

Final Report

Volume 1 Aquatic Ecological Risk Assessment

Prepared for



Papua, Indonesia

Prepared by

Parametrix

5808 Lake Washington Blvd. NE, Suite 200
Kirkland, Washington 98033-7350
(425) 822-8880
www.parametrix.com

August 2002

Project No. 055 1250 002

ABSTRACT

PTFI has operated a copper mine in Papua, Indonesia since 1973. Tailings from the milling operation are carried by a dedicated river drainage to a lowlands tailings deposition area (the modified Ajkwa Deposition Area or ADA) where the majority of tailings settle. This risk assessment seeks to estimate potential risks posed by the substances in the tailings to freshwater and saltwater aquatic life both within and beyond the lower portion of the modified ADA. All of the stressors associated with tailings were examined earlier in a screening-level risk assessment (SLRA) (Parametrix Project Team 1999). The substances that were not screened out during the SLRA, requiring more detailed examination in this document, were tailings solids and metals in surface waters, sediments, sediment porewaters, and tissues of aquatic life. The areas evaluated included the lower Ajkwa River and swamps, the Ajkwa estuary and its mangroves, neighboring estuaries to the east and west, and the Arafura Sea, both nearshore and offshore.

An internationally accepted risk assessment methodology was used. It sought to quantitatively examine every possible potential risk. These were examined using multiple lines of evidence, namely biological monitoring, water quality monitoring, aquatic toxicity bioassays of water and sediment, and model predictions of current (1995 to 2000) and future (to 2068) water and sediment quality. In addition, special studies were undertaken where data were limited.

Risks from all lines of evidence are summarized in Table A-1. The identified potential risks had been predicted in the 300 ktpd ANDAL, the Government of Indonesia's environmental impact analysis process for the mine's expansion to 300,000 tons per day ore production. Of the 70 multiple lines of evidence examined (see Table A-1), eleven (16%) suggested moderate to high risks to select aquatic life. All of the identified moderate to high risks appeared to occur within the ADA boundaries and were associated with benthic (bottom-dwelling) invertebrates. Low risks to bottom-dwelling benthos extended beyond the lower ADA boundary. These low risks could be derived from any one or combination of stressors: suspended solids occurring just above the sediment, copper in the sediments, settleable solids, or uninvestigated factors, such as the food supply for benthic organisms.

Some potential risks within the ADA are projected to increase at specific locations over time to at least 2014 (end of Grasberg open pit mining), then subside at varying rates upon cessation of mining. Low risks from total suspended solids risks associated with waters near the water-sediment interface have been projected to persist beyond the end of mining.

Most species of fish, zooplankton, and mangrove crabs (an ecologically keystone species) did not appear to be at significant risk in terms of the number of species. Potential risks were highest for the benthic invertebrates that live in the sediments within the lower ADA. Also at high potential risk in

ABSTRACT (CONTINUED)

the lower ADA were select species of snails and the hermit crabs that occupy the shells of these snails. Other snail species appear unaffected. At lesser risk were epibenthic invertebrates and phytoplankton in the lower ADA (Ajkwa estuary). The foregoing risks pertain to changes in the number of species comprising each group, relative to those in a nearby reference location (i.e., species richness or species biodiversity). The abundance (biomass) of these groups was considered when data were available. In general, the total number of organisms present and their total weight appear comparable to reference locations.

A number of the risk projections were uncertain and additional biological monitoring and investigation may improve their reliability. Future emphasis should be accorded to the uncertainties in future tailings inputs to the lower ADA, the resolution of the copper fate model, the degree of sediment cohesiveness, and the fate and effects of tailings and metals on the key species of organisms inhabiting sediments and the mangroves.

ABSTRACT (CONTINUED)

Table A-1. Overall Judgments Concerning Risk Magnitude Based on Multiple, Independent Lines of Evidence

Line of Evidence	Overall Estimated Risk Magnitude ^a							
	Lower ADA (Upper Estuary)		Lower ADA (Lower Estuary)		Lower ADA (includes part of Outer Estuary and Nearshore Arafura Sea)		Offshore Arafura Sea	
	Upper Water Column	Bottom/ Near Bottom	Upper Water Column	Bottom/ Near Bottom	Upper Water Column	Near Bottom	Upper Water Column	Bottom/ Near Bottom
Biological Monitoring								
Fish	Negligible	Negligible-Low	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
Zooplankton			Negligible	Negligible	Negligible		Negligible	Negligible
Phytoplankton			Moderate				Negligible	Negligible
Epibenthic Invertebrates		Negligible	Low-High ^b	Moderate		Low		Negligible
Benthic Invertebrates		High	High	High		Low		Negligible
Toxicity Testing	Negligible	Moderate-High	Negligible	Moderate	Negligible	Low	Negligible	Negligible
Measured Water Quality								
Copper ^c	Low		Moderate-High			Low		Negligible
Suspended Solids	Low		Low-Moderate			Low		Negligible
Modeled Water Quality								
Suspended Solids	High	High	Low	Low	Negligible	Low	Negligible	Negligible
Sedimentation Rate		Low	Negligible-Low	Low			Negligible	Negligible
Changes in Water Depth		Negligible	Low-Moderate	Negligible			Negligible	Negligible
Salinity	Negligible	Negligible	Negligible	Negligible			Negligible	Negligible

^a Blank indicates the line of evidence was not studied in that location. Risk magnitudes: Negligible risk = < 5% reduction in species, Low risk = > 5 to 30% reduction in species, Moderate risk = > 30 to 50% reduction in species, and High risk = > 50% reduction in species.

^b Risks are low for certain crabs, e.g., Grapsidae and Ocypodidae, but high for mangrove snails and hermit crabs (Diogenidae).

^c Of the metals and metalloids examined, copper was the only metal, with zinc as one minor exception, posing potential risks to certain species of aquatic life in some circumstances.

ACKNOWLEDGMENTS

This report reflects the contribution of many individuals and would not have been undertaken without the support of PT Freeport Indonesia's management. We are especially indebted to Dr. Wisnu Susetyo, Dr. Jim Miller, Dr. David Norriss, Mr. Kent Hortle, and Mr. Gesang Setyadi for their support of the many data collection activities. The ERA Review Panel Team (RPT), chaired by Professor Retno Soetaryono of the University of Indonesia, provided valuable comments, information and perspectives as part of their reviews of interim findings and the final reports. The members of the Review Panel Team and of their support team from the University of Indonesia are identified in the tables below.

ERA Review Panel Team

Name	Affiliation
Dr. Ali Kastela	BAPEDALDA Propinsi Papua
Prof. Dr. Ir. Asis Djajadiningrat	Institut Teknologi Bandung
Ir. Bambang Poerwono	Kementerian Lingkungan Hidup
Prof. Corrie Wawolumaya, SKM, Msc., Ph.D.	Universitas Indonesia
Dr. Dedi Setiapermana	Puslitbang Oseanologi LIPI
Dr. D. Dimara	BAPEDALDA Propinsi Papua
Engel Bertus Rahaded, A. Md., S. Sos	Pemerintah Daerah kabupaten Mimika
Prof. Dr. dr. Farid Afansa Moeloek	Universitas Indonesia
Prof. Dr. Ir. Frans Wanggai	Universitas Papua
Ir. H. E. Mackbon	Pemerintah Daerah Propinsi Papua
Prof. Dr. Ir. Hadi S. Alikodra, MS	Institut Pertanian Bogor
Dr. Ir. Haryadi, M. Arch	Universitas Gadjah Mada
Prof. Dr. Ir. Muchammad Sri Saeni, MS	Institut Pertanian Bogor
Prof. Retno Soetaryono, SH, Msi.	Universitas Indonesia
Prof. Dr. Ir. Rizald Max Rompas, M. Agr.	Departemen Kelautan dan Perikanan
Dr. Ronald Tambunan, ME	Departemen Energi dan Sumberdaya Mineral
Ir. S. Witoro Soelarno, Msi.	Departemen Energi dan Sumberdaya Mineral
Tom Beanal	LEMASA
Yacobus Owemena	LEMASKO

UI ERA Supporting Team

Name	Affiliation
Dr. Ir. Bianpoen	Universitas Indonesia
Ir. E. Budirahardjo, APU	Universitas Indonesia
Ir. Madrim Gondokusumo, Msi.	Universitas Indonesia
Dr. Ir. Mch. Hasroel Tahyib, APU	Universitas Indonesia
Dr. Tr. Bddhi Soesilo, Msi.	Universitas Indonesia

ACKNOWLEDGMENTS (Continued)

The on-site data collections were critical to achieving a risk assessment based on site-specific data. We are indebted especially to staff from PTFI's Tailing and Coastal Division, Tailing and Biodiversity Division, and Timika Environmental Laboratory. Contributing staff are identified in the tables below. The respective leadership of Dr. Yahya Husin and Messrs. Gesang Setyadi and Dedi Mahdar of PTFI were critical in carrying out the work. The performance of staff with the analytical and testing laboratories was especially noteworthy: Australian Governmental Analytical Laboratory (AGAL, Sydney, Australia), CSIRO (Australia's Commonwealth Scientific and Industrial Research Organization, Sydney, Australia), DPI (Brisbane, Australia), and EVS Environment (Vancouver, BC, Canada). They had to deal with large sample volumes, ultra-trace analyses, and swift turn-around times.

This report was prepared by Joe Volosin and Dr. Rick Cardwell (Parametrix), supported primarily by Barbara Mullen, Lisa Allen, Rick Rosario, Debbie Fetherston, and Lorena Dinger (Parametrix).

We are especially grateful to the scientists who contributed data, reports and insights to specific sections, including Mr. Kent Hortle, Dr. Muslim Muin (ITB), Dr. Paul Anid (HydroQual), Dr. Dominic Di Toro (HydroQual), Dr. Simon Apte (CSIRO), Robert Santore (HydroQual), Dr. Andrew Storey (Wetland Research & Management), and Dr. Russ Hanley (Hanley, Caswell and Associates, Brisbane, Australia).

We also are indebted to the following scientists for their reviews of this report: Dr. David Norriss (Crescent Technology), Dr. Herb Allen (University of Delaware), Dr. Peter M. Chapman (EVS Environment), and Dr. Dominic Di Toro (HydroQual).

ACKNOWLEDGMENTS (Continued)

PTFI Staff: Tailing and Biodiversity Division

Name	Title	Name	Title
Dr. Wisnu Susetyo	VP/Project Manager	Dr. Rudhi Pribadi	Mangrove Expert (UNDIP)
Aloysius Muka	Trainee Advanced	Martinus Muyapa	Contract
Arie Mandessy	Supervisor	Michael Mirapuru	Sampler III
Belasius Mirapuru	Helper	Michael Apaseray	UNCEN Consultant
Benediktus Muka	Eq. Operator	Melky Nixon Paisey	UNCEN Consultant
Bernadus Gobay	Trainee	Nerius Wayne	Trainee Advanced
Bernadus Rahayaan	Carpenter	Novertus Edoway	Sampler II
Betsiana Mano	Time Keeper	Ode Kasmin	Sampler
Bosco Amawo	Trainee Advanced	On Yatipay	Sampler
Damaskus Operawiri	Trainee Advanced	Otto Kirihio	Contract
Daniel Edoway	Trainee	Pius Nimaipo	Carpenter III
Denisius Amawo	Helper	Pratita Puradyatmika	Env. Specialist
Derek Bunay	Sampler II	Robert Sarwom	UNCEN Consultant
Djemianus Romainum	Technician I	Romanus Aymuka	Agriculture I
Ernes Muka	Crafts III	Sigit Darmawanto	HH2 Project Mgr
Emilia Ubra	UNCEN Consultant	Silas Bunay	Sampler
Fabianus Adii	Trainee Advanced	Stenly Fatahan	Contract
Falentinus Nimaipo	Trainee Advanced	Thomas Yatipay	Trainee Advanced
Fitri Sudradjat	Student Training	Tonny Rumalnum	Contract
Frederikus Mirapuru	Crafts II	Victor Pautapea	Technician IV
Herman Purafae	Eq. Operator	Vithalis Nirigi	Driver III
Hendrik Wabiser	Contract	Waluyo Basuki	Supervisor
Januarius Gobay	Agriculture I	Wiem Degey	Technician III
Kaytanus Aypapenae	Sampler III	Wempi Mitapo	Helper
Koman Mambay	Contract	Willem Mairimau	Helper
Leander Zonggonau	Trainee Advanced	Yahya Alkatiri	Sr. Coordinator
Marinus Djopari	Contract	Yance Kanipiau	Sampler
Markus Jitmau	Supervisor	Yupiter Reba	Contract
Marthen Yatipay	Trainee Advanced	Yulius Owemena	Driver III

Environmental Highland Division

Administration Division

Name	Title	Name	Title
Clifton Potter	Technical Advisor	Andreas Hartono	Administrator
Iyan Suryana	Chemical Engineer	Diana Dayme	Clerk

ACKNOWLEDGMENTS (Continued)

Timika Environmental Laboratory

Name	Title	Name	Title
Amelia Robeka Wamafma	Technician	Joni Binga	Technician
Abdul Aziz	Information Engineer	Jeni Tandi	Technician
Bernardus Irmanto	Information Engineer	Karolina Runtuboy	Technician
Dedi Mahdar	Superintendent	Linus Wandikbo	Technician
Demas Rumasewu	Technician	Maya Messet	Administrator
Domianus	Technician	Naomi Sauyai	Technician
Edy Junaedi	Superintendent	Novriadi Visco	Senior Chemist
Elisabeth Yaimaya	Technician	Sugio	Junior Chemist
Esmar Parore	Technician	Suryono	Senior Chemist
Evi Kusmayati	Technician	Threesen Manguling	Technician
Fajar Mulyana	Junior Chemist	Vincent Mitapo	Technician
Felix Pamungkas	Senior Chemist	Yakin Ratta	Technician
Grace Coloay	Technician	Yosina Romainum	Technician
Hery Wahyudi	Senior Chemist	Yunus Ronsumbre	Technician

Tailing And Coastal Division

Name	Title	Name	Title
Abdul Haris	Biologist Fisheries	Manu Mahere	General Hand
Amiruddin	Biologist Contract	Marianus Kamoka	General Hand
Arif Natsir	Biologist Contract	Maya Wellmin Maryen	Administrator
Aloysius Poviaka	Technician	Ode Kasmin	Field Coordinator
Alexander Makamo	Lab Assistant II	Paulus Bunay	Technician II
Benyamin Randing	L/H Technician	Silfester Siaro	Field Technician
Deky Samuel Lala	Senior Scientist	Saverius Nimoreyau	General Hand
Didimus Kukaro	General Hand	Sigit A.P. Dwiono	LIPI Consultant
Darsina Korwa	Junior Clerk	Tenius Tabuni	Technician
Dwi Listyo Rahayu	LIPI Consultant	Thomas Magay	Technician
Esti Gesang Setyadi	Biologist	Toto Simaha	Field Technician
Hendrik Wabiser	Field Technician	Yohanes Emeyau	General Hand
Jonathan Randing	Lab Assistant I	Yance Kanipiau	Field Technician
Junina Tabuni	General Hand	Yohanes Kaize	Biologist
Junior Kotouki	Technician	Yupiter Reba	Field Technician
Kent Gregory Hortle	Technical Advisor	Wellem Pusung	General Hand
Keret Mitapo	General Hand	Wens Omanini	General Hand
Kristinus Muka	General Hand	Welliam Waromi	Ship Mate
Logus Tumuka	General Hand	Woro W. Kastoro	LIPI Consultant
		Zakharias Makamo	General Hand

EXECUTIVE SUMMARY

PTFI has operated a copper mine in Papua, Indonesia since 1973. Tailings from the milling operation are carried by a dedicated river drainage to a lowlands tailings deposition area (the modified Ajkwa Deposition Area or ADA) where the majority of tailings settle. This comprehensive risk assessment seeks to estimate potential risks posed by the substances in the tailings to freshwater and saltwater aquatic life within and beyond the lower portion of the ADA. This document sought to comprehensively assess and quantify current and future potential risks to aquatic life as a result of tailings disposal. Stressors examined included metals (cadmium, copper, lead, nickel, selenium, silver, and zinc), solids (suspended and deposited), and habitat descriptors (salinity and water depth). Special attention was given to the organisms eaten by local people. In addition, potential risks to fish, phytoplankton, zooplankton, and the invertebrates living on and in the sediments and mangroves were examined.

The scope of this analysis included the following areas:

- Lower Ajkwa River within the lower ADA, including associated freshwaters (i.e., Kwamki Lakes and swamps).
- Mangrove forests within the lower ADA, both mature ones and those developing on newly created islands in the lower ADA (Ajkwa estuary)
- All adjacent estuaries, including the Kamora, Tipoeke, Minajerwi, Mawati, and Otokwa
- Arafura Sea, emphasizing locations within 5 to 10 km of shore, but extending more than 100 km offshore

The Ajkwa River above the ADA and the ADA above the former construction access road (upper ADA) were excluded because they are used solely for tailings management.

Past, present, and future potential risks were evaluated. Past and current potential risks were based on ~~water quality measurements and biological monitoring data from 1995 through 2000.~~ These were compared with model projections from 2000 through 2035, the projected date for mine closure, and with 2068, a point believed to represent a long-term benchmark.

A standard risk assessment methodology that has been widely adopted in Australia, Canada, Europe, and the United States was employed. Potential risks were screened sequentially through two separate tiers before quantifying them in the third, comprehensive assessment tier. The first tier, a screening-level risk assessment, has been reported previously in a separate document (Parametrix Project Team 1999). It examined hundreds of potential stressors, eliminated a subset from further consideration because they clearly posed negligible risk, and identified a subset for further examination because of

EXECUTIVE SUMMARY (Continued)

their risk potential or because of uncertainties in the data. The second tier re-examined the potential sediment risks posed by a number of heavy metals using newly collected data. Only copper, and to a minor extent zinc, were identified during the Tier 2 assessment to pose potential risks, and they plus selenium were examined further along with suspended and settleable solids and the habitat descriptors.

Many lines of evidence were used to assess risks, and they principally comprised (1) biological monitoring, (2) toxicity testing, (3) chemical measurements of water and sediment quality, and (4) model predictions of water and sediment chemical quality based on state-of-the-art sediment transport and copper fate models. Each of these comprised multiple lines of evidence, some of which replicated or otherwise were independent of other lines. In interpreting the results, some lines of evidence were accorded more weight than others. For example, biological monitoring data were given more weight than toxicity testing. Toxicity testing was given more weight than risks projected from chemical measurements of water quality, and all three of these were accorded more weight than model estimates of water quality. Relying on all lines of evidence, an overall assessment was performed, and the findings are reported in Table ES-1.

Potential risks were limited to a few substances, locations, and groups of species, and they occurred for different durations. Of the 70 multiple lines of evidence examined, as part of the detailed aquatic risk assessment (see Table ES-1), eleven (16%) suggested moderate to high risk to select aquatic life. All of these moderate to high risks appear to be confined within the ADA boundaries. Copper and tailings solids were the primary substances posing potential risks, and all other metals except zinc in sediment posed negligible risks. The tailings solids can stress organisms by interfering with their feeding or ventilation (breathing), or by smothering. Both copper and solids appear to pose the highest potential risks, although sedimentation and other factors may play a role. Low risks to sediment-dwelling invertebrates extended seaward of the ADA boundary (see Table ES-1). These risks were predicted by the 300 ktpd ANDAL, which stated that *“Significant sediment deposition and elevation of copper concentrations in estuarine sediments is expected to result from the release of tailings fines from the ADA. Impacts are likely to be of high intensity and widespread for the duration of high percentage tailings release. There is a (yet unconfirmed) potential for copper to remobilize from sediments with a subsequent impact on water quality and biota.”*

EXECUTIVE SUMMARY (Continued)

Table ES-1. Overall Judgments Concerning Risk Magnitude Based on Multiple, Independent Lines of Evidence

Line of Evidence	Overall Estimated Risk Magnitude ^a							
	Lower ADA (Upper Estuary)		Lower ADA (Lower Estuary)		Lower ADA (includes part of Outer Estuary and Nearshore Arafura Sea)		Offshore Arafura Sea	
	Upper Water Column	Bottom/ Near Bottom	Upper Water Column	Bottom/ Near Bottom	Upper Water Column	Near Bottom	Upper Water Column	Bottom/ Near Bottom
Biological Monitoring								
Fish	Negligible	Negligible-Low	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
Zooplankton			Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
Phytoplankton			Moderate	Moderate	Negligible	Negligible	Negligible	Negligible
Epibenthic invertebrates		Negligible	Low-High ^b	Moderate	Low	Low	Negligible	Negligible
Benthic invertebrates		High	High	High	Low	Low	Negligible	Negligible
Toxicity Testing		Moderate-High		Moderate	Negligible	Low	Negligible	Negligible
Measured Water Quality								
Copper ^c	Low		Moderate-High	Low	Low	Low	Negligible	Negligible
Suspended Solids	Low		Low-Moderate	Low	Low	Negligible	Negligible	Negligible
Modeled Water Quality								
Suspended Solids	High	High	Low	Low	Negligible	Low	Negligible	Negligible
Sedimentation Rate		Low	Negligible-Low	Low	Negligible	Negligible	Negligible	Negligible
Changes in Water Depth	Negligible	Negligible	Low-Moderate	Negligible	Negligible	Negligible	Negligible	Negligible
Salinity	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

^a Blank indicates the line of evidence was not studied in that location. Risk magnitudes: Negligible risk = < 5% reduction in species, Low risk = > 5 to 30% reduction in species, Moderate risk = > 30 to 50% reduction in species, and High risk = > 50% reduction in species.

^b Risks are low for certain crabs, e.g., Grapsidae and Ocypodidae, but high for mangrove snails and hermit crabs (Diogenidae).

^c Of the metals and metalloids examined, copper was the only metal, with zinc as one minor exception, posing potential risks to certain species of aquatic life in some circumstances.

EXECUTIVE SUMMARY (Continued)

No significant adverse changes are anticipated in the overall character of aquatic habitat, and some of the changes should be beneficial. The Ajkwa estuary and part of the adjacent Arafura Sea will shallow as tailings are deposited. This will expand the estuary seaward, creating more habitat for species that use the estuary as a nursery. Because there will be a large turbidity plume offshore, predation may be reduced on the larval fish and invertebrates that seek food and refuge from predators in these plumes.

Overall, the benthic invertebrates that live within the sediments and some invertebrates that live on the sediments appear at highest risk. More than 50 percent of the 16 identified snail species from mangroves in the reference Kamora system have not yet been found in mangroves in the Ajkwa system. Hermit crabs may be at secondary risk through loss of snail shells as habitat. Risk to benthic invertebrates, including snails, may be due to any one or a combination of stressors, including suspended solids just above the sediment, copper in the sediments, settleable solids, or uninvestigated factors, such as disruption of the food supply to benthic organisms. Further investigation is required. Risks to benthos were predicted by the 300 ktpd ANDAL, which stated *"It can be expected that the 300 ktpd expansion project of PTFI will create significant negative impacts on the benthic community in the estuaries and marine areas that will receive additional tailings."*

There is evidence that benthic macroinvertebrates will recover once mining ceases. The number of benthic invertebrate species rebounded substantially in the Minajerwi estuary 3 years after cessation of tailings inflow upstream, and the number of species appears close to those observed in reference estuaries. The majority of benthic species in this estuary may recover in 5 years. Continued monitoring will document the rate and completeness of recovery in the Minajerwi.

Newly created islands of tailings are colonized by a diverse assemblage of plants and invertebrates, but there appears to be high risks to some invertebrates. It is currently unknown if conditions on these new islands are unsuitable for the missing snail species, or if their absence means they have not yet colonized these new island areas. The hermit crab species that occupy the empty shells of these snail species also appear at potential risk. Tailings islands have been created in the Ajkwa estuary, and monitoring reveals that initial colonization occurs rapidly (months) and involves diverse plant and animal assemblages that appear, overall, to be functioning normally. The early colonizing plant species include the mangrove trees *Avicennia* and *Sonneratia*, a variety of mangrove grasses and sesamid crabs (ecologically keystone groups), plus other invertebrates like polychaetes, which have proliferated in sediments containing tailings.

EXECUTIVE SUMMARY (Continued)

In the open-water channels, a few of the invertebrates that live near the bottom (epibenthos) and some phytoplankton species also were at low to moderate potential risk in the lower Ajkwa estuary and within the ADA. In contrast, fish and zooplankton inhabiting the upper water column in the same area and the nearshore Arafura Sea were not at risk. It appears that as tailings settle out, they do not affect most species in the uppermost water column (i.e., nekton and plankton), but do pose potential risks to organisms living on and in the bottom. Although the 300 ktpd ANDAL specifically predicted significant negative impacts to the benthic community in both the estuary and marine areas containing tailings, it overpredicted risks to other species: *“In the estuaries, potential impacts to biota from tailings include smothering, bioaccumulation and toxicity arising from mobilization of copper. The aquatic biota potentially impacted include fish, invertebrates, aquatic reptiles, plankton, and benthos.”*

All risk assessments depend on limited and uncertain data, and this risk assessment is no exception. The predictions made concerning current risks by this assessment appear relatively reliable because they are based on multiple, sometimes duplicate, and separate lines of evidence. Nevertheless, several uncertainties have been identified that may significantly influence the predictions concerning future risks: (1) tailings loading; (2) resolution of copper fate model; (3) sediment cohesiveness; (4) metal fate and effects in sediments and mangroves; and (5) biological monitoring data for the lower/outer Ajkwa estuary and nearshore Arafura, especially the deeper waters and sediments.

If the amount of tailings discharged by the mill in the future differs from the amount assumed, the potential risks could be different in character from those projected by the modeling data. PTFI's tailings management is a dynamic process that is being adaptively managed. Therefore, confidence in the risk assessment's predictions will be enhanced if its assumptions about tailings loading are considered in light of future tailings management plans.

A copper fate model was initially developed as a coarse-grid model by HydroQual, Inc. (Mahwah, NJ USA) to predict copper concentrations in environmental media, locations and time periods that cannot be sampled. However, the course-grid model was not sufficient for future model predictions. It is anticipated that a fine-grid model will be run to further refine model predictions.

Another model uncertainty concerns the extent of sediment cohesiveness. Cohesiveness defines depositional and erosion potential, and ultimately defines the tailings' spatial distribution over time plus the degree to which the tailings will be covered up by natural sediments upon cessation of mining. Additional laboratory data and field monitoring will clarify tailings behavior over time.

EXECUTIVE SUMMARY (Continued)

The fate and effects of copper in sediment and mangroves are uncertain. It is apparent that water quality and solids behave differently within sediments and mangroves compared to open-water channels, and these may significantly influence potential risks. The biology, ecology, and sensitivity of the key mangrove fauna are poorly understood, as are cause-effect relationships involving benthos, tailings, and copper.

The biological monitoring information significantly increased confidence in the risk predictions, because this program measured how the Ajkwa and adjacent estuaries were actually responding over time to tailings and lack of tailings. Although it has been comprehensive, ongoing, and multi-year, it is desirable to modify this program to address the potential risks and uncertainties identified in this document.

Although this document has focused on those factors associated with potentially significant aquatic risks, many ecosystem components have not changed in response to tailings disposal. Some populations have increased in response to tailings (e.g., standing stocks of polychaetes, shrimp, and catfish). In addition, the increased turbidity and shallowing of the estuary may constitute a benefit rather than a risk to some but not all species by enhancing and creating rearing habitat for fish and invertebrates.

ACRONYMS

ACR	Acute-Chronic Ratio
ADA	Ajkwa Deposition Area
AERA	Aquatic Environmental Risk Assessment
AMDAL	Analisis Mengenai Dampak Lingkungan (Translated to Analysis Concerning Environmental Impact)
AMU	Aimau
ANC	Acid-Neutralizing Capacity
ANDAL	Analisis Dampak Lingkungan (Translated to Analysis of Environmental Impact)
ANZECC	Australian and New Zealand Environment and Conservation Council
ARD	Acid Rock Drainage
AVS	Acid-Volatile Sulfide
BLM	Biotic Ligand Model
CAS	Cold Acid-Soluble Copper
COW	Contract of Work
CSM	Conceptual Site Model
EC50	Median Effective Concentration. In laboratory toxicity test, this is the concentration that effects 50% of the organisms tested.
ERA	Environmental Risk Assessment
GBT	Gambut
GOI	Government of Indonesia
ITB	Institute for Technology at Bandung, Indonesia
IWK	Iwika
KJP	Kajapah
ktpd	kilo ton per day
LC50	Median lethal concentration. In a laboratory toxicity test, this is the concentration that causes mortality in 50% of the organisms tested.
LIPI	Indonesian Institute of Sciences
LOEC	Lowest Observed Effect Concentration
LOEL	Lowest Observed Effect Level
LTEMP	Long-Term Environmental Monitoring Program
MPA	Maximum Acid-Generating Potential
MRT	Molecular Recognition Technology
MSL	Mean Sea Level
NOEC	No Observed Effect Concentration
NOEL	No Observed Effect Level

ACRONYMS (CONTINUED)

NTU	Nephelometric Turbidity Unit, a measure of turbidity
OECD	Organization for Economic Cooperation and Development
P&WERA	Plant and Wildlife Ecological Risk Assessment
PGO	Pandago
ppb	parts per billion
ppm	parts per million
PTFI	PT Freeport Indonesia
PTG	Putting
PTHP	PT Hatfindo Prima
SEM	Simultaneously Extracted Metals
SLRA	Screening Level Risk Assessment
SMACR	Species Mean Acute Chronic Ratio
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
SPW	Sapauwar
SSD	Species Sensitivity Distribution
TMK	Timika
TRMP	Tailings River Management Project of PTFI
TSS	Total Suspended Solids
95 UCL	95 percent upper confidence limit
UNCEN	University Cendrawasih
US EPA	U.S. Environmental Protection Agency
WER	Water Effect Ratio
WHO	World Health Organization

TABLE OF CONTENTS

EXECUTIVE SUMMARY		v
1 INTRODUCTION		1-1
1.1 PURPOSE AND SCOPE.....		1-1
1.2 KEY FINDINGS AND RECOMMENDATIONS OF ECOLOGICAL SCREENING LEVEL RISK ASSESSMENT (PARAMETRIX PROJECT TEAM 1999).....		1-3
1.3 OBJECTIVES OF DETAILED RISK ASSESSMENT.....		1-3
1.4 REPORT CONTENTS AND ORGANIZATION.....		1-4
2 PROBLEM FORMULATION (METHODOLOGY)		2-1
2.1 STUDY AREA.....		2-1
2.1.1 Physical Setting.....		2-1
2.1.2 Ecological Setting – Overview.....		2-2
2.1.3 Ecological Setting – Historical Overview of Environmental Studies, Impact Analyses, and Risk Assessments Conducted for the PTFI Mine.....		2-3
2.1.4 Environmental River Study (Freeport Indonesia, Inc. 1990a).....		2-5
2.1.5 1990: Environmental Ocean Study of the Arafura Sea (Freeport Indonesia, Inc. 1990b).....		2-6
2.1.6 Fish Biodiversity Survey (Allen et al. 1997).....		2-7
2.1.7 Freshwater Fish of the Timika Region, New Guinea (Allen et al. 2000).....		2-9
2.1.8 Aquatic Insect Survey (Polhemus and Polhemus 1997).....		2-9
2.1.9 2001: Wanagon Event Risk Assessment (Hindarti and Parkhurst 2000).....		2-10
2.1.10 1998 Through 2001: PTFI-Sponsored Studies Conducted Specifically to Fill Data Gaps and Reduce Uncertainties in the Detailed Risk Assessments.....		2-11
2.2 SOURCE CHARACTERIZATION.....		2-12
2.2.1 Acid Rock Drainage.....		2-18
2.3 CHEMICAL AND PHYSICAL SUBSTANCES EVALUATED.....		2-19
2.4 FATE AND TRANSPORT OF COPPER IN TAILINGS.....		2-20
2.5 RESOURCES TO BE ASSESSED.....		2-20
2.5.1 Habitats Evaluated.....		2-21
2.5.2 Communities and Species Evaluated.....		2-21
2.5.3 Ecological Function.....		2-28
2.6 ASSESSMENT AND MEASUREMENT ENDPOINTS.....		2-34
2.7 CONCEPTUAL MODEL FOR AQUATIC LIFE.....		2-36
3 EXPOSURE CHARACTERIZATION		3-1
3.1 OBJECTIVES, SCOPE, AND METHODOLOGIES.....		3-1
3.1.1 Data Sources.....		3-1
3.1.2 Data Analysis Methods.....		3-12
3.2 RESULTS.....		3-13
3.2.1 Copper.....		3-13
3.2.2 Selenium in Fish Tissues.....		3-20
3.2.3 Suspended Solids in Surface Waters.....		3-21

TABLE OF CONTENTS (Continued)

3.2.4	Sedimentation Rate	3-23
3.2.5	Changes in Bathymetry and Mangrove Elevation.....	3-25
3.2.6	Salinity	3-27
4	EFFECTS CHARACTERIZATION	4-1
4.1	DATA SOURCES.....	4-2
4.2	DATA DESCRIBING THE EFFECTS OF COPPER ON AQUATIC LIFE	4-4
4.2.1	Specific Toxicological Data Sources	4-4
4.2.2	Toxicity Expressed in Terms of Dissolved and Ionic Copper.....	4-9
4.2.3	Acute-Chronic Ratios.....	4-10
4.2.4	Geographical Differences in Species Sensitivity	4-13
4.2.5	Relative Sensitivity of Species.....	4-14
4.2.6	Methodology for Calculating Species Sensitivity Distributions (SSDs).....	4-15
4.2.7	Assumptions and Uncertainties in Extrapolating From Single-Species Toxicity Tests to the Field.....	4-16
4.3	DATA DESCRIBING THE EFFECTS OF SUSPENDED SOLIDS ON AQUATIC LIFE	4-18
4.4	DATA DESCRIBING THE EFFECTS OF SEDIMENTATION ON AQUATIC LIFE	4-22
4.5	ASSUMPTIONS MADE CONCERNING THE EFFECTS OF SALINITY ON AQUATIC LIFE	4-22
4.6	TOXICITY DATA FOR SELENIUM IN FISH OVARIES.....	4-25
5	RISK CHARACTERIZATION.....	5-1
5.1	TIER 2 RISK SCREENING	5-2
5.2	RISKS ESTIMATED USING BIOLOGICAL MONITORING DATA, MEASURED WATER QUALITY DATA, AND MODELED WATER QUALITY DATA	5-7
5.2.1	Introduction.....	5-7
5.2.2	Risks Based on Existing Biological Monitoring Data.....	5-8
5.2.3	Risks Based on Existing Water Quality Data.....	5-12
5.2.4	Risks Based on Aquatic Toxicity Tests of Surface Waters and Sediments	5-15
5.2.5	Risks Based on Copper Residues in Fish and Invertebrates.....	5-23
5.2.6	Risks Predicted From Water Quality Models.....	5-24
5.2.7	Overall Risk Potential: Examination of All Lines of Evidence and Uncertainties	5-33
6	LITERATURE CITED	6-1
7	GLOSSARY	7-1

TABLE OF CONTENTS

LIST OF FIGURES

- 1-1 Project Area
- 1-2 Sites from Which Data were Used in the SLRA
- 1-3 The Framework for Ecological Risk Assessment
- 2-1 Grasberg Open Pit Mine
- 2-2 Altitudinal Features of PTFI Mine and Project Area
- 2-3 Biogeographical Regions of Indonesia
- 2-4 Major Ecosystems in the Contract of Work Area
- 2-5 Tailings Production at PTFI Mine: Past and Projected
- 2-6 Tributary to the Aghawagon River Without Tailings
- 2-7 Number of Taxa Identified by PTFI in 1990 Baseline Survey in the Arafura Sea
- 2-8 Photographs of the Tailings Management System
- 2-9 Differences in the Distributions of Dissolved Aluminum in Freshwater-Dominated Reaches of the Ajkwa, Kamora, Minajerwi, and Otokwa Estuaries (1996-1999)
- 2-10 Differences in the Distributions of Dissolved Aluminum in Saltwater-Dominated Reaches of the Ajkwa, Kamora, Minajerwi, and Otokwa Estuaries (1996-1999)
- 2-11 Upper Ajkwa Estuary
- 2-12 Outer Ajkwa Estuary & Arafura Sea
- 2-13 Ajkwa Mangroves
- 2-14 Southern Coast of Papua Showing Sediment Plumes of Highland Rivers
- 2-15 Conceptual Model of Key Aquatic Ecosystem Components: Lower Ajkwa River
- 2-16 Conceptual Model of Key Aquatic Ecosystem Components: Ajkwa Estuary
- 2-17 Conceptual Model of Key Aquatic Ecosystem Components: Arafura Sea Where Suspended Solids Are Below Approximately 50 to 70 mg/L
- 2-18 Kwamki Lakes Along the West Levee and the Ajkwa Deposition Area, South View
- 2-19 Fish Food Habits in Uppermost Estuaries (Kamora to Otokwa)
- 2-20 Fish Food Habits in Outer Estuaries (Kamora to Otokwa)
- 2-21 Relationship Between Mangrove Area and Shrimp Production
- ~~2-22 Conceptual Model Showing How Aquatic Life are Potentially Exposed to Substances in Tailings~~
- 3-1 Areas Encompassed by Model Domains
- 3-2 Cumulative Probability Distribution and Examples
- 3-3 Example of How Maps Will Be Used to Display Temporal and Spatial Differences in Risk Levels and Concentrations of Stressors
- 3-4 Biotic Ligand Conceptual Model
- 3-5 Accuracy and Uncertainty in Biotic Ligand Model Predictions: Lab and Field Toxicity Tests with Fish and Invertebrates

TABLE OF CONTENTS (Continued)

- 3-6 Dissolved Copper Concentrations in Surface Waters of the Upper and Lower Ajkwa Estuary, 1996-1999
- 3-7 Differences in Sediment Porewater Concentrations in 2000: Ajkwa, Minajerwi, and Otokwa Estuaries
- 3-8 Sediment Porewater Copper Concentrations in the Arafura Sea
- 3-9 Copper Concentrations in Surface Waters, Crab Burrow Waters, and Sediment Porewaters from Ajkwa and Kamora Estuaries
- 3-10 Mangrove Crab and Burrows
- 3-11 Cumulative Distribution of Copper Residues in Tissues (Muscle) of All Fish Species Sampled From Various Locations in Study Area
- 3-12 Distributions of Copper Residues in Fish Species at Station S-260 Based on Year Sampled
- 3-13 Distributions of Copper Residues by Fish Species: Station S-260 in Upper Ajkwa Estuary
- 3-14 Cumulative Distribution of Copper Residues in Invertebrate Species from Locations Sampled
- 3-15 Relationship Between Body Size and Copper Residue: *Geloina* Clams Collected From Mangroves
- 3-16 Cumulative Distributions of Copper Residues in Invertebrates Sampled From Various Locations in the Study Area
- 3-17 Selenium Residues in Ovaries of 12 Fish Species from Lower Ajkwa and Kamora Rivers and Estuaries
- 3-18 Selenium Residues in Ovaries of all Fish Sampled from Different Riverine and Estuarine Locations in the Lower Ajkwa and Kamora
- 3-19 Selenium Residues in Ovaries of Fish Species Caught From the Lower Ajkwa and Kamora Rivers
- 3-20 Background Concentrations of TSS (mg/L) Predicted by Hydrodynamic Modeling
- 3-21 Measured TSS Concentrations in Surface Water Along the Main Ajkwa River Channel and Arafura Sea
- 3-22 Changes in Surface Water TSS Proceeding into Mangroves From Main River Channels: Ajkwa and Kamora Year 2000 Data
- 3-23 Changes in TOC Concentrations Proceeding into Mangroves From Main River Channels: Ajkwa and Kamora Year 2000

- 3-24 TSS Distributions in Ajkwa and Kamora Mangrove Surface Water: Year 2000
- 3-25 Predicted Median TSS Concentrations in Mangroves: 2000
- 3-26 Predicted Median TSS Concentrations in Mangroves: 2014
- 3-27 Predicted Median TSS Concentrations in Mangroves: 2034
- 3-28 Predicted Median TSS Concentrations in Mangroves: 2068
- 3-29 Predicted Median TSS Concentrations in Uppermost Water Column: 2000
- 3-30 Predicted Median TSS Concentrations in Uppermost Water Column: 2014
- 3-31 Predicted Median TSS Concentrations in Uppermost Water Column: 2034

TABLE OF CONTENTS (Continued)

- 3-32 Predicted Median TSS Concentrations in Uppermost Water Column: 2068
- 3-33 Predicted Median TSS Concentrations in the Water Column Just Above the Bottom: 2000
- 3-34 Predicted Median TSS Concentrations in the Water Column Just Above the Bottom: 2014
- 3-35 Predicted Median TSS Concentrations in the Water Column Just Above the Bottom: 2034
- 3-36 Predicted Median TSS Concentrations in the Water Column Just Above the Bottom: 2068
- 3-37 Average Sedimentation Rates in the Mangroves at Various Distances From the Ajkwa River Channel
- 3-38 Background Sedimentation Rates (mm/mo) Projected for the Estuaries and the Ocean
- 3-39 Background Sedimentation Rates Projected for Mangroves
- 3-40 Median Sedimentation Rates in Estuaries: 2000
- 3-41 Median Sedimentation Rates in Estuaries: 2014
- 3-42 Median Sedimentation Rates in Estuaries: 2034
- 3-43 Median Sedimentation Rates in Estuaries: 2068
- 3-44 Median Sedimentation Rates in Mangroves: 2000
- 3-45 Median Sedimentation Rates in Mangroves: 2014
- 3-46 Median Sedimentation Rates in Mangroves: 2034
- 3-47 Median Sedimentation Rates in Mangroves: 2068
- 3-48 Topography of Mangroves Proceeding 500 m from Channel (0 m) Into Forest on Ajkwa Transect 33
- 3-49 Topography of Mangroves Proceeding 500 m from Channel (0 m) Into Forest on Ajkwa Transect 36
- 3-50 How the Estuarine Sediment Transport Model Assumed Sediment Would Accumulate in Estuarine Areas Relative to Tide and Mean Sea Level
- 3-51 Water Depths Projected for Estuaries and the Ocean: 2000
- 3-52 Water Depths Projected for Estuaries and the Ocean: 2014
- 3-53 Water Depths Projected for Estuaries and the Ocean: 2034

- 3-54 Water Depths Projected for Estuaries and the Ocean: 2068
- 3-55 Depths of Tailings Projected to be Deposited in the Mangroves: 2000
- 3-56 Depths of Tailings Projected to be Deposited in the Mangroves: 2014
- 3-57 Depths of Tailings Projected to be Deposited in the Mangroves: 2034
- 3-58 Depths of Tailings Projected to be Deposited in the Mangroves: 2068
- 3-59 Surface Salinities Projected for Estuaries and the Ocean: 2000
- 3-60 Surface Salinities Projected for Estuaries and the Ocean: 2014
- 3-61 Surface Salinities Projected for Estuaries and the Ocean: 2034
- 3-62 Surface Salinities Projected for Estuaries and the Ocean: 2068

TABLE OF CONTENTS (Continued)

- 3-63 Bottom Salinities Projected for Estuaries and the Ocean: 2000
- 3-64 Bottom Salinities Projected for Estuaries and the Ocean: 2014
- 3-65 Bottom Salinities Projected for Estuaries and the Ocean: 2034
- 3-66 Bottom Salinities Projected for Estuaries and the Ocean: 2068
- 3-67 Median Salinities in Mangroves: 2000
- 3-68 Median Salinities in Mangroves: 2014
- 3-69 Median Salinities in Mangroves: 2034
- 3-70 Median Salinities in Mangroves: 2068
- 4-1 Species Sensitivity Distributions for the Acute and Chronic Toxicity of Dissolved Copper to Freshwater Organisms at 150 ppm Hardness
- 4-2 Species Sensitivity Distributions for the Acute and Chronic Toxicity of Dissolved Copper to Saltwater Organisms
- 4-3 Species Sensitivity Distribution for SEM-AVS/foc Concentrations Associated With Chronic Toxicity to Benthic Organisms
- 4-4 Regression Used to Generate the Acute-Chronic Ratio for Copper Based on Species Mean Acute Value (SMAV) and Species Mean Acute Chronic Ratio (SMACR)
- 4-5 Acute and Chronic Toxicity of Copper to Freshwater Organisms Based on Species Mean Acute and Chronic Values (SMAV and SMCV)
- 4-6 Distributions Comparing the Sensitivities of Freshwater Papuan, Tropical, and Temperate Species to Copper at 150 ppm Hardness
- 4-7 Distributions Comparing the Sensitivities of Saltwater Papuan, Tropical, and Temperate Species to Copper (all salinities tested)
- 4-8 Differences in the Sensitivities of Invertebrates and Fish to Copper in Freshwater at 150 ppm Hardness
- 4-9 Differences in the Sensitivities of Invertebrates and Fish to Copper in Saltwater (all salinities)
- 4-10a Relationship Between Turbidity and TSS for Freshwater-Dominated Portion of Ajkwa Estuary (S-260)
- 4-10b Relationship Between Turbidity and TSS for Saltwater-Dominated Portion of Ajkwa Estuary (EM-270)
- 4-11 Effect of Total Suspended Solids on the Ability of Rainbow Trout to React and Predate Prey

- 4-12 Species Sensitivity Distributions Based on the Stress Index for Total Suspended Solids and Exposure Time (hr)
- 4-13 Species Sensitivity Distribution for Effects of Sedimentation Rate on Estuarine Organisms Compared to Laboratory Data
- 5-1 Estuarine Sampling Locations
- 5-2 Ocean Sampling Locations
- 5-3 Differences in the Number of Macroinvertebrate Species Caught by Electroshocking in the Upper Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)

TABLE OF CONTENTS (Continued)

- 5-4 Differences in the Number of Fish Species Caught by Electroshocking in the Upper Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)
- 5-5 Differences in the Number of Fish Species Caught by Gill Nets in the Upper Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)
- 5-6 Number of Gill Nets in Use by Fishermen From Karaka Island (Portsite) and Poriri Island (Outer Ajkwa Estuary): 1995-2000
- 5-7 Total Number of Outboard Motors Observed at Villages in Local Estuaries: 1995-1998
- 5-8 Differences in the Number of Fish Species Caught by Otter Trawl in the Lower Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)
- 5-9 Differences in the Number of Phytoplankton Species Caught in the Lower Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1997-2000)
- 5-10 Differences in the Number of Zooplankton Species Caught in the Lower Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1997-2000)
- 5-11 Differences in the Number of Benthic Invertebrate Families in the Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1995-2000)
- 5-12 Differences in the Number of Benthic Invertebrate Families in the Outermost Reaches of the Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries, Including the Nearshore Arafura Sea (1997, 1999, and 2000)
- 5-13 Differences in the Number of Epibenthic Invertebrate Species Caught by Otter Trawl in the Lower Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)
- 5-14 Total Number of Benthic Macroinvertebrate Families in the Minajerwi, Kamora, and Otokwa Estuaries (1995-2000)
- 5-15 Number of Macroinvertebrate Species in Ajkwa and Kamora Mature Mangroves: 2000
- 5-16 Differences in the Biomass of Fish Caught by Otter Trawl in the Lower Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)
- 5-17 Differences in the Biomass of Epibenthic Invertebrates Caught by Otter Trawl in the Lower Ajkwa, Minajerwi, Kamora, and Otokwa Estuaries (1996-1999)
- 5-18 Bioavailable Copper Concentrations in Ajkwa Mangroves in 2000 Compared to the Chronic Saltwater Species Sensitivity Distribution (SSD) for Copper
- 5-19 Example of Correlations Between Water Quality Risks and Biological Monitoring Estimated Risks for Bioavailable Copper and TSS Compared to Number of Fish Data: Caught by Trawl in the Lower Ajkwa Estuary at EM-270 in 1996-1999
- 5-20 Toxicity of Sediments Collected from Study Area in 1999 and 2000 to the Amphipod *Ampelisca abdita* Over a 10-Day Period
- 5-21 Relationship Between Porewater Dissolved Copper and Toxicity of Sediments and Water Containing Copper and Other Substances to *Ampelisca abdita*
- 5-22 Comparison of Measured 10-day Sediment Toxicity to *Ampelisca abdita* to that Predicted Based on Porewater Concentrations and Water-Only, 4-day Toxicity Test
- 5-23 Relationship Between 20-Day Mortality of *Ampelisca abdita* and the Number of Benthic Invertebrate Families in a Sample
- 5-24 Illustration of How Risks Were Computed by Solving for the Area Overlapped by the Exposure and Species Sensitivity Distributions (See Text for Further Discussion)
- 5-25 Predicted Background TSS Risks in the Uppermost Water Column

TABLE OF CONTENTS (Continued)

- 5-26 Predicted TSS Risks in the Uppermost Water Column: Year 2000. Background Risks Have Been Subtracted.
- 5-27 Predicted TSS Risks in the Uppermost Water Column: Year 2014. Background Risks Have Been Subtracted.
- 5-28 Predicted TSS Risks in the Uppermost Water Column: Year 2034. Background Risks Have Been Subtracted.
- 5-29 Predicted TSS Risks in the Uppermost Water Column: Year 2068. Background Risks Have Been Subtracted.
- 5-30 Predicted Background TSS Risks in Water Just Above the Bottom
- 5-31 Predicted TSS Risks in Water Just Above the Bottom: Year 2000
- 5-32 Predicted TSS Risks in Water Just Above the Bottom: Year 2014
- 5-33 Predicted TSS Risks in Water Just Above the Bottom: Year 2034
- 5-34 Predicted TSS Risks in Water Just Above the Bottom: Year 2068
- 5-35 Predicted Background TSS Risks in Mangrove Surface Waters
- 5-36 Predicted TSS Risks in Mangrove Surface Waters: Year 2000
- 5-37 Predicted TSS Risks in Mangrove Surface Waters: Year 2014
- 5-38 Predicted TSS Risks in Mangrove Surface Waters: Year 2034
- 5-39 Predicted TSS Risks in Mangrove Surface Waters: Year 2068
- 5-40 Predicted Background Sedimentation Rate Risks in the Main Channels
- 5-41 Predicted Sedimentation Rate Risks in the Main Channels: Year 2000
- 5-42 Predicted Sedimentation Rate Risks in the Main Channels: Year 2014
- 5-43 Predicted Sedimentation Rate Risks in the Main Channels: Year 2034
- 5-44 Predicted Sedimentation Rate Risks in the Main Channels: Year 2068
- 5-45 Projected Sedimentation Rate Over Time in Upper Ajkwa Estuary Mangroves
- 5-46 Projected Sedimentation Rate Over Time in Lower Ajkwa Estuary Mangroves
- 5-47 Predicted Background Sedimentation Rate Risks in the Mangroves
- 5-48 Predicted Sedimentation Rate Risks in the Mangroves: Year 2000
- 5-49 Predicted Sedimentation Rate Risks in the Mangroves: Year 2014
- 5-50 Predicted Sedimentation Rate Risks in the Mangroves: Year 2034

- 5-51 Predicted Sedimentation Rate Risks in the Mangroves: Year 2068

TABLE OF CONTENTS

LIST OF TABLES

ES-1	Overall Judgments Concerning Risk Magnitude Based on Multiple, Independent Lines of Evidence.....	vii
2-1	Physiographic Types and Land Systems in Lowland Areas of the PTFI COW Area.....	2-4
2-2	Major Aquatic Environmental Investigations Sponsored by PTFI.....	2-4
2-3	Aquatic Species Found in Lowland and Highland Rivers Not Containing Tailings.....	2-6
2-4	Environmental Management Plan Summary From 300 ktpd Regional AMDAL.....	2-13
2-5	Substances Examined in Detailed Aquatic Ecological Risk Assessment.....	2-19
2-6	Fish Species, Shellfish, and Crabs Caught in Kamoro Camps for 1-2 Days and 1 Night at Two Freshwater, Lowland Locations Along the Kamora River.....	2-24
2-7	Relationships Between Assessment and Measurement Endpoints.....	2-35
3-1	Years Modeled.....	3-3
4-1	Concentrations of (Σ SEM-AVS)/ f_{oc} That Pose Potential Acute and Chronic Risk to Sediment-Dwelling Organisms.....	4-7
4-2	Comparative Toxicity of Copper to Freshwater Crustacea and Fish From Tropical Australia and Temperate North America.....	4-14
4-3	Salinity Tolerance Ranges for Freshwater, Estuarine, and Marine Fish and Invertebrates.....	4-23
5-1	AVS, SEM, and Metal Concentrations in Whole Sediment Compared to US EPA (2000) Criteria.....	5-4
5-2	Modeled Background TSS Concentrations in the Estuaries.....	5-26
5-3	Areal Extent (km^2) of Different Salinities in the Upper Water Column Beyond the ADA Boundary.....	5-30
5-4	Areal Extent (km^2) of Different Salinities in the Lowermost Layer of the Water Column Beyond the ADA Boundary.....	5-31
5-5	Areal Extent (km^2) of Different Salinities in Ajkwa Mangroves and Areas That Ultimately Become Dry Because Tailings Deposition Has Elevated Them Above Maximum Tidal Elevation.....	5-32
5-6	Overall Judgments Concerning Risk Magnitude Based on Multiple, Independent Lines of Evidence.....	5-34

TABLE OF CONTENTS (Continued)

APPENDICES

- A DATA RELATED TO THE PROBLEM FORMULATION
 - A1 Locally Important Fish Species
 - A2 Fish Food Habits Data
 - A2.1 Tabular Summary
 - A2.2 Detailed PTFI Fish Food Habits Data
 - A3 Sources of Carbon in Prey of Key Fisheries Species
 - B DATA RELATING TO EXPOSURE
 - B1 Maps Showing Sampling Locations
 - B2 Relationship Between Turbidity and Total Suspended Solids Measurements
 - B3 Assessment of the Fate of Copper and Status of the Macroinvertebrate Community in the Ajkwa and Kamora Mangroves in 2000
 - B4 Nearfield Hydrodynamic Modeling of Institute of Technology – Bandung
 - B5 HydroQual, Inc. Report: Hydrodynamic Modeling and Copper Fate Application of the Biotic Ligand Model to Predicting Site-Specific Copper
 - B6 Sediment Porewater and SEM/AVS Data Obtained by CSIRO and LIPI
 - B6.1 Porewater – Sampling and Analysis Methodology
 - B6.2 AVS and SEM Metals – Sampling and Analysis Methodology
 - B7 Copper Residues in Fish and Invertebrates
 - B7.1 Fish
 - B7.2 Invertebrates
 - B8 Selenium in Ovaries of Fish
 - C DATA RELATED TO THE EFFECTS CHARACTERIZATION
 - C1 Toxicity Data for Copper and Aquatic Life
 - C2 Toxicity Data Used for Total Suspended Solids and Aquatic Life
 - C3 Data Used Concerning Effects of Sedimentation Rate on Aquatic Life
 - D DATA RELATED TO THE RISK CHARACTERIZATION
 - D1 Relationship Between Shrimp Production and Area of Mangrove Forest
 - D2 Acute Toxicity Testing With a Local Aquatic Species to Determine Copper Bioavailability in the Lower Ajkwa River and Upper Estuary
 - D3 Rainbowfish Hatchability Testing
 - D4 Comparison of Aquatic Ecological Risks Based on Measured and Modeled Water Quality Data and Biological Monitoring Data
-

PTFI Aquatic Environmental Risk Assessment

Appendices Report List

A1

Timko, Mark. 1998. Fisheries survey of the PT Freeport Area, Papua, Indonesia. P.T. Freeport Indonesia, Kuala Kencana, Papua, Indonesia. 24 pp.

Affiliation of Author:

PT Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Study Description:

Fisheries survey table identifying fish species and number of fish individuals in the Timika market.

A2.1

PTFI (PT Freeport Indonesia). 1998. Fish Food Habits Data – PTFI, 1996-1998 (unpublished Biological Monitoring Data). P.T. Freeport Indonesia, Kuala Kencana, Papua.

Affiliation of Author:

PT Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Study Description:

Fish food habit data were compiled by PTFI based on the Coastal Environmental Monitoring Program, quarterly monitoring program fish collection. Stomach contents from fish collected between 1996 and 1998 from the Kamora, Ajkwa and Otokwa estuaries were evaluated by PTFI personnel.

A2.2

~~**Hanley, Russel¹. 2000. Invertebrate Food Habits Data – PTFI (unpublished Biological Monitoring Data). P.T. Freeport Indonesia, Kuala Kencana, Papua.**~~

Author Affiliation:

¹Hanley Caswell and Associates, Brisbane, Australia.

Study Description:

Invertebrate food habit data were evaluated by Dr. Hanley based on the quarterly monitoring program invertebrate collection. Stomach contents from invertebrates collected between 1998 and 2000 were evaluated.

A3

Storey¹, A.W., S.C. Apte², C. Davies², and K.G. Hortle³. 2001. Sources of carbon in prey of key fisheries species. Report on preliminary results. PTFI Freeport Indonesia, Kuala Kencana, Papua. 31 pp.

Affiliations of Authors:

¹Wetland Research & Management, 28 William Street, Glen Forrest, WA 6071, Australia

²Centre for Advanced Analytical Chemistry, CSIRO Energy Technology, Lucas Heights Research Laboratories Private Mail Bag 7, Bangor, NSW 2234

³PT Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Study Description:

The objectives of this study were to identify and describe the major food chains and carbon (energy) sources supporting key estuarine and lower river species (fish, crustaceans and molluscs) of the tailings-affected Ajkwa Estuary, and of the Kamora Estuary, which is not influenced by tailings or other anthropogenic activities.

B.1

Maps showing sampling locations.

Affiliation of Authors:

P.T. Freeport Indonesia, Kuala Kencana, Papua, Indonesia

B2

Hortle¹, Kent G. 2000. Water quality data, TSS and turbidity comparison. PT Freeport Indonesia Co., Environmental Monitoring Program.

Affiliation of Authors:

¹PT Freeport Indonesia Co. Environmental Department.

Study Description:

Total suspended solid and turbidity data from the quarterly monitoring program were evaluated to define a relationship between the two parameters. The relationship was developed so that site-specific regressions useful for converting TSS to turbidity and vice-versa could be conducted.

B3

Parametrix Project Team. 2002. Assessment of the fate of copper and status of the macroinvertebrate community in the Ajkwa and Kamora mangroves. Prepared for P.T. Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Affiliation of Authors:

Parametrix, Inc. and PT Freeport Indonesia

Study Description:

The objective of this study was to evaluate potential cause-effect relationships between the physical, chemical, and biological parameters defining copper exposure in the mangroves. This study attempted to define the relationship between tailings exposure in the field and indicators of stress on the aquatic community.

B4

Muin, M. 2001. Long-term hydrodynamic and sediment simulation in Ajkwa estuary, adjacent mangrove, and Arafura Sea using three dimensional boundary fitted model. 3 volumes. LAPI, Institut Teknologi Bandung, Bandung, Indonesia.

Affiliation of Author:

LAPI, Institut Teknologi Bandung, Bandung, Indonesia.

Study Description:

A model was developed to predict sedimentation properties for tailings discharged from the ADA. Dr. Muslim developed a three dimensional model to predict the sedimentation pattern in the Ajkwa Estuary, the mangroves, estuaries to the west and east of the Ajkwa, and the nearshore Arafura Sea. The three dimensional model calculates the distribution of tailings concentration and deposition, both in the surface waters of the main channels, in the sediments, and in the mangroves.

B5s

HydroQual, Inc. 2002. Fate and transport of tailings in the Ajkwa River, Ajkwa estuary and Arafura Sea.

Affiliation of Authors:

Study Description:

A description of the methods and results of modeling sediment transport in the Arafura Sea.

B6

CSIRO (Centre for Advanced Analytical Chemistry). 1999. Sediment porewater and SEM/AVS Data – 1998-1999 (Unpublished Data). Prepared for P.T. Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Affiliation of Authors:

Centre for Advanced Analytical Chemistry, CSIRO Division of Energy Technology,
Private Mail Bag 7, Bangor, NSW 2234, Australia

Study Description:

The analysis of porewater copper and SEM/AVS were conducted by CSIRO. Samples were collected by CSIRO and PTFI personnel. These samples were collected for special studies as well as for the Coastal Environmental Monitoring Program, quarterly monitoring program.

B7

PTFI (PT Freeport Indonesia). 2000. Copper Residues in Fish and Invertebrates – PTFI, 1996-2000 (unpublished Biological Monitoring Data). P.T. Freeport Indonesia, Kuala Kencana, Papua.

Affiliation of Authors:

PT Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Study Description:

Copper residues in fish and invertebrate were evaluated as a component of the Coastal Environmental Monitoring Program, quarterly monitoring program. Data were also derived from special studied conducted for the ERA. Residue data from fish and invertebrates collected between 1996 and 2000 were compiled by PTFI personnel.

B8

PTFI¹ (PT Freeport Indonesia). 2001. Selenium residues in fish ovaries – PTFI, 2001 (unpublished Biological Monitoring Data). P.T. Freeport Indonesia, Kuala Kencana, Papua.

Affiliation of Authors:

PT Freeport Indonesia, Kuala Kencana, Papua, Indonesia.

Study Description:

Selenium residues in fish ovaries were evaluated based on special study conducted for the ERA. Residue data from fish collected between 1999 and 2000 were compiled by PTFI personnel.

C1

Toxicity data for copper and aquatic life

Affiliation of Authors:

Compiled by Parametrix using a variety of literature sources, especially the U.S. Environmental Protection Agency.

Study Description:

A compilation and tabulation of the world's known, high quality aquatic toxicological data (acute and chronic) for copper. The sensitivities of freshwater and saltwater organisms are addressed separately.

C2

Toxicity data for total suspended solids and aquatic life

Affiliation of Authors:

Compiled by Parametrix using a variety of literature sources.

Study Description:

A compilation and tabulation of the world's known, high quality aquatic toxicological data (acute and chronic) for suspended solids.

C3

Data used concerning effects of sedimentation rate on aquatic life

Affiliation of Authors:

Compiled by Parametrix using a variety of literature sources.

Study Description:

~~A compilation of the data relating the sedimentation rate or amount and the responses of biological communities, based on a computer search of the literature, including review articles.~~

D1

Relationship between shrimp production and area of mangrove forest

Affiliation of Authors:

Indonesian Scientists who published in the following: Martosubroto, P. and N. Naamin. 1977. Relationship between tidal forests (mangroves) and commercial shrimp production in Indonesia. Marine Research in Indonesia 18:81-86.

Study Description:

Re-analyzed Table 1 of Martosubroto and Naamin (1977). Compiled data by specific areas into regional information, using the categories specified in the authors' publication.

D2

Acute toxicity testing with a local aquatic species to estimate copper bioavailability in the lower Ajkwa River and upper estuary. Prepared for P.T. Freeport Indonesia, Environment Department, Kuala Kencana, Papua, Indonesia. 2001

Affiliation of Authors:

Parametrix, Inc., Kirkland, WA USA

Study Description:

Toxicity testing was conducted to evaluate the acute toxicity of copper as CuSO_4 on survival of larval *Caridina sp.*, a sensitive, local species of freshwater shrimp. Static renewal bioassays were conducted with larval *Caridina* to assess site-specific effects of copper on aquatic life in the Ajkwa River and its estuary. A second study objective was to generate empirical data for validating the Biotic Ligand Model (a model that defines copper bioavailability to aquatic life).

D3

Templeman, M.A. and Chris.D. Williams. 1999. Review of whole effluent toxicity testing of waters from Ajkwa deposition area 1997-1999 using *Melanotaenia splendida rubrostriata* (Red Striped Rainbowfish) embryos. Prepared for PT Freeport Indonesia Environmental Department. Report No. AES01R16. Kuala Kencana, Papua, Indonesia.

Affiliation of Authors

Primary Authors: Aquatic Environmental Services, Townsville, Australia.

Reviewers: Parametrix, Inc., Kirkland, WA USA

Study Description:

A review of effluent toxicity tests on survival of *Melanotaenia splendida rubrostriata* (Red Striped Rainbowfish) embryos. These data re-analyzed to further explore the concentration-response relationships in the data in the report by Templeman and Williams (1999).

D4

Comparison of aquatic ecological risks predicted using water quality monitoring data: 1996 to 2000.

Affiliation of Authors:

Parametrix, Inc., Kirkland, WA USA

Study Description:

An analysis of biological monitoring data collected by PT Freeport Indonesia in the upper and lower ADA estuary and nearshore Arafura Sea from 1996 to 2000. The purpose was to learn what impacts, if any, were revealed by the biological monitoring data for fish and invertebrates captured at different estuarine locations by gill net, electroshocking, trawling, plankton sampling, and benthic grabs. The Ajkwa estuary and nearby estuaries were sampled, including reference estuaries.
