Final Report

Volume 1
Aquatic Ecological Risk Assessment

Prepared for

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Affiliate of Freeport-McMoRan Copper & Gold

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August 2002
Project No. 555-3259-003

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.

Table A-1. Overall Judgments Concerning Risk Magnitude Based on Multiple, Independent Lines 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	
Line of Evidence	Upper Water Column	Bottom/ Near Bottom	ADA Mangroves	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
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		Low		Negligible	
Suspended Solids	Low		Low-Moderate	Low				Negligible	
Modeled Water Quality									
Suspended Solids	High	High	Low	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	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.

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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).

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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, Tipoeka, 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

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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."*

Table ES-1. Overall Judgments Concerning Risk Magnitude Based on Multiple, Independent Lines 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	
Line of Evidence	Upper Water Column	Bottom/ Near Bottom	ADA Mangroves	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
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		Low		Negligible	
Suspended Solids	Low		Low-Moderate	Low				Negligible	
Modeled Water Quality									
Suspended Solids	High	High	Low	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	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 grapsid and sesarmid crabs (ecologically keystone groups), plus other invertebrates like polychaetes, which have proliferated in sediments containing tailings.

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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.

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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

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APPENDICES

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, Russel[1]. 2000. Invertebrate Food Habits Data – PTFI (unpublished Biological Monitoring Data). P.T. Freeport Indonesia, Kuala Kencana, Papua.

Author Affiliation:

[1]Hanley 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

Storey[1], A.W., S.C. Apte[2], C. Davies[2], and K.G. Hortle[3]. 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:

[1]Wetland Research & Management, 28 William Street, Glen Forrest, WA 6071, Australia
[2]Centre for Advanced Analytical Chemistry, CSIRO Energy Technology, Lucas Heights Research Laboratories Private Mail Bag 7, Bangor, NSW 2234
[3]PT 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

Hortle[1], Kent G. 2000. Water quality data, TSS and turbidity comparison. PT Freeport Indonesia Co., Environmental Monitoring Program.

Affiliation of Authors:

[1]PT 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

PTFI[1] (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.