In the event of a spill on the MSV or at the port, absorbent material will be used to remove spill material prior to any washing activities.
- Pipe/hose pressure will be monitored during fuel transfers to enable early detections of any leakages or spillage.
- There will be regular transfer hose integrity testing and maintenance.
- Bunding will be in accordance with PNG and Australian standards.
- Weather forecasts and alerts will be monitored and fuel transfers suspended during extreme weather.
- There will be a high level of operator training on fuel transfer procedures and emergency response to spills to ensure that personnel are aware of requirements.
- Procedures will be put in place for warning potentially affected parties.
- There will be appropriate storage and disposal of clean up materials (Chapter 13).

Nautilus will utilise existing fuel infrastructure at the port. The Ports Corporation's hydrocarbon, spill contingency and emergency management plans will be reviewed by Nautilus to ensure they meet both Nautilus' and regulatory requirements.

11.4.3 Residual Impacts

The safeguards described in Section 11.4.2 will minimise the potential for hydrocarbon spills during both offshore and onshore operations and, should they occur, minimise the volume of material spilled.

If the spill is contained either on a vessel or at the port, drainage and waste management procedures will minimise the contaminants that are released to the environment. It is expected that, given the relatively remote location of the offshore components of the Project, there would be limited impact to the coast should the spill be directly into the water. Also, the marine diesel oil will evaporate and degrade quickly in tropical temperatures; however, this will be verified by spill trajectory modelling during baseline studies (Chapter 13). Further, compared to coastal areas, the open ocean lacks environmental sensitivities that could be impacted by a hydrocarbon spill. A spill directly into the water at or close to the port would be more visible, raising the concerns of local communities, and have the potential to cause greater environmental harm to vegetation and marine fauna.

In the event of a spill, the animals most likely to have direct physical contact with the slick are seabirds and it is possible that oiled birds will ingest toxic hydrocarbons and have difficulty flying. Lesser effects would be experienced by other marine fauna such as plankton, fish, reptiles and mammals; however, some fauna deaths may be observed. Some localised coral death is expected if spilled oil comes into contact with coral within Simpson Harbour. Recovery would occur once clean, hard surfaces emerge and new settlement occurs, as would be the case after a volcanic ash dump.

11.5 Fire and Explosion

11.5.1 Issues to be Addressed

Mining operations involve the storage and handling of flammable and combustible substances that can lead to the generation of potentially explosive and/or flammable gas emissions resulting in a fire or explosion. While the Project does not require the use of explosives, potential environmental impacts associated with the use of other consumables, such as fuel, may include breakout of fire into neighbouring properties, release of significant quantities of air emissions and contaminated runoff from firewater.

11.5.2 Mitigation and Management Measures

While no explosives are required by the Project, flammable and combustible substances will be used. Preliminary mitigation measures include:

- Storage and handling of all flammable and combustible substances, including waste, under conditions which minimise the risk of fire or toxic emissions.
- Specific design criteria for fire prevention, detection, control and personnel safety requirements.

- Ensuring that 'hotworks' do not take place near flammable materials.
- Identification and regular maintenance and testing of fire equipment adequate for the level of risk to ensure good working order.
- Implementation of waste (solid and liquid) management plans for the mining support vessel, shuttle barges and tugs.
- Implementation of a drainage management plan for the Port of Rabaul that minimises the potential for the release of contaminated water.
- Implementation of appropriate measures from relevant PNG and Australian standards (see Chapter 3) on the mining vessels and barges and at the Port of Rabaul, as required.

11.5.3 Residual Impacts

Implementation of the measures detailed in Section 11.5.2 will minimise the potential for fire and explosion and, in the event of a fire, reduce the potential for air and water pollution. However, safety will take precedence over the control of off-site emissions. The remote location of the mining operation would further reduce the potential for air pollution. Any pollution associated with a fire or explosion is expected to be short-term in duration.

11.6 Collisions

11.6.1 Issues to be Addressed

Collisions between Project vessels (including the MSV, shuttle barges and tugs) and other marine traffic may occur during extreme weather conditions or due to human error. Resulting damage could result in the release of ballast water, fuel (especially if the collision occurs during the refuelling process) or ore. Such releases have the potential to impact water quality and marine fauna through the introduction of marine pests that compete with local endemic species for food and habitat, in the case of ballast water, or the release of contaminants, in the case of fuel and ore.

11.6.2 Mitigation and Management Measures

A number of mitigation and management measures will be implemented to minimise the potential for collisions:

- Provision of digital and printed information to fishing operators and other commercial vessels travelling past Solwara 1 on the mining location and position of MSV, shuttle barges and tugs.
- Appropriate navigational lights on all Project vessels. Vessels will be equipped with sound horns that will be used if required.
- Vessel positioning equipment, including marine radar and a Global Navigation Satellite System (i.e., the United States Government NAVSTAR Global Positioning System).
- Vessel masters to determine a safe working distance between vessels.
- Constant radio communication between vessels and the Ports Corporation.

- Establishing a permanent 500-m exclusion zone around the mining operation and advising appropriate marine organisations of this zone.
- Ongoing consultation with commercial fishing groups and other marine operations regarding the mining location, ore transport routes and duration of activities.
- Extreme weather procedures as described in Section 11.2.

Measures that will be implemented to manage materials with the greatest potential to cause environmental harm if spilled in the event of a collision, i.e., ballast water, fuel and ore, include:

- Each vessel will have their own ballast management plan that will be consistent with the requirements of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (adopted 13 February 2004) (IMO, 2004).
- All vessels related to the Project will be subject to standard requirements for the prevention of the introduction of exotic pests including the exchange of ballast water in the open ocean before arrival at the Port of Rabaul, such that the potential to introduce marine pests in the event of an emergency, e.g., a collision where ship safety would take priority over avoiding the release of ballast water, would be minimised.
- Procedures for the management of hydrocarbons, e.g., fuel, especially refuelling and the transfer of fuel from one vessel to another as described in Sections 5.8 and 11.4.2.
- Storage of ore in covered cargo holds on bulk carriers and in covered stockpiles surrounded by a deck side wall on barges, minimising risks of material and metalliferous runoff being released in the environment in case of adverse event.

11.6.3 Residual Impacts

The implementation of the above measures are expected to minimise the potential for collision especially with third party vessels since fishing activity in the Project area is low and other marine traffic through the area is limited.

It is not expected that marine pests would be introduced to the environment, should a collision occur resulting in the release of ballast water, as the:

- Open, deep water ocean environment lacks suitable habitat for fouling species.
- Likelihood for the introduction of fouling species is lower in open ocean environment than coastal waters.

Shuttle barges shall only carry ballast water originating from PNG coastal and deep waters, eliminating the risk of introducing exotic marine pest.

Potential impacts associated with the release of hydrocarbons are discussed in Section 11.4.3.

It is not expected that spillage of ore resulting from a collision will impact water quality or marine fauna as:

- The ore will become saturated in the ocean and therefore any oxidation processes will cease, stopping the formation of acid.

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- Dispersion of any metalliferous runoff, formed from the oxidation and wetting of the ore prior to the collision, will be diluted.

12. GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

12.1 Introduction

Papua New Guinea is a signatory to the Kyoto Protocol United Nations Framework Convention on Climate Change (Kyoto Protocol), which has as its objective the reduction of negative changes to the Earth's climate, with a particular focus of greenhouse gases (GHGs).

GHG emissions from the Phase 1 project consist almost entirely of fuel combustion CO₂ emissions. As there is no ore processing in this phase of the Project, total GHG emissions are relatively low compared to other PNG mining projects and therefore the contribution to PNG GHG emissions in the context of potential climate change impacts is minor.

12.2 Estimated GHG Emissions

Fuel use estimates and resulting GHG emission estimates from Phase 1 of the Project are shown in Table 12.1.

Table 12.1 Predicted emissions of greenhouse gases (CO₂-equivalent)

Activity	Diesel Use (t/a)	CO ₂ -equivalent Emissions (Mt/a)
Seafloor Mining Tool and Mining Support Vessel	14,600	
Barging	3,830	
Crewboat	1,825	
Rabaul (ore handling)	99	
Total	20,354	0.062

12.3 GHG Emissions Assessment

Total annual GHG emissions from Phase 1 Project activities are estimated to be 0.062 Mt/a CO₂-equivalent. This compares to total PNG GHG (CO₂) emissions for 2005 (latest available data) of 4.35 Mt/a CO₂-equivalent emissions from fuel combustion (including flaring from the gas fields in the Southern Highlands).

Therefore, within the context of PNGs small industrial sector, the Project is expected to increase annual GHG emissions from fuel combustion in PNG by 1.43%.

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13. ENVIRONMENTAL MANAGEMENT, MONITORING AND REPORTING

13.1 Introduction

The preparation of environmental management plans (EMPs) is expected to be a condition of approval of the EIS. The EMPs, which will demonstrate how Nautilus' environment policy (Section 13.3) will be implemented, will compile the commitments and conditions applied to the Project during the EIS approvals process and propose the programs for their implementation. The EMPs have three specific objectives to:

- Document the more general aspects of Nautilus' approach to environmental management, such as the environmental management system, schedule for environmental management and organisational structure and responsibilities.
- Describe how the Project's waste management and associated environmental issues will be addressed. Nautilus' management measures will be based on a hierarchical approach determined by technical feasibility, cost and benefit, and involving firstly, pre-emption and secondly, mitigation or containment of the impact.
- Detail the program that will monitor and report on the Project's effects and its compliance with regulatory permits and licences. In particular, this program will:
 - Validate and monitor impact predictions as described in Chapters 9 and 10.
 - Identify unforeseen effects and the need for additional management, mitigation or remedial measures.

This chapter describes the environmental management framework that will be implemented by Nautilus to achieve the above objectives.

13.2 Organisational Structure and Responsibilities

The Solwara 1 Project will be managed by Nautilus and the management structure is shown in Figure 13.1. Specific responsibilities and accountabilities for the key personnel who will oversee environmental management of the Project will be assigned to Nautilus personnel and contractors and documented in the EMPs.

The Nautilus Project/Operations Manager will be responsible for ensuring that activities associated with the Project are undertaken in full compliance with all statutory regulations and are consistent with the Nautilus environmental policy. Nautilus will ensure that the environmental approval conditions are accessible to senior management and other personnel on request at all times. All personnel are responsible for ensuring that their work complies with these conditions and the EMPs.

Individual accountability will continue to be defined through conditions of contracts of employment. Further, environmental and social responsibilities will be written into the service agreements for contractors.

13.3 Environmental Management System

The Solwara 1 Project will be managed under the governance of an environmental management system (EMS) that will be developed in accordance with the international EMS standard, ISO 14001:2004, adapted for use in Australia and New Zealand as AS/NZS ISO 14001:2004. These standards provide Nautilus with the elements of an effective EMS, that is, a procedure for implementing, achieving, reviewing and maintaining the company's environment policy (Box 13.1). Good industry environmental management practice, which forms the basis of a Project-specific EMS, is also incorporated.

Box 13.1 Environment Policy

Environment Policy

Nautilus Minerals as a responsible corporate citizen, has the obligation to minimise the impact of its operations on the environment. Nautilus is committed to comply with and where appropriate, surpass environmental statutes and regulations. In addition, Nautilus is dedicated to improving its environmental performance at every operational site. Nautilus will also work with government and civic agencies, the local population, environmental groups and the scientific community to enable continual enhancement of its environmental performance.

To achieve its Environmental Policy objectives, Nautilus Minerals will:

- As a minimum, comply with all local and/or applicable environmental laws and regulations. In jurisdictions where regulation is absent or inadequate, Nautilus will apply appropriate management practices to minimise environmental impacts and risks.
- Maintain environmental care as a core company value and the integration of environmental policies, programs, and practices will be a vital part of management.
- Develop project environment management plans and, once developed, ensure that its directors, officers, managers, and employees understand and adhere to these plans.
- Conduct periodic reviews of its operations to monitor environmental performance and to guide its environmental management plan, with the vision to continually improve its environmental performance.
- Support research aimed at expanding scientific knowledge and/or developing improved technologies to protect the environment and/or achieving optimal solutions to environmental issues.
- Recognise local communities as stakeholders and engage with them in discussions regarding environmental management issues.
- Promote environmental awareness among its employees and the communities within which it operates.

13.4 Environmental Management Plan

The EMPs for the Solwara 1 Project will be prepared and implemented within the EMS framework. The Project's EMPs will address the management, monitoring and reporting requirements for the various phases of the Project, e.g., baseline, operations and

decommissioning. These plans will take into account the commitments made in this EIS and the conditions of approval stipulated by the State.

The purpose of the plans will be to ensure that the required environmental commitments to control discharges and losses to the environment are applied to engineering and operational practices involved in offshore mining, ore transfer and operations at the Port of Rabaul, and to manage aqueous and airborne emissions to specified standards.

Plans will also be required, where practicable, for the application of policies for the employment, training and accommodation of the workforce that will maximise benefits to the community and minimise disruption to normal community life from outside workers. These will meet the regulatory requirements anticipated to arise from the following management and mitigation measures proposed by Nautilus.

13.4.1 Mitigation and Management

Proposed management and mitigation measures that will be adopted by Nautilus to avoid adverse environmental and socioeconomic impact during the implementation of the Project include, the following:

- The application of sound engineering design, deployment and operational practices for the Seafloor Mining Tool so as to minimise disturbance to the seafloor and the suspension of sediments.
- The adoption of a dewatering management strategy that will involve discharge at depths from which the material originated (i.e., close to the seafloor), thereby avoiding impacts to the water column.
- The retention of a set-aside (unmined) area at South Su and temporary reserve areas in Solwara 1 as necessary to aid in the recolonisation of the mined areas and conservation of biodiversity. Transplanting of animals to unmined and mined-out areas will also be considered as will placement of artificial substrates to enhance recolonisation.
- The adoption of lighting and noise strategies that will address surface and subsea operational and safety requirements and minimise the potential for the attraction of, and interaction with, marine animals.
- The adoption of a waste management strategy that will address the management of sewage, chemical and hazardous materials to minimise the potential for contamination of the water column.
- The adoption of appropriate water management strategies at the Port of Rabaul that will involve the containment and, possibly, treatment of surface runoff to ANZECC/ARMCANZ (2000) standards (to avoid any impacts of acid drainage) prior to any discharge to minimise impacts to receiving water quality, e.g., shallow Simpson Harbour waters.
- Where practicable, the application of policies for the employment and training of the workforce that will maximise benefits to the local communities and minimise adverse social effects.
- The development of emergency response plans to mitigate the effects of natural disasters and unplanned events.

Further details of Nautilus' environmental management program will be described in the detailed EMPs to be submitted to the government after approval of the EIS.

13.4.2 Monitoring

Approach

The validity of the predicted effects of the Project, as set out in Chapters 9 and 10, depends upon the following conditions:

- The Project is constructed and operated in the manner described in this EIS in all environmentally relevant respects.
- The understanding of the relevant environmental dynamics (and hence the derived predictions of the impacts) presented in this EIS has, as far as possible, been correct.

With regard to the first condition, Nautilus will notify the provincial and national governments should significant changes be made to the Project subsequent to the issue of this EIS. The second condition is met by the monitoring program, which is designed to allow periodic reassessment of the Project's effects and a review of management and mitigating measures and safeguards.

The monitoring program will involve the following sequential steps:

- Compilation of an environmental baseline with a range of pertinent variables describing background conditions. To a large extent, this has already been completed (see the appendices supporting this EIS). The baseline was supplemented by the August 2008 Norsky 08 Campaign and will be extended to address information gaps, prior to operations.
- An intensive short-term validation study in order to verify the adopted mixing zones for discharges from the Project.
- Operations monitoring to ensure regulatory compliance and to identify material unforeseen effects.

Program

Details of Nautilus's proposed monitoring program, including descriptions of the components to be monitored, frequency of monitoring and purpose, will be included in the detailed EMPs to be submitted to the government after approval of the EIS, and will take into account any relevant conditions of approval. These will typically include the environmental aspects relevant to each offshore and onshore activity, to confirm impact predictions and to demonstrate compliance with regulatory permits and licences.

At the Port of Rabaul, a focus will be on the management of potential acid runoff from ore stockpiles and, in the offshore location of the Mining Support Vessel, supply vessels and barges, an important aspect will be management of possible interactions with large marine animals such as whales and turtles. However, the nature of the Project involves none of the land disturbance, sedimentation and air quality issues normally associated with a new mine development and which comprise a large part of a monitoring program.

Instead, Project impacts are predominantly to the seafloor at Solwara 1, in hydrothermally active areas where impacts from disturbances have not previously occurred, but for which a number of mitigation plans and expected residual impacts have been developed in detail as part of this EIS.

Scientific findings from the Wave Mercury 07 Campaign formed the basis for the monitoring program, which was developed during the scientific workshop that was held in San Diego in April 2008 (Section 4.4.3). Details are provided in Table 13.1. These details have been structured around expected impacts and are presented as testable hypotheses (and in part completed during the 2008 Norsky 08 Campaign) for the baseline studies (which are required to be undertaken prior to mining). The validation monitoring is also listed in Table 13.1.

13.4.3 Reporting

Monitoring

The Solwara 1 Project will provide the State with the compliance reports as stipulated in environment, water abstraction and waste discharge permits.

Regulatory authority and internal assessments of EMP implementation will occur, with the schedule for such assessments and reporting (including monitoring) to be determined in consultation with DEC.

Much of the proposed monitoring of the deep seafloor is anticipated to extend into more general scientific research, for which Nautilus will encourage publication through the normal scientific peer review process.

Incidents

Incidents that occur as a result of an emergency, accident or malfunction or that cause or threaten serious adverse environmental impacts or are likely to adversely impinge on relations with local communities will be immediately reported to Project senior management in addition to the relevant PNG regulatory authorities. Other lesser incidents will be reported within an agreed timeframe to the relevant PNG authorities.

Table 13.1 Summary of proposed seafloor monitoring program

Environmental Issue	Impact Hypotheses	Proposed Baseline (=baseline studies)	Proposed Monitoring and Mitigation (=validation/monitoring)
Venting dynamics	<p>H01. New vents and chimneys will form in the active areas after mining and there will be fluctuations in the venting dynamics of the mined and adjacent unmined vents.</p>	<ul style="list-style-type: none"> • Prepare a baseline temperature map of the areas to be mined (using thermal lances and thermistors). • Resurvey vents previously photographed during exploration and research cruises using an autonomous underwater vehicle (AUV). • Place time-lapse cameras on the seafloor to observe selected vents. • Complete fluid chemistry baseline data. • Complete baseline water quality at low-temperature (near vent) areas. 	<ul style="list-style-type: none"> • Repeat temperature mapping of mine area at appropriate intervals, at least annually. • Video and map active chimneys in areas after Seafloor Mining Tool (SMT) (i.e., mining) activity. • Obtain long-term temperature monitoring in selected vents using thermistors. • Observe vent activity within temporary refuge areas at Solwara 1 and at South Su. • Complete a centre-line transect imaging survey at Solwara 1 and South Su after three to six months, and thereafter six-monthly or at an appropriate frequency to be determined. • Photo mosaic/video pass (frequency as above). • Resample chemistry of fluid flow at an appropriate frequency (as above).
Animal recolonisation	<p>H02. Within two years after cessation of mining an area, animal communities will recolonise and return towards baseline abundance/diversity structure (following a predicted sequence specific to the active/inactive vents).</p>	<ul style="list-style-type: none"> • Establish permanent observation transects at Solwara 1 and South Su for baseline (and ongoing) visual census monitoring of abundance and diversity at active/inactive hard and soft seafloor areas. • Establish a trial clearing patch and install a time-lapse camera to observe recolonisation. • Place artificial settlement surfaces for observation of recolonisation. 	<ul style="list-style-type: none"> • Continue video transect observations at Solwara 1 temporary refuge areas and at South Su transect sites at approximately six-monthly intervals. • Visual analysis of species, density and abundance from video transects. • Select observation areas (active and inactive) in locales where mining is completed. Video or time-lapse observations of succession (microbial mats to macrofauna) and species, density and abundance. • Observe life cycles of snails (abundance and size frequencies).

Table 13.1 Summary of proposed seafloor monitoring program (cont'd)

Environmental Issue	Impact Hypotheses	Proposed Baseline (=baseline studies)	Proposed Monitoring and Mitigation (=validation/monitoring)
Animal recolonisation (cont'd)		<ul style="list-style-type: none"> Supplementary sampling at Solwara 1 and South Su (not at observation areas) to extend species/effort curves for inactive hard and soft sediments. Sample heterogeneous sediments as far as practicable. Analyse/compare proportions of rare species; improve taxonomic resolution. Examine growth rates by staining of bamboo corals (<i>Keratoisis</i>). 	<ul style="list-style-type: none"> Resample stained bamboo corals to assess growth annually. Set up sediment recolonisation trays at mined areas and resample annually. Record numbers, sizes and species of fish observed in video transects. Continue transect monitoring for three years after mining or for a period (earlier or later) determined by results in consultation with DEC and scientists.
The genetic structure of the population	<p>H03. The genetic structure of the populations in the area will not be altered.</p>	<ul style="list-style-type: none"> Obtain six strategic species (biomass-dominant and associated) from Solwara 1, South Su and Solwara 8 (45 km west-northwest of Solwara 1) (using scoop and traps for shrimps). Analyse genetic alliance (DNA flow) between upstream (South Su) and downstream (Solwara 8) cohorts. Obtain juvenile samples using artificial substrates. Establish the genetic structure of species in the area. 	<ul style="list-style-type: none"> Use settlement collectors to obtain settling animals. Collect and analyse DNA of the same species colonising mined areas at Solwara 1 (annually to include the six baseline species). Include other recolonising species that may be abundant or easy to catch.
Enhancement of recolonisation by transplantation	<p>H04. If animals are transplanted, they will establish a community.</p>	<ul style="list-style-type: none"> Conduct opportunistic transplant observations if practicable. 	<ul style="list-style-type: none"> Using ROV and scoops (opportunistically and/or during routine monitoring), transport samples of densest clumps of snails in path of mining and relocate to adjacent areas (initially). Pick up everything with the snails e.g., mussels as practicable. Transplant to areas away from mining or reformed venting areas where mining is complete. Select areas with temperature alignment if practicable.

Table 13.1 Summary of proposed seafloor monitoring program (cont'd)

Environmental Issue	Impact Hypotheses	Proposed Baseline (=baseline studies)	Proposed Monitoring and Mitigation (=validation/monitoring)
<p>Enhancement of recolonisation by transplantation (cont'd)</p>			<ul style="list-style-type: none"> • Where dense patches of <i>Keratosis</i> occur in areas to be mined, place fragments into chambers of weighted crates (or similar) for relocation away from the mining path (opportunistically or during routine monitoring). • Video areas of translocated animals (snails, <i>Keratosis</i>, etc.,) to determine ongoing survival (including the use of time lapse cameras) opportunistically or during routine monitoring. • Continue photographic monitoring for three years after mining or for a period (earlier or later) determined by results in consultation with DEC and scientists.
<p>Alterations in plume formation by resuspension of sediment</p>	<p>H05. Sediment resuspension and plume formation (from mining activities, sediment removal, competent waste material side casting and from dewatering) will not affect communities (suspension and filter feeders) outside a defined modelled (mixing zone) boundary.</p>	<ul style="list-style-type: none"> • Establish sampling sites at sediment habitats (representative of array of heterogeneous types) at periphery of Solwara 1 where deposition is expected (from modelling (combine with hypothesis H02 sampling as practicable). • Video transects and take scoop/core samples of meiofauna at the established sampling sites. • Estimate density and ratios of suspension/filter feeders. 	<ul style="list-style-type: none"> • Video observation of plumes generated by SMT activities (including mining, sediment removal and competent waste material side casting) during operation. • CTD observation of plumes from return-water discharge. • Establish sedimentation traps at the selected/control sites to monitor natural/mine-induced settlement. • Bottom current measurements. • Particle size analysis annually. • Repeat video and sampling of suspension/filter feeders, and meiofauna at the same sites (annually).
<p>Temporary sediment deposition, mixing and disruption</p>	<p>H06. Sediment deposition, mixing and disruption will temporarily alter community structure.</p>	<ul style="list-style-type: none"> • X-ray analysis of layering, burrowing etc., in sediment cores in expected areas of deposition and in path of the SMT (use of appropriate coring equipment). • Determine grain sizes at selected mining area sites, e.g., at those selected under hypothesis H02 for supplementary sampling. 	<ul style="list-style-type: none"> • Repeat X-ray analysis of sediment cores (annually to end of mine life). • Video redeposition of sediments on mine areas and changes to topography of mined areas. • Core samples for grain size analysis (annually).

Table 13.1 Summary of proposed seafloor monitoring program (cont'd)

Environmental Issue	Impact Hypotheses	Proposed Baseline (=baseline studies)	Proposed Monitoring and Mitigation (=validation/monitoring)
Effects on abundance and recruitment downstream of Solwara 1	H07. Decreased recruitment and lower abundance will result downstream of Solwara 1 during mining from reduction in recruitment potential.	<ul style="list-style-type: none"> Set transect sites and obtain video of existing conditions at Solwara 8 (downstream site). Include samples from Solwara 8 in gene flow study (hypothesis H03). 	<ul style="list-style-type: none"> Repeat video observations of communities at Solwara 8 after mining is complete at Solwara 1 and before any (as yet unplanned) but potential mining at Solwara 8. Sample colonising animals at Solwara 8 for DNA analyses.
Recovery of the trophic structure	H08. The trophic structure will return to the pre-existing basis within two to three years.	<ul style="list-style-type: none"> Undertake stable isotope (C, N, S) analyses of selected species at Solwara 1 and South Su. Include invertebrate predator species. 	<ul style="list-style-type: none"> Repeat stable isotope sampling from recolonising animals at Solwara 1 and South Su (active inactive) (after one and two years). Analyse same array of species in mined area to determine potential changes to base of food source.
Water removal affecting larval recruitment	H09. The rate of water removal (i.e., being sucked into the SMT during mining) will not reduce larval recruitment.	<ul style="list-style-type: none"> Desktop comparisons (risk assessment of pumping rates and natural current flow, and proportions of larvae potentially affected). Review of relevant literature on distribution/timing of larvae. 	<ul style="list-style-type: none"> See monitoring for hypothesis H02. No specific task.
Light, noise and vibration that SMT creates will attract animals	H10. Animals will be attracted to the SMT by the light, noise and vibration that it creates.	<ul style="list-style-type: none"> Record any marine mammals/other large animals in vicinity of MSV and if observed from ROV. 	<ul style="list-style-type: none"> Video monitoring of SMT attracting or repelling organisms (routine operational). Hydrophone monitoring of sound characteristics of MSV, Riser and Lift System and SMT operations. Record any observations of marine mammals in the vicinity of operations during life of mine.

Table 13.1 Summary of proposed seafloor monitoring program (cont'd)

Environmental Issue	Impact Hypotheses	Proposed Baseline (=baseline studies)	Proposed Monitoring and Mitigation (=validation/monitoring)
Concentration of contaminants in the return water discharge	H11. Any concentrations of contaminants in return water discharge will meet dilution characteristics within the modelled mixing zone boundaries. (Dilution chosen as measure as ambient water quality may be close to environmental guidelines.)	<ul style="list-style-type: none"> Select sampling sites and take samples downstream of dewatering exit and mixing zone boundary (based on modelling results). Supplement baseline sedimentation rates and water quality at these sites (see low temperature water quality task for hypothesis H01). 	<ul style="list-style-type: none"> Confirm dilution characteristics at distances from dewatering discharge point using fluorescent tracer and fluorimeter. Sampling of water quality (including CTD profiles) at sites to detect plumes and validate mixing zone boundary. Compliance monitoring (at start-up and three to six monthly).
Changes to flow regime and stable habitats through topography changes	H12. Topographic changes will change current flow regime and habitats.	NA	<ul style="list-style-type: none"> Deploy a current meter (ADCP) for continuous recording at a fixed site for ocean currents and plume predictions.

Definitions:

Baseline Studies occur prior to construction and operation. These studies characterise conditions prior to any Project activities and form a baseline against which conditions during construction, operations and post-closure can be measured. The Norsky 08 Campaign may be the only opportunity for baseline work, therefore, priorities of the proposed baseline studies will need to be set.

Validation Studies generally occur as soon as possible after normal operating conditions are achieved. These studies are usually short term and are used to compare predicted Project impacts during operations with actual conditions.

Monitoring Studies are conducted during the course of operations and can continue post-closure. These studies are designed to provide regular updates on environmental conditions and are used to manage and minimise Project impacts.

14. STUDY TEAM

Coffey was commissioned by Nautilus to assist in the preparation of this Environmental Impact Statement (EIS). Coffey engaged a number of specialist subconsultants and the EIS draws on their work. These contributions are gratefully acknowledged.

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15. REFERENCES

- Alt, J.C., and Bach, W. 2003. Alteration of oceanic crust: Subsurface rock-water interactions. In *Energy and Mass Transfer in Marine Hydrothermal Systems*. Edited by P.E. Halbach, V. Tunncliffe, and J.R. Hein. Dahlem University Press, Berlin. 7-28.
- ANZECC/ARMCANZ. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Canberra, Australia: Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand.
- APPEA. 2005. A compilation of recent research into the marine environment. Report prepared by the Australian Petroleum Production and Exploration Association.
- AS. 1997, AS 1055 Acoustics: Description and Measurement of Environmental Noise, Sydney.
- AS. 2000. Australian Standards AS 2508.10.001: Safe storage and handling information card - Agricultural and veterinary chemicals. Prepared by Standards Australia.
- AS. 2001. Australian Standard AS 2508.2.007: Safe Storage and Handling Information Cards - Liquefied petroleum gas. Prepared by Standards Australia.
- AS/NZS. 1993. Australian Standard AS 2243.10:1993 – Safety in laboratories Part 10: Storage of chemicals. Prepared by Standards Australia/Standards New Zealand.
- AS/NZS. 2001. Australian Standard AS 4804:2001 Occupational Health and safety management systems - General guidelines on principles, systems and supporting techniques. Prepared by Standards Australia/Standards New Zealand.
- Binns, R.A. 2004. Eastern Manus Basin, Papua New Guinea: Guides for volcanogenic massive sulphide exploration from a modern seafloor analogue. In *Copper-zinc massive sulphide deposits in Western Australia*. Edited by T.F. McConachy, and B.I.A. McInnes. CSIRO Exploration and Mining, Australia.
- Binns, R.A., and Scott, S.D. 1993. Actively forming polymetallic sulfide deposits associated with felsic volcanic rocks in the Eastern Manus Basin, Papua New Guinea. *Economic Geology* 88:2226-2236.
- BirdLife International. 2008. Species factsheet: *Puffinus heinrothi*. A WWW publication accessed on 3 June 2008 at <http://www.birdlife.org/datazone/species/index.html?action=SpcHTMDetails.asp&sid=3947&mode=0>.
- Birney, K., Griffin, A., Gwiazda, J., Kefauver, J., Nagai, T., and Varchol, D. 2006. Potential deep-sea mining of seafloor massive sulfides: A case study in Papua New Guinea. Donald Bren School of Environmental Science and Management Thesis. 117 pages.
- Blake, E.A., Erickson, K.L., and Van Dover, C.L. 2005. A review of the biology of chemosynthetic ecosystems in Manus Basin. Report prepared for Placer Dome Oceania Ltd.
- Cellula Robotics. 2006. PDTS sea floor mining project: Mining system design concept. Report prepared by Cellula Robotics Ltd for Nautilus Minerals Inc., Milton, Queensland.
- CIA. 2008. The World Factbook. Papua New Guinea. A www publication accessed on 3 May 2008 at <http://www.cia.gov/library/publications/the-world-factbook/geos/pp.html>.
- City Population. 2008. Papua New Guinea. A WWW publication accessed on 8 May 2008 at <http://www.citypopulation.de/PapuaNewGuinea.html>.

- Clarke, K.R., and Warwick, R. M. 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd ed. PRMER-E. Plymouth.
- Clough. 2008. Solwara 1 FEED Study, Provision of Mining Services, Tender No. SOL01/002. April. Report prepared by Clough Oil and Gas International Ltd for Nautilus Minerals Niugini Ltd.
- Coull, B. 1988. Ecology of marine meiofauna. In *Introduction to the study of meiofauna*. Edited by R. P. Higgins and H. Thiel. Smithsonian Institution Press, Washington D.C.
- Cresswell, G. 2007. Solwara Project: Regional Oceanographic Characterisation - Progress Report. Report prepared by George Cresswell and Associates for Nautilus Minerals Niugini Limited.
- Crone, T.J., Wilcock, W.S.D., Barclay, A.H., and Parsons, J.D. 2006. The sound generated by mid-ocean ridge black smoker hydrothermal vents. PLoS ONE 1(1): e133.
doi:10.1371/journal.pone.0000133
- CSA. 2005. National Instrument 43-101 – Standards of Disclosure for Mineral Projects. December. Canadian Securities Administrators.
- CSIRO. 1994. Research on Jarosite Dumping at Sea. A program of research on jarosite dumping by Pasminco Metals-EZ: physical dispersal of jarosite and surveys of marine biota heavy metal levels 1991/1994 (5 volumes) CSIRO Australia.
- CSIRO. 2005. Baseline Environmental Study, Eastern Manus Basin, Papua New Guinea. Proposal prepared by McConachy, T.F. for CSIRO Exploration and Mining, North Ryde, New South Wales.
- CSIRO. 2007. Baseline environmental study, Eastern Manus Basin, Papua New Guinea: Module 3. Report prepared by Johns, S.M., Yeats, C.J., Hough, R.M., Binns, R.A., and Rouse, G.W. CSIRO Exploration and Mining, North Ryde, New South Wales.
- DEC. 2004. Guideline for conduct of Environmental Impact Assessment and Preparation of Environmental Impact Statement. Information Guideline No. GL-Env/02/2004. Department of Environment and Conservation, Waigani, PNG.
- Desbruyères, D., Segonzac, M., and Bright, M. 2006. *Handbook of the deep sea hydrothermal vent fauna*. Linz, Austria: Denisia, Volume 18; Land Oberosterreich, Biologiezentrum der Oberosterreichische Landesmuseen.
- Devaux, M., and Clarke, D. 2006. Nautilus Minerals Inc. - Solwara 1 Project Subsea Cutting Report. Report prepared for Nautilus Minerals Inc., Milton, Queensland.
- DEWHA. 2008. EPBC Act Referral: Woodside Energy Ltd/Exploration (mineral, oil and gas - marine)/Permits WA-28-L WA-255-P WA-155-P1 WA-32-L WA-271/WA/Enfield M3 4D, Vincent 4D & 4D Line Test Marine Seismic Surveys. A WWW publication accessed on 21 Spetember 2008 at http://www.environment.gov.au/cgi-bin/epbc/epbc_ap.pl?name=current_referral_detail&proposal_id=4122. Australian Government.
- DEWR. 2007. EPBC Act Policy Statement 2.1 – Interaction between offshore seismic exploration and whales. May. Australian Government Department of the Environment and Water Resources.
- DNV. 2005. DNV Managing Risk Webshop. A WWW publication accessed on 15 May 2008 at <http://webshop.dnv.com/global/>. Det Norske Veritas, Norway.
- Earth Mechanics Institute. 2004. Linear cutting test results for mechanical mining of sub-sea poly-metallic sulfides. Report prepared for Cellula Robotics, Vancouver, BC.

- Enesar. 2006a. Solwara Project: Water Quality Monitoring Report. Report prepared by Enesar Consulting Pty Ltd for Nautilus Minerals Inc., Milton, Queensland.
- Enesar. 2006b. Project Salty Daug: Preliminary Oceanographic Data Summary. Report prepared by Enesar Consulting Pty Ltd for Placer Dome Oceania.
- Enesar. 2007. Environmental Inception Report. May. Report prepared by Enesar Consulting Pty Ltd for Nautilus Minerals Niugini.
- EPFI. 2006. The Equator Principles A financial industry benchmark for determining, assessing and managing social and environmental risk in project financing. July. Prepared by Equator Principles Financial Institutions.
- EPHC/NEPC. 1998. Ambient Air Quality National Environmental Protection Measure. Measure prepared by the Environment Protection and Heritage Council Secretariat National Environment Protection Council Service Corporation.
- ESM. 2008. Kavieng (New Ireland, Papua New Guinea). From Embedded Semantics Wiki. A www publication accessed on 8 May 2008 at [http://liverpool.informatik.uni-freiburg.de/index.php/Kavieng_\(New_Ireland,_Papua_New_Guinea\)](http://liverpool.informatik.uni-freiburg.de/index.php/Kavieng_(New_Ireland,_Papua_New_Guinea)).
- Galkin, S.V. 1997. Megafauna associated with hydrothermal vents in the Manus Back-Arc Basin (Bismarck Sea). *Marine Geology* 142:197-206.
- Geological Survey PNG. undated. Active volcanoes of Papua New Guinea. A WWW publication accessed on 6 March 2008 at <http://www.mineral.gov.pg/volcObs/activeVolc.htm>. Geological Papua New Guinea. Department of Mining.
- Geoscience Australia. 2008. Major Historic Volcanic Eruptions. A WWW publication accessed on 6 March 2008 at <http://www.ga.gov.au/hazards/volcano/historic.jsp>. Australian Government.
- Giardini, D., Grünthal, G., Shedlock, K., and Zhang, P. Undated. The GSHAP Global Seismic Hazard Map. A www publication accessed on 23 September 2008 at <http://www.seismo.ethz.ch/GSHAP/>.
- Golder Associates. 2008. Mineral resource estimate: Solwara 1 Project, Bismarck Sea, Papua New Guinea. Report prepared by Lipton, I. for Nautilus Minerals Niugini Limited.
- Golder Associates & Nautilus Minerals. 2008. Solwara 1 SMS deposit geotechnical review, Manus basin, Papua New Guinea. April.
- Greenbaum, D., Tutton, M., Bowker, M. R., Browne, T. J., Buleka, J., Grealley, K. B., Kuna, G., McDonald, A. J. W., Marsh, S. H., O'Conner, E. A. and Tragheim, D. G. 1995. Rapid methods of landslide hazard mapping: Papua New Guinea case study. Technical report WC/95/27. Overseas Geology Series. British Geological Survey. Geological Survey of Papua New Guinea.
- Greene, G., Tiffin, D. and McKee, C. 1985. Structure and Sedimentation in an active caldera, Rabaul, Papua New Guinea. A WWW publication accessed on 23 May 2008 at <http://www.sopac.org/data/virlib/TR/TR0039.pdf>.
- Groom, R.A., Lawler, I.R., and Marsh, H. Undated. The risk to dugongs of vessel strike in the southern bay islands of Moreton Bay. School of Tropical Environment Studies and Geography, James Cook University, Townsville.
- Halbach, P.E., Fouquet, Y., and Herzig, P. 2003. 'Mineralization and compositional patterns in deep-sea hydrothermal systems'. In *Energy and Mass Transfer in Marine Hydrothermal Systems*. Edited by P.E. Halbach, V. Tunnicliffe, and J.R. Hein. Dahlem University Press, Berlin. 85-122.

- Hashimoto, J., Ohta, S., Fiala-Medione, A., Auzende, J., Kojima, S., Segonzac, M., Fujiwara, Y., Hunt, J.C., Gena, K., Miura, T., Kikuchi, T., Yamaguchi, T., Toda, T., Chiba, H., Tsuchida, S., Ishibashi, J., Henry, K., Zbinden, M., Pruski, A., Inoue, A., Kobayashi, H., Birrien, J-L., Naka, J., Yamanaka, T., Laporte, C., Nishimura, K., Yeats, C., Malagun, S., Kia, P., Oyaizu, M., and Katayama, T. 1999. Hydrothermal vent communities in the Manus Basin, Papua New Guinea: Results of the BIOACCESS cruises '96 and '98. *InterRidge News* 8(2):12-18.
- Henry, M. S., Childress, J. J., and Figuera, D. 2008. Metabolic rates and thermal tolerances of chemoautotrophic symbioses from Lau Basin hydrothermal vents and their implications for species distributions. *Deep-Sea Research* 1 55:679-695.
- Hodkiewicz, P., Clark, D. and Williams, P. 2005. Independent technical assessment of exploration tenements in the Bismarck Sea and the Solomon Sea, Papua New Guinea. Report prepared by SRK Consulting for Nautilus Minerals Inc., Milton, Queensland.
- Hrischeva, E., Scott, S.D., and Weston, R. 2007. Metalliferous sediments associated with presently forming volcanogenic massive sulfides: The SuSu Knolls hydrothermal field, Eastern Mauns Basin, Papua New Guinea. *Economic Geology* 102:55-73.
- IFC. 2006a. IFC's policy and performance standards on social and environment sustainability. Report prepared by the International Finance Corporation, Washington.
- IFC. 2006b. IFC's Guidance Notes: performance standards on social and environment sustainability. Report prepared by the International Finance Corporation, Washington.
- IFC. 2007a. Environmental, health and safety general guidelines. Report prepared by the International Finance Corporation, Washington.
- IFC. 2007b. Environmental, health and safety guidelines for mining. Draft report prepared by the International Finance Corporation, Washington.
- IFC. 2007c. Environmental, health and safety guidelines for offshore oil and gas development. Report prepared by the International Finance Corporation, Washington.
- IFC. 2007d. Environmental, health and safety guidelines for shipping. Report prepared by the International Finance Corporation, Washington.
- IMO. 1973/1978. International Convention for the Prevention of Pollution From Ships. A WWW publication accessed on 22 May 2008 at http://www.amsa.gov.au/Marine_Environment_Protection/Revision_of_Annexes_I_and_II_of_MARPOL_73-78/index.asp.
- IMO. 1997. Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens. December. Prepared by the International Maritime Organisation.
- IMO. 2001. International Convention on the Control of Harmful Anti-fouling Systems on Ships. October. Prepared by the International Maritime Organisation.
- IMO. 2004. International Convention for the Control and Management of Ships' Ballast Water and Sediments. A WWW publication accessed on 22 May 2008 at http://194.196.162.45/Conventions/mainframe.asp?topic_id=867.
- Independent State of Papua New Guinea. 1984. Regulation. Public Health (Drinking Water), Schedule 1 (Raw Water) and Schedule 2 (Drinking Water).
- Independent State of Papua New Guinea. 2002. Environment (Water Quality Guidelines) Regulation, Schedule 1.
- IUCN 2008a. The IUCN redlist. A WWW publication accessed on the 27 March 2008 at <http://www.iucnredlist.org/search/search.php?freetext=marine+turtles&modifier=phrase&criteri>

- a=wholedb&taxa_species=1&redlistCategory%5B%5D=all&country%5B%5D=all&cty_default=1&aquatic%5B%5D=all&aqu_default=1®ions%5B%5D=all®_default=1&habitats%5B%5D=all&threats%5B%5D=all&redlistAssessyear%5B%5D=all&growths%5B%5D=all.
- IUCN 2008b. New assessment for *Lepidochelys olivacea*. A report prepared for the update of the IUCN Redlist of threatened species. A WWW publication accessed at http://intranet.iucn.org/webfiles/doc%5CSSC%5CRedList%5CLepidochelys_olivacea_2008_assessment.pdf
- IUCN. 2007. IUCN Red List of Threatened Species. A WWW publication accessed on 4 June 2008 at www.iucnredlist.org.
- Jackson, E. 2006. Nautilus Minerals Inc. - Solwara 1 Project Rock-Cutting Test Program Report. Report prepared for Nautilus Minerals Inc., Milton, Queensland.
- James, M.C., and Mrosovsky, N. 2004. Body temperatures of leatherback turtles (*Dermochelys coriacea*) in temperate waters off Nova Scotia, Canada. *Canadian Journal of Zoology* 82:1302–1306.
- Jankowski, P., and Hodkiewicz, P. 2006. Independent technical assessment of seafloor massive sulphide exploration tenements in Papua New Guinea and Fiji. Report prepared for Nautilus Minerals Inc., Milton, Queensland.
- Johnson, G. 2001. Voyage of the Odyssey – Papua New Guinea logs. A WWW publication accessed on the 21 November 2007 at http://www.pbs.org/odyssey/20010402_log_transcript.html.
- Johnson, K. S., Childress, J. J., Beehler, C. L., and Sakamoto, C. M. 1994. Biogeochemistry of hydrothermal vent mussel communities: The deepsea analogue to the intertidal zone. *Deep-Sea Research* 1 41:993-1011.
- Kashefi, K., and Lovley, D. R. 2003. Extending the Upper Temperature Limit for Life. *Science* 301:394.
- Klohn Crippen Berger. 2006. Processing Plant Site Evaluation. Report prepared fby Klohn Crippen Berger Ltd or Nautilus Minerals Niugini Limited.
- Kumoru L. and Koren. L. 2006. Tuna Fisheries Report. Papua New Guinea National Fisheries Authority, Port Moresby, PNG July 2006.
- Kumoru, L. 2003. The Shark Longline Fishery in Papua New Guinea. Report prepared for the Billfish and By-catch Research Group, Mooloolaba, Queensland.
- Kumoru, L., and Koren, L. 2007. Tuna fisheries report - Papua New Guinea. Report prepared for the 3rd Science Committee Meeting, Honolulu, Hawaii.
- Lampitt, R. and Antia, A. 1997. Particle flux in deep seas: regional characteristics and temporal variability. *Deep-Sea Research* 1. 44:1377-1403. Elsevier Science Ltd Great Britain.
- Limpus, C.J., Miller, J.D., Parmenter, C.J., Reimer, D., McLachlan, N., and Webb, R. 1992. Migration of green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles to and from Eastern Australian rookeries. *Wildlife Research*, 19:347-358.
- Maniwavie, T., Rewald, J., Wagner, T., Aije, J. and Munday, P.L. 2001. Recovery of coral reefs from volcanic eruptions at Rabaul. *Coral Reefs* 20:24.
- Marsh, H. 2006. *Dugong dugon*. A WWW publication accessed on 5 August 2008 at www.iucnredlist.org. International Union for Conservation of Nature.
- Marsh, H., Eros, C., Corkeron, P., and Breen, B. 1999. A conservation strategy for dugongs: implications of Australian research. *Marine and Freshwater Research* 50:979-990.

- Marsh, H., Penrose, H., Eros, C., Hugues, J. 1996. Dugong: Status report and action plans for countries and territories. A report compiled for the IUSN/SSC Sirenia specialist group.
- Martinez, F., and Taylor, B. 1996. Backarc spreading, rifting, and microplate rotation, between transform faults in the Manus Basin. *Marine Geophysical Researches* 18:203-224.
- MCA. 2004. Australasian code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (The JORC Code 2004 Edition). Minerals Council of Australia.
- McAlpine, J. Keig, G. and Falls, R. 1983. Climate of Papua New Guinea. CSIRO. Australia.
- McAlpine, J. Keig, G. and Short, K. 1975. Climatic Tables for Papua New Guinea. Division of Land Use Research Technical Paper No. 37. CSIRO. Australia.
- McCarthy, E. 2004. International regulation of underwater sound: Establishing rules and standards to address ocean noise pollution. Springer Publishing, Dordrecht.
- Moss, R., and Scott, S.D. 2001. Geochemistry and mineralogy of gold-rich hydrothermal precipitates from the Eastern Manus Basin, Papua New Guinea. *The Canadian Mineralogist* 39:957-978.
- Moss, R., Scott, S.D., and Binns, R.A. 2001. Gold content of Eastern Manus Basin volcanic rocks: Implications for enrichment in associated hydrothermal precipitates. *Economic Geology* 96:91-107.
- MRA. 2007. Corporate Profile. A WWW publication accessed on 17 May 2008 at <http://www.mra.gov.pg/LinkClick.aspx?fileticket=uYX%2FTVEM7Jg%3D&tabid=36&mid=444>
- Mullineaux, L.S., Mills, S.W., and Goldman, E. 1998. Recruitment variation during a pilot colonization study of hydrothermal vents (9°50'N, East Pacific Rise). *Deep Sea Research Part II: Topical Studies in Oceanography* 45:441-464.
- Munday, P. 2000. The Status of Coral Reefs in Papua New Guinea. GCRMN. AIMS, Townsville.
- NRC 2003. Ocean noise and marine mammals. The National Academic Press. National Research Council of National Academy of Science, Washington, D.C.
- NSW EPA. 2001. Approved Methods and Guidance for Modelling and Assessment of Air Pollutants in New South Wales. Prepared by NSW Environment Protection Authority, a part of the Department of Environment and Conservation, NSW.
- NSW EPA. 2000. NSW Industrial Noise Policy. Prepared by the Environment Protection Authority, NSW.
- NTC. 2008. Australian Dangerous Goods Code, 7th Edition. Prepared by the National Transport Commission.
- Parr, J.M., and Binns, E.A., 1997. Report on the PACMANUS-III cruise, RV "Franklin", Eastern Manus Basin, Papua New Guinea: Exploration and Mining Report 345R, CSIRO Division of Exploration and Mining pp 179.
- Pinto, A.M.M., Barriga, F.J.A.S., and Scott, S.D. 2003. Data report: Sulfide and oxide mineral chemistry of an active backarc hydrothermal systems: PACMANUS, ODP holes 1188A, 1188F, 1189A, and 1189B. *Proceedings of the Ocean Drilling Program, Scientific Results* 193:1-31.
- Pinto, A.M.M., Relvas, J.M.R.S., Barriga, F.J.A.S., Munha, J., Pacheco, N., and Scott, S.D. 2005. Gold mineralisation in recent and ancient volcanic-hosted massive sulphides: the PACMANUS field and the neves corvo deposit. *Mineral Deposits Research: Meeting the Global Challenge* 1:683-686.

- Placer Dome and Nautilus Minerals. 2006. Live video survey of Solwara 1 using a TST 212 ROV aboard the DP Hunter. Events logged using WinFrog software. Recorded by Placer Dome Group for Nautilus Minerals Niugini Ltd.
- PNGS. 1982. PNGS 1001-1982: Part 4. General Structural Design and Design Loadings for Buildings. Part 4 - Earthquake Loadings. National Standards Council of Papua New Guinea.
- Quin, N., Anguru, B., Chee Kapua, K.O. 1983. Preliminary survey of Leatherback rookeries in Morobe Province with notes on their biology. Research Report. Series 83/1. A report prepared for the Department of Fisheries, University of Technology, Lae, Papua New Guinea.
- Richardson, W.J., Greene, C.R. Jnr., Malme, C.I., and Thomson, D.H. 1995. *Marine Mammals and Noise*. Academic Press, California.
- Richardson, W.J., Wursig, B., and Greene, C.R. Jnr. 1990. Reactions of bowhead whales (*Balaena mysticetus*) to drilling and dredging noise in the Canadian Beaufort Sea. *Marine Environmental Research* 29:135-160.
- RPS Metocean. 2008. Final Metocean design criteria study for Solwara 1 location in the Bismarck Sea. August. Report prepared by RPS Metocean Engineers Pty Ltd for Nautilus Minerals Niugini Pty Ltd.
- Sarti Martinez, A. L. 2000. *Dermochelys coriacea*. A WWW publication accessed on 1 June 2008 at www.iucnredlist.org.
- Saunders, S. and Patia, H. 2008. Rabaul Volcanological Observatory Monthly Reports. A WWW publication accessed on 18 June 2008 at http://www.volcano.si.edu/world/volcano.cfm?vnum=0502-14=&volpage=var#bgvn_3303
- Scott, S.D. and Binns, R.A. 1995. 'Hydrothermal processes and contrasting styles of mineralisation in the western Woodlark and eastern Manus Basins of the western Pacific'. In *Hydrothermal vents and processes*. Edited by L.M. Parson, C.L. Walker and D.R. Dixon. Geological Society Special Publication 87:191-205.
- Shirihai, H. 2008. Rediscovery of Beck's Petrel *Pseudobulweria becki*, and other observations of tubenoses from the Bismarck archipelago, Papua New Guinea. *Bulletin of the British Ornithologists' Club* 128:3-16.
- SMD. 2008. SMT preliminary analysis for vibrations and noise generated by a drum cutter. Report prepared by Soil Machine Dynamics for Nautilus Minerals Inc., Milton, Queensland.
- Soto, N.A., Johnson, M.P., Madsen, P.T., Diaz, F., Dominguez, I., Brito, A. and Tyack, P. 2008. Cheetahs of the deep sea: deep foraging sprints in short-finned pilot whales off Tenerife (Canary Islands). *Journal of Animal Ecology* in press.
- Southward, E.C. and Galkin, S.V. 1997. A new vestimentiferan (Pogonophora: Obturata) from hydrothermal vent fields in the Manus Back-arc basin (Bismarck Sea, Papua New Guinea, Southwest Pacific Ocean). *Journal of Natural History* 31:43-55.
- Spring, 1995. Status of marine turtle populations in Papua New Guinea. In Bjorndal, K.A. (ed) *Biology and Conservation of Sea Turtles*. Smithsonian Institution Press. Washington. 281-289.
- SRK. 2006. Independent Technical Assessment of Sea Floor Massive Sulphide Exploration Tenements in Papua New Guinea, Fiji and Tonga. Report prepared by Jankowski, P. and Hodkiewicz, P. F., SRK Australasia Pty Ltd for Nautilus Minerals Limited.
- Steinberg, C.R., Choukroun, S.M., Slivkoff, M.M., Mahoney, M.V., and Brinkman, R.M. 2006. Currents in the Bismarck Sea and Kimbe Bay, Papua New Guinea. Report prepared by the Australian Institute of Marine Science for The Nature Conservancy. TNC Pacific Island Countries Report No. 6/06.

- Technip Offshore. 2005. Placer Dome Deepwater Mining Project: Pre-feed Report. Report prepared by Technip Offshore Inc for Placer Dome Group.
- Technip Offshore. 2006a. Placer Dome Deepwater Mining Project: Dewatering System Study. Report prepared by Technip Offshore Inc for Placer Dome Group.
- Technip Offshore. 2006b. Placer Dome Deepwater Mining Project: Riser and Jumper Analysis Report. Report prepared by Technip Offshore Inc for Placer Dome Group.
- Technip USA. 2008. Riser Temperature Study. Solwara 1 Project– Riser and Lifting System (RALS). Report prepared by Technip USA, Inc for Nautilus Minerals Singapore Limited.
- Tiden, G. 2008. Shark calling under threat. *Postcourier*. 16 August 2008. p24.
- Tivey, M. 1998. How to build a black smoker chimney: The formation of mineral deposits at mid-ocean ridges. *Oceanus* 41(2):22-26.
- Tivey, M., Bach, W., Seewald, J., Tivey, M. and Vanko, D. 2006. Hydrothermal systems in the Eastern Manus Basin: Fluid chemistry and magnetic structure as guides to seafloor processes. Cruise report prepared for Nautilus Minerals Inc., Milton, Queensland.
- TOPP. 2008. Tagging of Pacific Pelagics. A WWW publication accessed on the 27 February 2008 at http://las.pfeg.noaa.gov/TOPP_recent/TOPP_tracks180.html?species=0&zone=10.
- Triton. 2004. Salty Daug Project Feasibility Study – Mining of Subsea Massive Sulphide Deposits. November. Report prepared by Triton Consultants Ltd. Placer Dome Group Vancouver, BC.
- Triton. 2006. SaltyDaug Project Feasibility Study – Mining of Subsea Massive Sulphide Deposits, Metocean Data Summary. Report prepared by Triton Consultants Ltd for Placer Dome Group, Vancouver, BC.
- UN. 2004. Papua New Guinea - Millennium Development Goals Progress Report 2004. Government of Papua New Guinea. United Nations in Papua New Guinea.
- UNEP-WCMC. 2006. Marine Turtle Interactive Mapping System; <http://stort.unep-wcmc.org/imaps/indturtles/viewer.htm> accessed in April 2006 and August 2008.
- USGS. 2003. Cascades Volcano Observatory. A www publication accessed on 22 September 2008 at http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/description_plate_tectonics.html. U.S Geological Survey.
- Van Dover, C. L. 2000b. The ecology of hydrothermal vents. Princeton University Press, New Jersey.
- Van Dover, C. L., Berg Jr., C.J. and Turner, R.D. 1988. Recruitment of marine invertebrates to hard substrates at deep-sea hydrothermal vents on the East Pacific Rise and Galapagos spreading center. *Deep-Sea Research* 35:1833-1849.
- Van Dover, C.L. 2000a. The ecology of deep-sea hydrothermal vents. Princeton University Press, Princeton, New Jersey, USA.
- Vanderlaan, A. S. M. and Taggart, C. T. 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. *Marine Mammal Science* 23:144-156
- Vanko, D.A., Bach, W., Roberts, S., Yeats, C.J. and Scott, S.D. 2004. Fluid inclusion evidence for subsurface phase separation and variable fluid mixing regimes beneath the deep-sea PACMANUS hydrothermal field, Manus Basin back-arc rift, Papua New Guinea. *Journal of Geophysical Research* 109:B03201.
- Visser, I.N. 2003. Kimbe Bay Second Marine Mammal Rapid Ecological Assessment (REA) April 2003. Unpublished survey report for the Nature Conservancy. A WWW publication accessed on 26 November at www.orcaresearch.org.

- Visser, I.N. and Bonoccorso, F.J. 2003. New observations and a review of killer whale (*Orcinus orca*) sightings in Papua New Guinea waters. *Aquatic Mammals* 29.1:150-172.
- Volcano Live. 2008. Rabaul Volcano. A WWW publication accessed on 6 March 2008 at <http://www.volcanolive.com/rabaul.html>. John Seach.
- Volcano World. 2005. Rabaul Caldera, Papua New Guinea. Eruptive History. A WWW publication accessed on 6 March at http://volcano.und.edu/vwdocs/current_volcs/rabaul/rabaul.html.
- Wells, M., Vallis, G. and Silver, S. 1999. Tectonic Processes in Papua New Guinea and Past Productivity in the Eastern Equatorial Pacific Ocean. *Nature* 398:601-604
- Williams, D., Jensen, S. and Winkel, K. 2004. *Clinical management of snakebite in Papua New Guinea*. Independent Publishing, Port Moresby.
- World Bank. 1999. Project Appraisal Document on the First Phase of a Proposed Loan in the amount of US\$25.26 million equivalent to the Independent State of Papua New Guinea for a Second Gazelle Restoration Project. A WWW publication accessed on 24 May 2008 at http://www-wds.worldbank.org/external/default/main?pagePK=64193027&piPK=64187937&theSitePK=523679&menuPK=64187510&searchMenuPK=64187283&theSitePK=523679&entityID=000094946_99112505311322&searchMenuPK=64187283&theSitePK=523679
- Worley Parsons. 2005. Seafloor massive sulphide mining project: Pre-feasibility study. Report prepared by Worley Parsons Services Pty Ltd for Nautilus Minerals Inc., Milton, Queensland.
- Worsley, T. and Davies, T. 1979. Cenozoic sedimentation in the pacific ocean: steps toward a quantitative evaluation. *Journal of Sedimentary Research*. 49:1131-1146.
- WWF. 2001. Marine Resource Management and Conservation Planning. Bismarck-Solomon seas Ecoregion: Papua New Guinea/Solomon Islands. World Wide Fund For Nature. Fiji.

Personal Communications

- Alexander, B. Rabaul Hotel. Email. 30 May 2008a.
- Alexander, B. Rabaul Hotel. Email. 30 May 2008b.
- Byrne, G. Rapopo Dive. Conversation in person. 6 June 2008.
- King, B. Chief Scientist and Managing Director of Asia-Pacific Applied Science Association. Queensland. E-mail. 13 September 2007.
- Riley, C. Exploration Manager, Nautilus Minerals, Milton, Queensland. Email. 17 July 2008.
- Smith, S. Environmental Manager, Nautilus Minerals, Milton, Queensland. Email. 23 May 2008.
- Saunders, S. Rabaul Volcano Observatory Email. 20 June 2008a.
- Saunders, S. Rabaul Volcano Observatory Email. 5 June 2008b.
- Van Dover, C. L. Email. 22 September 2008.

Environmental Impact Statement
Solwara 1 Project

16. GLOSSARY

abundance	total numbers of individual animals or of taxonomic groups of animals.
antifouling	substances applied to the hulls of vessels to prevent attachment and growth of marine organisms that could affect the performance of the vessels and introduce exotic marine organisms.
barnacle	a type of encrusting arthropod, barnacles attach themselves permanently to a hard substrate, mostly in shallow and intertidal tidal waters, but also on floating objects and deep sea
bathypelagic zone	the region of an ocean below 1,000 m depth. No light penetrates this zone.
biogenous	producing or produced by living things (adj.)
bioluminescence	emission of visible light by living organisms.
bivalve	molluscs belonging to the class Bivalvia. They have two-part shells, and typically both valves are symmetrical along the hinge line.
caldera	a volcanic feature formed by the collapse of land following a volcanic eruption.
chemoautotroph	an organism, typically a bacterium, that derives energy from the oxidation of inorganic compounds.
chemosynthesis	the synthesis of organic compounds by bacteria or other living organisms using energy derived from reactions involving inorganic chemicals, typically in the absence of sunlight.
chemotrophic	the derivation of energy by organisms, not from the sun but from the oxidation of molecules in the environments (in the present case, from inorganic H ₂ S molecules)
chimney	a structure on the seafloor that forms when hot hydrothermal fluids vent in cold seawater and sulphide materials precipitate on the edges of a conduit, forming a chimney
density	with respect to animals, the numbers (of individuals or taxa) per unit area
diversity	a statistical index describing, in combination, the numbers of individuals representing the numbers of species within a sample or location.
Dobson unit	the Dobson unit (DU) is defined to be 0.01 mm thickness at STP (standard temperature and pressure). Ozone layer thickness is expressed in terms of Dobson units, which measure what its physical thickness would be if compressed in the Earth's atmosphere.

epifaunal	living on and in association with other animals (but not parasitic).
epipelagic zone	the region of an ocean extending from the surface to a depth of about 200 m. Light penetrates this zone, allowing photosynthesis.
euphotic zone	the upper region of an ocean that receives light and thus where photosynthesis is possible.
free on board	FOB is an abbreviation for Free On Board (an alternative term is Freight on Board). The term FOB (often seen as f.o.b.) is commonly used when shipping goods, to indicate who pays loading and transportation costs, and/or the point at which the responsibility of the goods transfers from shipper to buyer. FOB shipping is the term used when the ownership/liability of goods passes from the seller to the buyer at the time the goods cross the shipping point to be delivered. FOB destination designates that the seller is responsible for the goods until the buyer takes possession. This is important in determining who is responsible for lost or damaged goods when in transit from the seller to the buyer. The buyer is responsible when shipped FOB shipping and the seller is responsible if shipped FOB destination. CAP, or customer arranged pickup, is used to denote that the buyer will arrange a carrier of their choice to pick the goods up and the liability for any damage or loss belongs to the buyer.
gastropod	belonging to the phylum of Mollusca, gastropods are soft bodied animals with a head, a foot, a visceral body mass and a mantle, often (but not always) protected by an external shell.
indicated resource	a resource whose size and grade have been estimated from sampling at places spaced closely enough that its continuity can be reasonable assumed.
infauna	aquatic animals that live within the bottom substratum rather than on its surface.
inferred resource	a resource whose size and grade have been estimated mainly or wholly from limited sampling data, assuming that the mineralized body is continuous based on geological evidence.
macrofauna	macrofauna are benthic or soil organisms, which are normally > 0.5 mm, but in this case, also include animals at least 0.25 mm in length.
meiofauna	microscopic, multicellular organisms that live in both marine and fresh water environments defined by size, being those that can pass through a 0.5 mm mesh but retained by a 45 µm mesh.
mesopelagic zone	the region of an ocean extending from 200 m down to 1,000 m below sea level. Some light penetrates this zone, however, it is insufficient for photosynthesis.
Metazoa	multicellular organisms (i.e. not bacteria or protozoa).

mollusc	belonging to the phylum of Mollusca, molluscs are soft bodied animals with a head, a foot, a visceral body mass and a mantle, often (but not always) protected by an external shell.
nekton	organisms with swimming abilities that permit them to move actively through the water column and to move against currents.
peak ground acceleration	a short-period ground motion parameter that is proportional to force, the most commonly mapped ground motion parameter because current building codes that include seismic provisions specify the horizontal force a building should be able to withstand during an earthquake.
pelagic	of, relating to, or living in open oceans or seas.
photosynthesis	the process by which green plants, algae, diatoms, and certain forms of bacteria make carbohydrates from carbon dioxide and water in the presence of chlorophyll, using energy captured from sunlight by chlorophyll, and releasing excess oxygen as a byproduct.
phylogenetic	the relationships between taxa (species, genus family etc.) on the basis of gene sequences.
phytoplankton	the photosynthesising organisms residing in the plankton.
plankton	organisms living suspended in the water column and incapable of moving against water currents.
ROV	remotely operated underwater vehicles, usually tethered, unoccupied and operated by a person aboard a vessel.
species richness	the number of different species in an area.
spring tide	the phase of the tidal cycle when tidal range is at a maximum.
spud	moveable anchor points allowing the Seafloor Mining Tool to walk over the seafloor.
stratovolcano	a stratovolcano, also called a composite volcano, is a tall, conical volcano composed of many layers of hardened lava, tephra, and volcanic ash. These volcanoes are characterised by a steep profile and periodic, explosive eruptions. The lava that flows from them is viscous, and cools and hardens before spreading very far. The source magma of this rock is classified as acidic, having high to intermediate levels of silica (as in rhyolite, dacite, or andesite). This is in contrast to less viscous basic magma that forms shield volcanoes (such as Mauna Loa in Hawaii), which have a wide base and more gently sloping profile.
subduction	the process by which one tectonic plate moves beneath another.

symbionts	microorganisms that live on or within the cells of host animals with both deriving mutual benefit
taxa	classification of organisms into groups (taxa) according to similarity
tsunami	an ocean wave generated by a submarine earthquake, volcano or landslide. (Also known as a seismic sea wave, and incorrectly as a tidal wave).
vestmentiferan	belonging to the phylum Vestimentifera, Vestimentiferan tube worms are soft bodied organisms that lack a digestive system and inhabit areas close to deep sea hydrothermal vents or areas of cold water seeps on continental margins.
zooplankton	the animal component of plankton.

Attachment A Risk Register

Attachment A – Risk Register

Source						
Component/ Activity	Hazard	Incident/ Event	Potential Impact	Mitigation	Residual effect / Severity	EIS chapter representation
Mining Machine						
	Settling on seafloor and moving	Removal of habitat	Seafloor surface structure (hard and soft surfaces) will change	Vent energy cannot be removed and will resume	Localised to mining area. Resumption of natural venting will recreate chimneys in the short term and mineralised seafloor habitat in the long term	9.6.2
		Removal of organisms	Death of organisms changes species diversity	Refugia zone, mining plan, creation of control area at South Su. Transplant of animals	Refugia and control areas will provide nearby communities for spawning / recolonisation of mined areas	9.6.2
	Cutting head operation	Plume generation	Smothering of organisms	Efficient operation of suction mouth to reduce sediment escape	Localised temporary impact; recovery	9.3, 9.4, 9.6.1, 9.6.2
		Plume generation	Reduction of bioluminescence, leading to changes in biodiversity	Efficient operation of suction mouth to reduce sediment escape	Localised around area of operation	9.3, 9.4, 9.6.1, 9.6.2
		Release of metals (from sediments) into the water column	Toxic effects on biota, bioaccumulation, human health	Efficient operation of suction mouth to reduce sediment escape	Effect (if any) to locally tolerant organisms restricted to seafloor layers	9.4, 9.6.1
		Lighting of Seafloor Mining Tool (SMT): fish attraction	Some individuals attracted to suction area may be lost	No practicable controls	Minor localised effect	9.6.3
		Noise	Disturbance of organisms; e.g. whales	No practicable controls	Sound levels and frequencies not likely to cause impacts to cetaceans or other animals. Low exposure at depths of Seafloor Mining Tool (SMT) operation near seafloor	9.6.3
		Vibration	Detectable noise but not at any harmful levels	No practicable controls	No detectable or harmful effect	9.6.3
		Hydraulic leak	Localised impact on water quality	Maintenance. Limited volume of hydraulic oil may be leaked, biodegradable, regular maintenance of machine	Minor, very localised effect	9.4
		Changes to hydrothermal venting	Removal of chimneys and seafloor material around active venting areas	Cannot remove underlying energy source: venting will resume	Venting will resume in the same or at new (e.g., unplugged) areas. Recolonisation will start in short term and reach similar diversity/biomass during and after mining (2-5 years)	9.6.2
	Raising/lowering machine to vessel	Plume generation of materials on skid	Smothering of organisms	Minimal amount, likely only to affect immediate mined area	9.6.3	
	Sonar	Noise	Cetacean disturbance	Impact expected to be minimal therefore no mitigation measures required	Sonar power too low to injure animals	9.6.3
	Umbilicals	Hazard in water column	Cetacean entanglement	No loose or floating ropes; Umbilicals too taught to cause entanglement	Unlikely and low risk	9.6.1
	Riser Transfer Pipe					
	Breakage/failure	Loss of material in riser transfer pipe (RTP) and riser pipe material - max 30 tonne	Smothering of organisms leading to death either directly or via plume	Keep pumping seawater to prevent material in riser pipe from escaping, engineering standards, existing technology	Localised smothering in already mined area	9.6.2
		Loss of material in riser transfer pipe (RTP) and riser pipe material - max 30 tonne	Localised impact on water quality - increased metals	Keep pumping seawater to prevent material in riser pipe from escaping, engineering standards, existing technology	Minimal amount, likely only to affect immediate mined area	9.4
Pump Modules						
	Operation	Noise	Cetacean detection; disturbance	Impact expected to be minimal therefore no mitigation measures required	Sound levels and frequencies not likely to cause impacts to cetaceans or other animals. Low exposure at depths of operation near seafloor	9.6.3
		Hydraulic leak	Localised impact on water quality	Maintenance. Limited volume of hydraulic oil may be leaked, biodegradable, regular maintenance of machine	Minor, very localised effect	9.4
		Vibration	Detectable noise but not at any harmful levels	Impact expected to be minimal therefore no mitigation measures required	No detectable effect	9.6.3
	Breakage/failure	Loss of material in riser pipe material - max 30 tonne	Smothering of organisms leading to death either directly or via plume	Keep pumping seawater (if possible) to prevent material in riser pipe from escaping, engineering standards, existing technology	Localised smothering in already mined area	9.6.2
Riser Pipe						
	Breakage/failure	Loss of material in riser transfer pipe (RTP) and riser pipe material - max 30 tonne	Smothering of organisms leading to death either directly or via plume	Keep pumping seawater to prevent material in riser pipe from escaping, eng standards, existing technology	Localised smothering in already mined area	9.6.2
		Loss of material in riser transfer pipe (RTP) and riser pipe material - max 30 tonne	Localised impact on water quality - increased metals	Engineering standards, existing technology	Minimal amount, likely only to affect immediate mined area	9.4
	Biofouling	Added loading causing failure	Leak of material	Cleaning; abrasion during normal use will prevent fouling	Limited to surface waters	9.6.1, 9.7
	Operation	Noise at bottom	Disturbance of organisms	Impact expected to be minimal therefore no mitigation measures required	Minimal noise at riser transfer pipe (RTP)/pipe link; no harmful effects	9.6.3
	Operation	Vibration	Detectable noise but not at any harmful levels	Vibration dampers	No detectable effect	9.6.3
Mining Support Vessel (MSV)						

	Operational discharges	Dewatering	Plumes, with elevated total suspended solids (TSS), metals, bioaccumulation	Design total suspended solids (TSS), water treatment to discharge only particles 5-10 µm	Modeling combined with geochemical (elutriate and toxicity) tests indicate plume dimensions < 500 m laterally (for 700 dilutions) and 120 m vertically (all dilutions); and will not rise shallower than 1,390 m	9.4
	Dynamic Positioning (DP) operation	Dynamic Positioning (DP) fails	Break connection between mining tool and riser transfer pipe - lost max 30 tonne material	Riser transfer pipe (RTP) provides a weak link Material can be recovered	No impact to water column. Localised smothering in already mined area	9.6.2
		Dynamic Positioning (DP) fails	Umbilical breaks on mining machine	No hydraulics in umbilical	No adverse environmental impacts	9.7
		Dynamic Positioning (DP) noise	Cetacean/turtle disturbance	Reduce use of Dynamic Positioning (DP) if whales seen to encroach within 3 km (if practicable regarding maintenance of operational safety). Record whale / turtle activity in project area	Some avoidance by whales at threshold distance of about 2 km on max Dynamic Positioning (DP) power. Low frequency of whale and exposure. No indication of adverse effects on turtles	9.6.3
	Operations	Light	Attraction of marine animals	Directional lighting will be implemented to reduce light exposure to the marine environment	Minor, very localised effect	9.6.1
		Vessel noise (other than Dynamic Positioning)	Cetacean/turtle disturbance	Reduce sources of noise (as practicable regarding maintenance of operational safety). Record whale / turtle activity in project area	Potential response distances less than for Dynamic Positioning (DP)	9.6.3
		Waste	Localised nutrient increase in discharge of macerated waste	MARPOL compliance, Environmental Management Plans (EMPs)	Localised and minor	9.9
	Operational discharges	Dewatering	Plumes, with elevated total suspended solids (TSS), metals, bioaccumulation	Design total suspended solids (TSS), water treatment to discharge only particles 5-10 µm	Modeling combined with geochemical (elutriate and toxicity) tests indicate plume dimensions < 500 m laterally (for 700 dilutions) and 120 m vertically (all dilutions); and will not rise shallower than 1,390 m	9.4
		Cleaning hull of biofouling	Toxicity from anti-fouling agents	Dry dock every 2 years when cleaning or hull cleaning on site. Adherence to PNG and international conventions on use of organotin compounds	No detectable effects	9.8, 9.10
	At sea	Sinking	Loss of life: spillage of fuels/chemicals causing pollution/kills/bioaccumulation	Maintenance, ship designed for Bismarck Sea conditions (it will also have to be designed for wherever else it will operate in the future e.g., Tonga), crew competency, maintenance of vessel class/in survey. Emergency Response Procedures	Extremely low probability	9.7, 9.9
		Collision with other ships / fishing boats	Damage, spills, sinking	500 m exclusion zone. Normal maritime radio communications	Extremely low probability	9.7
Supply and Servicing Mining Support Vessel						
	Transfer of hazardous materials (incl. fuel oil)	Spillage of hazardous materials	Pollution - animal kills, particularly to surface animals	Correct materials storage during transfer; standard operating procedures, use of non-toxic/biodegrading materials wherever possible. Spill response / cleanup equipment available; assess trajectory; and implement Emergency Response Procedures	Emergency Response Plan will minimise extent and duration of any spills.	9.4, 9.6.1, 9.9
Ore transfer	Transfer of ore between vessels	Spillage	Pollution - potential animal kills, bioaccumulation, increased contamination of sediments	Monitor transfers to detect spillages and stop transfer ASAP to minimise spill volumes	Small volumes and rapid dispersal; any impacts restricted to localised area of spill	9.6.2
Ore barging to shore	Barging	Ore spillage during loading	Pollution - potential animal kills, bioaccumulation, increased contamination of sediments	Avoidance of overloading	Small volumes and rapid dispersal; any impacts are restricted to localised area of spill	9.6.2
		Sinking	Spillage of fuel/ore; navigation hazard in shallow water; bioaccumulation	Operate to standard navigational and communication procedures	Extremely low probability	9.4, 9.9
		Collisions with other vessels	Spillage of fuel/ore; loss of life	Operate to standard navigational and communication procedures	Extremely low probability	9.7, 9.9
		Piracy	Loss of life, spillage of fuel/ore	Security systems operational at all times. Communication links with authorities	Extremely low probability	9.7, 9.9
		Collisions with cetaceans/turtles	Loss of animal life	All speeds <10 km during barge movements	Whales / turtles are able and expected to avoid slow moving vessels	9.6.1, 9.6.2
		Interference with resource use e.g., commercial fishing	Loss of fishing income (real or claimed), knock-on economic effects, deterioration of community acceptance	Operate to standard navigational and communication procedures	Occasional need to avoid barges; no loss of fishing grounds	9.7
Ore transfer from barge to shore	Transfer of materials	Spillage to nearshore/inshore waters	Pollution - potential animal kills, bioaccumulation, increased contamination of sediments nearshore reefs	Procedures to minimise loss during transfer and clean up as necessary	Small volumes and localised to port - minimal effect after clean up	9.4, 9.6.1, 9.6.2
		Spillage to land outside storage area				9.10
		Dust	Human health, vegetation kills	Wet ore, design of transfer system to minimise potential	Baseline medicals of local population	9.2, 9.10
		Noise/light	Annoyance to locals	Shield lighting if necessary, Nearest residential areas xx km from port	Impacts managed to low levels	9.10
		Dust	Human health, vegetation kills	Watering	Dusting will be avoided	9.2
		Dewatering	Escape of water to environment leading to pollution	Storage on constructed compacted base, bunding, lining. Water treatment prior to discharge. Covering stockpile to minimise rainfall infiltration and runoff as necessary	Escape of runoff or drainage to environment prevented	9.4, 9.6.1, 9.6.2, 9.9

Ore Storage	Storage	Land alienation - storage and facilities	> 250 x 100 m loss of bush resources, cash crops, archaeological/cultural sites, travel routes (restricted beach access, along shore, land routes), biodiversity	Within existing Port of Rabaul facilities	Impacts managed to low levels	9.10
		Acid formation	Acidic drainage to environment, seepage to groundwater	See dewatering above	Impacts managed to low levels	9.9
		Fire	Fire spreads, leading to damage to land/resources outside of storage area	Environmental Response Plan (ERP)	Impacts managed to low levels	9.9
		Light/noise	Annoyance to locals	Shield lighting if necessary, Nearest residential areas xx km from port.	Impacts managed to low levels	9.10
	Workforce	Interaction with locals	Social tensions - gambling, alcohol, violence, sexually transmitted diseases (STDs), immigration, hunting bushland fauna, aquatic, marine resources	Within existing Port of Rabaul facilities		10.8
	Security	Stoppage of operations	Erosion of community relations, bad public relations	Within existing Port of Rabaul facilities		10.8
	Accommodation	Waste disposal - general, hazardous, sewage	Pollution - on site, transport to off-site disposal facility	Standard operating procedures (SOPs), batch sewage plant, waste disposal, recycling etc		9.9
	Feral/exotic animals	Introduction to site	Death of local flora and fauna	Inspection of sea containers, etc arriving on site, correct food storage, eradication program	African snails, cane toads already on site	9.8
	Visual amenity			Within existing Port of Rabaul facilities		
	Barge movement	Prop wash	Degraded water quality - impacts on reefs, mangroves, fish, etc			9.4, 9.6.1, 9.6.2
	Pile construction	Construction	Turbidity, noise, water quality on resource use, aesthetics			9.4, 9.6.1, 9.6.2, 9.6.3
	Navigation markers/piles/buoys			Within existing Port of Rabaul facilities		
	Fuel storage	Leak	Fish kill	Bundling etc		9.4, 9.6.1
	Transfer to bulk carrier	Transfer	Ore spillage	Potential pollution, sedimentation	Correct loading procedures	
	Dust		Public health, visual amenity	Manage moisture content of ore		9.2
Bulk carrying to international waters	Steaming	Bulk carrier steaming into port	Social impact, visual amenity	Unavoidable but all activity near populations will be within existing shipping lanes	See barging to shore above for others	9.7
	Ballasting	Introduction of exotic species	Impact on local species	Specify ballasting restrictions/treatment in contracts		9.8
	Crew down time in port	Interaction with locals	Social tensions - gambling, alcohol, violence, sexually transmitted diseases (STDs)	MSV crew transfer schedules will result in minimal stop over times in Rabaul		10.8 (?)
	Anchoring	Anchoring in non-specified locations	Drag damage to corals, seagrass (?), other sensitive marine benthic habitats	Fixed mooring/dolphins		9.6.2
Natural hazards	Seismic	Earthquake at ore storage	Damage to facilities - spillage	Design to seismic area standards		9.9, 9.10
	Tsunami	Event at ore storage	Damage to facilities - spillage	Siting of facilities above water line		9.9, 9.10
	Volcanic activity	Event at Solwara 1	Damage to ship/mining equipment - spillages/loss of life			9.7, 9.9
	Volcanic activity	Event in Rabaul	Blamed on project - bad public relations			9.9, 9.10
	Natural Gas	Escape at Solwara 1	Damage to ship/mining equipment - spillages/loss of life			9.7, 9.9
	Cyclone	Occurrence in project area	Damage to ship/mining equipment - spillages/loss of life	Monitor weather reports	Rabaul/Bismarck Sea too far north for cyclones	9.7, 9.9
Political Environment	Change of provincial/ national government	Change of process, baseline data no longer sufficient	Delayed approval		European Union (EU) group deep sea tailing placement (DSTP) recommendations (more applicable to Phase 2)	3.0
		Corruption	Delayed approval	Maintain company integrity		3.0
Engineering Design	Design process	Changes during design	Delayed ESIA completion to accommodate design changes	Continuous communication between engineering and ESIA team		4.0
External Political Unrest/Agitation						
Non-government organisation (NGO)	Scrutiny	Opposition	Approval delay, increased opposition in local communities	Non-government organisation (NGO) engagement/ proactive publicity from project/ "get there first" with local communities/ and government		4.0
		Publishing incorrect information/spurious arguments	Negative project perception	Non-government organisation (NGO) engagement/ proactive publicity from project/ "get there first" with local communities/ and government		4.0
		He said she said expert arguments	Erosion of our expert's credibility	Non-government organisation (NGO) engagement/ proactive publicity from project/ "get there first" with local communities/ and government		4.0
		Uninformed arguments	Raising project opposition	Non-government organisation (NGO) engagement/ proactive publicity from project/ "get there first" with local communities/ and government		4.0
Lack of community acceptance		No support for project	Project delay	Proactive publicity from project/ "get there first" with local communities/ and government		4.0
DEC, PNG government	Lack of familiarity with vent mining process	Fear of approving the unknown	Delayed approval	Continuous liaison with Department of Environment and Conservation (DEC) /PNG government departments		3.0, 4.0
ESIA specialist consultants	Unrealistic requirements/ recommendations	Rejection by project	Removal of project support by sub-consultants	Get sign off from sub-consultants of ESIA content		3.0, 4.0
Public - international and PNG	Non-specific project opposition "just because"	Large-scale opposition	PNG government/local communities influenced - approval delayed	Proactive publicity from project/ "get there first" with local public		3.0, 4.0

Local/provincial communities	Expectations	Unrealistic expectations	Shutting down construction/operations	Community affairs (CA) to manage level of expectation, understanding of memorandum of agreement (MOA)		3.0, 4.0
Approvals	Process	Approval conditions	More stringent/unrealistic approval conditions	Continuous liaison with DEC/PNG government departments		3.0, 4.0
Perception	Public, international, government perception	Misperception of project affecting fisheries, volcanoes, greenhouse gas (GHG), global warming, tsunami, cetaceans, turtles, shark culling, birth defects, fish kills, disease (skin rashes, cancer) etc.	Project approval delay, project gets shut down	Proactive publicity from project/ "get there first" with local, national, international communities and government		4.0
Port Operations						
Ore transfer from barge to shore	Transfer of materials	Dust	Human health, vegetation kills	Wet ore, design of transfer system to minimise potential	Baseline medicals of local population	9.2, 9.10
		Noise/light	Annoyance to locals	Shield lighting if necessary, Nearest residential areas xx km from port	Impacts managed to low levels	9.10
Ore Storage	Storage	Dust	Human health, vegetation kills	Watering	Dusting will be avoided	9.2
		Dewatering	Escape of water to environment leading to pollution	Storage on constructed compacted base, bunding, lining. Treatment of any drainage water prior to discharge. Covering of stockpile to minimise rainfall infiltration and runoff as necessary	Escape of runoff or drainage to environment prevented	9.4, 9.9
		Acid formation	Acidic drainage to environment, seepage to groundwater	See dewatering above	Impacts managed to low levels	9.9
		Land alienation - storage and facilities	Use of existing facilities - no alienation of new land	Upgrading of facilities as required to managed dust and runoff	Impacts managed to low levels	9.10
		Fire	Fire spreads, leading to damage to land/resources outside of storage area	Emergency Response Plan. Plan / construct bunding to prevent fire water impacting coast (in event of fire)	Impacts managed to low levels	9.9, 9.10
		Light/noise	Annoyance to locals	Shield lighting if necessary, Nearest residential areas xx km from port	Impacts managed to low levels	9.10
	Workforce	Interaction with locals	Social tensions - gambling, alcohol, violence, sexually transmitted diseases (STDs), immigration, hunting bushland fauna, aquatic, marine resources	Within existing Port of Rabaul facilities		10.8
	Security	Stoppage of operations	Erosion of community relations, bad public relations	Within existing Port of Rabaul facilities		10.8
	Accommodation	Waste disposal - general, hazardous, sewage	Pollution - on site, transport to off-site disposal facility	Standard operating procedures (SOPs), batch sewage plant, waste disposal, recycling etc		9.9
	Feral/exotic animals	Introduction to site	Death of local flora and fauna	Inspection of sea containers, etc arriving on site, correct food storage, eradication program	African snails, cane toads already on site	9.8
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		Ore spillage	Potential pollution, sedimentation	Correct loading procedures		9.4, 9.6.1
Bulk carrying to international waters	Steaming	Ore spillage	Public health, visual amenity	Manage moisture content of ore		9.4, 9.6.1, 9.6.2
		Dust				
	Ballasting	Introduction of exotic species	Impact on local species	Unavoidable but all activity near populations will be within existing shipping lanes. Specify ballasting restrictions/treatment in contracts	See barging to shore above for others	9.2
	Crew down time in port	Interaction with locals	Social tensions - gambling, alcohol, violence, sexually transmitted diseases (STDs)	MSV crew transfer schedules will result in minimal stop over times in Rabaul		9.6.1, 9.6.2, 9.8, 9.10
Natural hazards	Anchoring	Anchoring in non-specified locations	Sensitive marine benthic habitats	Fixed mooring/dolphins		9.1
	Seismic	Earthquake at ore storage	Damage to facilities - spillage	Design to seismic area standards		9.6.2
	Tsunami	Event at ore storage	Damage to facilities - spillage	Sitting of facilities above water line		9.8, 9.9, 9.10
	Volcanic activity	Event at Solwara 1	Damage to ship/mining equipment - spillages/loss of life			9.8, 9.9, 9.10
	Volcanic activity	Event in Rabaul	Blamed on project - bad public relations			9.8, 9.9
	Natural Gas	Escape at Solwara 1	Damage to ship/mining equipment - spillages/loss of life			9.8, 9.9, 9.10
Cyclone	Occurrence in project area	Damage to ship/mining equipment - spillages/loss of life	Monitor weather reports	Rabaul/Bismarck Sea too far north for cyclones	9.8, 9.9	



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