OK TEDI MINING LTD. (OTML) ENVIRONMENT PEER REVIEW GROUP (PRG): COMMENTS ON KEY ISSUES AND REVIEW COMMENTS ON THE FINAL HUMAN AND ECOLOGICAL RISK ASSESSMENT DOCUMENTS

April 2000

1. INTRODUCTION

In 1997 Ok Tedi Mining Limited (OTML) formed a Peer Review Group (PRG) to provide advice, recommendations and peer review related to a human and ecological risk assessment (HERA) of the terrestrial and aquatic ecosystems of the Ok Tedi/Fly River systems downstream of the mine. The HERA was based on the state of knowledge to July 1999. There are five members of the PRG:

Dr. Peter Chapman, EVS Environment Consultants, North Vancouver (Chair)
Professor Margaret Burchett, University of Technology, Sydney
Professor Peter Campbell, Univestité du Québec
Professor William Dietrich, University of California, Berkeley
Professor Barry Hart, Water Studies Centre, Monash University

The PRG's terms of reference are as follows:

- Advise OTML management on the HERA programme, with particular focus on the approach (conceptual basis and methodology), the screening level risk assessment (SLRA), and the final detailed level risk assessment (DLRA).
- Recommend additional scientific studies necessary to ensure that the HERA has an adequate information base.
- Review key reports and individual projects related to the HERA programme as referred to the PRG by OTML management.
- Provide further advice as requested by OTML management.

The PRG has been involved in the HERA process since August 1997 and have attended all workshops and provided detailed review comments on individual proposals, projects, and on all aspects of the HERA.

The purpose of this report is two fold. First, in Section 2.0, the PRG comments on key issues, effectively updating our previous report (Fourth PRG Report [20/07/99]). Second, in Section 3.0, the PRG provides summary review comments on the November 1999 report prepared for OTML by Parametrix Inc. and URS Greiner Woodward Clyde "Assessment of Human Health and Ecological Risks for Proposed Mine Waste Mitigation Options at the Ok Tedi Mine, PNG". These summary review comments summarize very detailed review comments provided as working documents to OTML and to the DLRA consultants (Fifth PRG Report [04/02/2000]). Our comments regarding the DLRA include: (1) limitations imposed by the scope mandated by OTML; (2) uncertainties; and, (3) errors or omissions. We conclude this report (Section 4.0) with a summary intended to provide context to the findings to date.

The DLRA still has a number of inadequacies, some of which could have been addressed (cf. Section 3 of this report). However, the DLRA is still a useful document (though not as useful as it might have been). In addition, the present risk assessment process has substantively advanced the science from the first risk assessment completed by OTML in 1996.

2. COMMENTS ON KEY ISSUES

The following Comments on Key Issues expand and develop on similar issues contained in the PRG's Fourth Report. Our intent in providing these comments here is to continue to emphasize their importance not only for short-term decision-making regarding the future of the mine but also regarding long-term monitoring and possible remediation efforts. For each Key Issue we briefly: explain its importance (Why), what we understand is presently occurring and will occur in the future (Present Situation and Prognosis), what makes this understanding less than perfect (Key Uncertainties), and recommended future actions (What Needs to be Done). We end with a Summary regarding the key issues.

2.I The Accuracy or Predictive Power of the Sediment Transport Model.

Why

The sediment transport model provides a quantitative causal linkage between sediment input and environmental change throughout the Ok Tedi - Fly River system. An acceptably accurate model is needed to evaluate controls on rates (or frequency) and location of: 1) channel bed level change (aggradation or degradation); 2) bed material grain size; 3) flooding; 4) particulate copper dispersal through the river and floodplain system; 5) floodplain sedimentation; and 6) tie channel closure. The model is the only quantitative means to evaluate various waste management options and the response of the system to eventual mine closure. *Understanding and investigation of all other key issues depend on the reliability of this model*.

Present Situation

A massive, long-term transformation of the Ok Tedi - Fly River system, driven by mine-derived sediment loading, is underway. Considerable data have been gathered that quantify how the system has changed since mining began. Two downstream tapering aggradation zones have become established, one in the gravel reach of the Ok Mani - Ok Tedi Rivers and the other in the sand bedded reach in the lower Ok Tedi - Fly Rivers. Mine derived sediment has spread across nearly all of the lower Ok Tedi and Middle Fly floodplain. Rates of floodplain deposition in both the lower Ok Tedi and Middle Fly have been estimated from field data. Monitoring by the OTML Environment department has provided essential data on stream flows, river profiles and cross-sections, floodplain dimensions, sediment inputs (from rock waste, wall erosion from waste dumping, and milling), and sediment discharge at various stations along the system. However, the quality of these data is generally poor in the complicated lower Middle Fly where backwater effects and extensive floodplain water storage influence discharge rating curves and where limited data exist on channel cross-sections and bed material grain size. Although there was a period of intensive monitoring of flooding processes on the Middle Fly, inadequate monitoring has occurred to quantify flow and sediment properties below the junction with the Strickland River. Limited data have been collected on tie channel topography or off-river water body infilling.

The sediment transport model used to investigate environmental change by OTML has been constructed by Drs. G. Parker and Y. Cui. This model has been in development for over 10 years. It is a physics-based model that represents state of the art modelling and was built specifically to address issues on the Ok Tedi and Fly River system. The most recent modelling results applicable to the HERA are those reported in July 1999 by Cui and Parker. This report and model results were reviewed by the PRG, T.R. Davies (for OTML) and C. R. Dietrich and A. J. Jakeman (for BHP). All three reviews accept the basic approach employed by Cui and Parker. Davies and the PRG conclude that the model performs reasonably well in the Ok Tedi and upper Middle Fly River in predicting observed bed level changes. Both reviews note (as do Cui and Parker) the apparent poor performance of the model in the lower Middle Fly, where aggradation rates appear to be under predicted, and attribute this to both inappropriate downstream boundary condition data and inadequate modelling of downstream sorting of sediment. There is, however, considerable uncertainty regarding the extent and magnitude of current (as of the time of this report) aggradation in this reach. The BHP sponsored review emphasized a recommendation by Davies that sensitivity analysis of the model should be performed. This has yet to be done.

Only a few model outcomes are mentioned here in this Key Issue analysis:

- The model predicts that upon mine closure a wave of sediment will continue to slowly propagate downstream through the Middle Fly, causing maximum aggradation to occur in the lower Middle Fly above D'Albertis Junction decades after mine closure.
- Modelling of the mine waste options shows that there is a benefit (relative to no waste management scheme, i.e., the Null case) of about a one meter reduction in bed aggradation in the lower Ok Tedi and upper Middle Fly if the higher dredging rate is used. This would cause a reduction in the maximum flood duration and frequency.
- Dredging has no significant effect on suspended particle concentrations.
- Dredging is predicted to reduce total deposition on the floodplain by about 50% at Konkonda, but to have relatively minor benefits on floodplain deposition rates in the Fly floodplain.

Prognosis

- The Ok Tedi - Fly River system has been and will continue to be massively altered for many decades into the future no matter what option (closure to dredging) is taken.
- The Parker-Cui model predicts that by 2010 about 70% of the total mine-derived sediment delivered to the system will still be in storage between the mine site and Manda in the Null case. This sediment will be remobilized and conveyed downstream, retarding recovery of the bed levels.
- Even by 2055, predicted bed levels will remain about 2 m above pre-mine levels at Kuambit.
- Over 100 Mt of mine derived sediment will be deposited on the floodplain in Reach 4 (D'Albertis to Manda).

The high dredging option, which is the option actively underway, does create tangible benefits. However, quantification of these benefits is not yet possible. These issues were the subject of discussions at a Sediment Transport Workshop on site, the third week of February 2000. Updated information from this workshop and from further modelling and field work will be included in the next PRG report.

The Cui-Parker model can be used to continue to explore waste management options. In order to improve model usefulness and accuracy, however, the downstream lower boundary condition needs to be changed so that the effects of high flow in the Strickland and tidal influences can be directly modelled. Further improvements in the downstream sorting of sediment in the Middle Fly are needed as well. Sorting effects may be important to the prediction of aggradation in the lower Middle Fly. There is evidence such sediment sorting effects are already occurring in the Ok Tedi River.

Key Uncertainties

<u>Field Observations</u>

- There remain uncertainties in the sand budget because of: 1) the breakdown rate of rock waste (and wall rock) and grain size produced by breakdown; 2) changing estimates of sand content from the mill; 3) amount of storage of sand in the Ok Tedi above the dredge.
- The spatial extent and rate of aggradation in the lower Middle Fly are poorly known.
- There are insufficient data to move the downstream boundary condition to Ogwa (below Everill Junction).
- Changes in tie channel geometry and the possible threat of closing of tie channels are unknown.
- Bed material grain size distribution through the Ok Tedi - Fly system appears to remain poorly defined.
- Due to difficulties in making measurements in the lower Middle Fly, there are large uncertainties in the observed sediment discharge at Manda and Obo.
- Limited data exist on sedimentation in the off-river water bodies.
- Rates of floodplain deposition since about 1994 are not well known.

<u>Modelling</u>

- The model does not predict the apparent aggradation that has occurred in the lower Middle Fly. This is of great concern because the extent of future environmental change in this reach thus cannot be predicted. Observations indicate that change is underway in this reach: aggradation may be greater than 2 m, dieback appears to be occurring, significant amounts of sediment are entering off-river water bodies, and tie channel closure appears to be a threat.
- The model is not designed to predicted tie channel sedimentation and the risk of closure.
- The fate of tie channels on the Fly is unknown.
- The lateral variation in floodplain deposition rate is based on an empirical exponential function based on limited field data. The spatial structure of floodplain deposition is only crudely modelled.

What Needs to be Done

<u>Field work</u>

- The high resolution channel surveys established by Andrew Marshall along the Fly, particularly the lower Middle Fly, need to be redone to document rates of aggradation.
- A water level and flow monitoring station needs to be set up below the Strickland and re-established on the Strickland in order to document potential backwater effects on the lower Middle Fly.

- A campaign should be undertaken to resolve the sand sediment budget in order to better estimate the benefits of dredging. This would include: 1) documenting abrasion rate and production of sand (and finer sediment) from waste rock, Harvey wall rock, and Ok Tedi gravels; 2) quantifying sand storage in the Ok Tedi; 3) documenting the grain size of the bed material in the Fly; and, 4) quantitatively performing a sediment budget from field observations.
- Field surveys of tie channels throughout the Fly system need to be done to document any tendency towards closure.
- Field surveys of sediment in-filling in off-river water bodies should be done. The model cannot predict what happens to these water bodies.
- The role of rain on the floodplain in preventing sediment rich flood waters from spreading across the valley has been documented by Geoff Day. This study needs to be reported to help guide improved modelling.

<u>Modelling</u>

- The Cui-Parker model should undergo a sensitivity analysis. This would at the least establish what factors have the largest control on model outcomes.
- The floodplain deposition model should be revised to account for the effects of rainfall on the floodplain reducing overbank deposition rates.
- The model needs to be rerun with improved downstream boundary conditions to address backwater effects on the lower Middle Fly.
- Improvements are needed in the computation of grain size sorting in sand rich sediments. This should have important consequences for predicting the fate of the lower Middle Fly.
- Construction of a tie channel sedimentation model should be considered. At present there is no predictive capability for this crucial issue.

2.2 Dieback Extents and Conversion in Floodplain Vegetation

Why

The ecological structure, composition, biodiversity and resource potential of the different types of vegetation are very different from one another. Any significant ecological disturbance caused by mine activities is human-induced environmental harm, and regrettable from an ecological perspective. The severity of harm is partly a function of area. In addition, the long-term harmful consequences (including failure to re-establish to an approximately pre-mine equilibrium of vegetation types and relative abundances), from evidence from other studies, increase as the area involved expands. The vegetation and its fauna are also important resources for the local people, different vegetation types supplying different plant and animal food sources, by different production, harvesting or catching methods.

Present Situation and Prognosis

Dieback and conversion have occurred, are occurring, and the affected areas are predicted to increase. The dieback area may eventually exceed 2,000 km^2.

Key Uncertainties

- Aggradation levels that flow from the sediment transport model. These affect severity and duration of stressor presence (sedimentation, flooding, scouring).

- Details of the topography of the floodplain, which must be related to the distribution of vegetation. However, the vegetation alone does not give precise information on standing water under flooding situations, or possible changes to flow patterns across the floodplain.

And, from the Fourth PRG Report:

- Present extent of dieback.
- Species-specific dieback thresholds.
- The rates of future dieback.
- Impacts on grass and swamp vegetation.
- Effects of dieback on genetic, species, and community biodiversity, ecosystem function, food resources.
- What "recovery" will mean in terms of vegetation type or species composition.
- Effects on faunal complement of the current and possible future mosaic of vegetation types in the catchment.

What Needs to be Done

- Accurate mapping of the current extent of dieback.
- More detailed, ground-truthed, topographic mapping of selected areas, from which more accurate topographical inferences can be drawn.
- Ground-truthing of processes of conversion to wetter vegetation types.
- If possible, more detailed floristic surveys of the species present and distribution of the four or five vegetation types in the catchment.
- Studies of relationships between flooding frequencies and durations and depths of flooding.

2.3 Fish Biomass Decline and Loss of Fish Biodiversity

Why

Fish biomass and diversity comprise one index of the health of the aquatic ecosystem; as well, the fisheries are an important food resource for the local people. Declines in fish biomass and diversity have been documented since the late 1980s and, because of a lack of mechanistic understanding of causality, it is not possible to judge whether declines will continue to the point of elimination of species and failure to recover after mine closure.

Present Situation

- Fish declines may be the result of direct or indirect exposure to stressors. Stressors may be chemical (predominantly Cu) or physical (loss of direct habitat by sedimentation along banks and smothering; loss of food derived from loss of plant habitat in the same way; and total suspended solids (TSS), which can be expected to adversely affect both plants and animals).
- Isotope studies clearly indicate that algae, which are very sensitive to copper, are an extremely important component of the aquatic food webs. Adverse effects on algae will also adversely affect the fisheries.

- Physical habitat attributes strongly affect diversity and biomass of fish communities; habitat is degraded due to aggradation.
- Some portion of the decline could be the result of over-fishing, caused in part by leaving out permanent nets, from which fish are removed on need, the rest dying and rotting.

Prognosis

No prognosis is possible. The possibility of a catastrophic collapse of the fisheries in the Fly River is high if bioavailable copper reaches levels that are toxic to algae; this situation is likely to occur before toxicity to fish occurs. This possibility becomes a certainty if copper bioavailability and toxicity increase as a result of widespread acid rock drainage (ARD). The possibility of a collapse as opposed to a stabilization at current low levels of diversity and biomass, if copper toxicity is not an issue, is real but no probabilities can be assigned.

Key Uncertainties

- No mechanistic understanding of the reasons for the fisheries declines. Without such an understanding, no realistic prognosis or remedial actions are possible.
- Mine-related issues that most affect the fisheries either directly (aggradation, toxicity) or indirectly (toxicity to the food chain).
- Whether copper "spikes", which may presently be toxic to algae, are real or artifacts of sampling/analyses.
- Whether the tie channels, which are critical to the fisheries, will be impaired by continued aggradation.

What Needs to be Done

- Conduct and report on studies planned pre-El Niño to determine the relationship between aggradation and fish habitat.
- Additional mechanistic studies as necessary to determine the relationship between mine-related stressors and fisheries declines.
- Further toxicity testing of key, representative aquatic (fish and food chain) species.
- Further studies of algae distributions and factors affecting their survival and growth.
- Minimization of needlessly destructive fishing methods.

2.4 Possible Chemical Stressors of Plants

Why

The DLRA listed a number of metals present in the system that are potential hazards to plants. The document points out that the physical stressors of sedimentation and flooding may be masking the effects of possible chemical toxicities (which may be chronic rather than acute).

Present Situation and Prognosis

To date only one species has been subjected to toxicity testing, and that was an exotic crop plant (maize). The nutrient trials that were carried out with this species, on dredge sediment, indicated that there was no toxicity of this substrate to maize. In addition, sago and cassava were found to be low in Cu and most other metals of concern. It is difficult to predict, however, the possibility of chronic toxicities and this possibility should not be overlooked. It is possible that as flooding recedes as a stressor, other toxicities may be revealed. This matter also relates to the next key issue - ARD.

Key Uncertainties

- Element-specific tolerances or sensitivities in any native species.
- Metal levels in a set of tissues from any species (i.e., root, stem, leaf, fruit or seed).

What Needs to be Done

- Acute toxicity testing on germination and early seedling growth of a range of ecosystem indicator species, of dredge and other relevant sediment sources.
- Acute toxicity testing as above, using standard soils spiked with each metal of concern individually, and in a few reasonable combinations.

2.5 Possible ARD Hazards

The question of acid rock drainage (ARD) was raised at the first PRG meeting in Melbourne (August 18-20, 1997) and is also one of five major concerns previously identified by the PRG (Third PRG Report to OTML [24/02/99]). A preliminary report on ARD was produced by the Australian-based consulting group EGI and was provided to the PRG on June 29, 1999. This was the first serious treatment of this issue. The preliminary report was the subject of both written PRG comments and intense discussions at the July 6-8, 1999 Brisbane workshop. The PRG has not received any further information on ARD since that time, although ARD was discussed at a technical workshop in Tabubil on January 19, 2000.

There appear to be two possible sources of very serious problems:

- The change within 5 years in the nature of the ore body to be mined, so that it appears necessary to mine limestone to mix with the mine wastes to maintain an acid neutralizing capacity. This leads to the question of whether that can be done successfully so as to prevent ARD from occurring.
- The possible acidification of the floodplain as aggradation and flooding are reduced, and more mine-derived sediments are exposed to wet-dry weather cycles.

Both these hazards need to be addressed with more detailed modeling, and more investigative, and perhaps field-manipulation studies.

Why

- Oxidation of sulphide ores produces acidic runoff with consequent low pH and high concentrations of sulphate.
- This low pH can release metals from sediments and other rocks, with consequent toxic effects to both terrestrial and aquatic biota.

Present Situation

- ARD is a very serious potential problem for OTML. If the risks from ARD and metal leaching from deposited material cannot be eliminated or at least minimized, the environmental consequences will be extremely grave.
- It is also predicted that deposited material from the mine may be resulting in localized areas with the potential for ARD. There is evidence that such sites presently exist.

- Based on the limited analyses to date of river-bank material it is predicted that ARD will not be an issue on the Fly River floodplain from presently deposited sediments; however, this needs more study. Additionally, the prediction that ARD may not be a problem may not be true for at least the Ok Tedi floodplain.

Prognosis

- It has been suggested that the predicted reduction in limestone content of the ore body over the next 10 years could be resolved by mining additional limestone from nearby and mixing it with the mine waste. In particular, it has been suggested that limestone additions would help avert the very serious risk of major and widespread toxicity problems. However, limestone addition will only be effective if the differential transport of sulphides and carbonates is taken into account. In other words, both acid-generating and acid-neutralizing minerals must co-deposit in the river reaches downstream. This latter effect seems unlikely.
- The EGI report predicts that the tailings will be potentially acid forming (PAF) for the life of the mine. Therefore, land-based disposal options must consider the need to prevent oxidation of stored tailings. This will require a high level of design and diligence, with ongoing maintenance to prevent ARD and Cu (and other metals) leaching from land storage.

Key Uncertainties

- The short-term (1-2 years) is reasonably certain – few ARD problems except perhaps in some localized regions. However, the longer term is less certain. There is some evidence that there is differential transport and settling of the tailings and waste rock resulting in localized areas where high concentrations of sulphidic material could occur. With time these areas could become PAF zones.
- The Fly River floodplain is not included in the ARD model. Based on river bank samples the flood plain deposits are expected to be NAF due to excess acid neutralizing content (ANC), but this aspect needs considerably more work to be certain.
- The mine pit is not yet included in the ARD model and is likely to be PAF.

What Needs to be Done

- Determine waste rock and tailings acid base characteristics and production schedules (by rock type and sulphur grade); oxidation kinetics, lag period, Cu leaching (load); geochemistry of river deposited material (by location and particle size).
- The ARD model needs to be linked with the CSIRO dCu chemistry model (see below).
- The sediment transport model needs to be modified to account for the specific gravity of the particles being transported downstream (to account for any downstream "winnowing" of the tailings, waste rock and slide material, leading to differential transport of sulphides and carbonates).
- The possibility of ARD on the floodplain needs to be fully evaluated.
- Appropriate sediment sampling (i.e., not biased to finer materials) needs to be done.
- Modeling needs to be continued and the key uncertainties outlined above need to be addressed. Some of this work program is presumably underway – but the PRG has not yet seen any results nor been asked to comment on the experimental design.
- Alternative measures (i.e., other than simply adding more limestone to the mine waste) need to be considered to address the risk of ARD.

2.6 Cu Chemistry Model/Cu Spikes (and in Relation to ARD Hazards)

Dissolved copper (dCu) is of concern because high concentrations of bioavailable Cu could kill key elements of the aquatic flora and fauna in the Ok Tedi/Fly River systems. Algae are an important component of the aquatic food chain and are well known to be very sensitive to Cu. Thus, they would be particularly adversely affected by any increase in bioavailable Cu. CSIRO modelling and the OTML Cu monitoring data base suggest little likelihood of toxic problems due to Cu unless ARD occurs (assuming that Cu "spikes" detected during monitoring are not real). However, there is a lack of Cu toxicity data for Fly River species. Further, dCu modelling is presently insufficiently sensitive.

Why

- According to OTML monitoring data, total dissolved copper levels (dCu) in the Ok Tedi and upper Middle Fly increased during the period from 1990 to 1996. At OTML's key monitoring station upstream, Nukumba, the most marked increase in average dCu levels was from 1996 to 1998.
- Although copper is an essential micronutrient, at quite low concentrations it can also exert toxic effects on aquatic biota.
- Therefore it is essential to know: (1) was the increase in dissolved Cu concentrations real?; (2) if so, what caused dissolved Cu concentrations to increase?; (3) will dissolved Cu concentrations continue to increase over mine life and beyond, or have they reached their maximum?; and, (4) are dissolved Cu concentrations presently encountered in the Ok Tedi / Fly having negative effects on aquatic life?

Present Situation

- There is a consensus that the increasing dCu trend shown in OTML monitoring data is real, but the occurrence of dCu "spikes" (i.e., transitory elevated values of dissolved copper) has not yet been confirmed - the apparent spikes may represent inadvertent contamination of the filtered river water samples.
- Dissolved copper concentrations are not related to total particulate copper levels, but do show a strong positive correlation with the concentration of particulate copper present in an oxidized form. Oxidation of mine-derived copper sulphides to mineral forms that are more amenable to solubilization (e.g., malachite and amorphous copper hydroxide) is clearly an important process. This oxidation of sulphide minerals increases the reactivity of the solid copper phase, thereby making it easier for other processes (e.g., complexation by dissolved organic matter) to solubilize copper.
- Dissolved Cu levels in the Ok Tedi and Fly Rivers are well below the solubility limit for inorganic copper(II), indicating that inorganic dCu levels are controlled by adsorption reactions rather than by precipitation reactions (note that adsorptive control is the general case in oxic surface waters world-wide).
- Most of the dissolved copper in the Ok Tedi / Fly River system is organically bound; based on annual average values, the residual inorganic dissolved Cu should not be of ecotoxicological concern.

Prognosis

- Based on the CSIRO geochemical model (which assumes that system pH values are unaffected by the various mine waste mitigation options), mean annual dCu levels will plateau between the years 2000 to 2010 at levels only slightly higher than those being measured currently. Dissolved copper concentrations in the Ok Tedi and Middle Fly will take over 40 years to return to pre-mining levels.

- Provided that ARD does not affect the overall pH of the system, the geochemical model predicts that the various proposed mine waste mitigation options will not appreciably affect dissolved Cu concentrations in the system. Closing the mine at end of FY 2000 has the effect of reducing dCu concentrations in the system some 10 years earlier than the other schemes. This is the only scheme that is predicted to significantly affect dCu concentrations in the river system.

Key Uncertainties

- The OTML temporal records of dissolved Cu at Nukumba, Obo and Ogwa show quite marked variations between sampling dates (i.e., dCu "spikes"). During their sampling of the Ok Tedi / Fly system, CSIRO researchers have not recorded any such high dCu concentrations. Are the dissolved Cu spikes real or a sampling artifact?
- The present CSIRO dCu model can only provide average dCu concentrations on an actual time frame; this needs to be improved so that dCu concentrations can be predicted at various locations on a weekly or daily time frame.
- What role will the aggraded material that has accumulated in the river channel during mine life play in the Cu balance after mine closure?
- Is the system pH sufficiently well buffered that it will remain constant throughout mine life (even as the type of ore being processed changes over the period 2000-2010) and beyond?
- To assess the risk of possible Cu toxicity to aquatic biota, concentrations of dissolved Cu were compared with an acute toxicity probability distribution. Is the toxicity database, which was used to derive the acute toxicity probability distribution, relevant for Fly River species?
- Do the new sediment aggradation calculations influence the prognosis (above)?

What Needs to be Done

- Initiate a monitoring programme (Reaches 1 and 2; current waste rock dumps; off-river water bodies; dredge spoils) to look for early warning indicators of ARD development.
- Consider a possible survey of the Bougainville mine (which has been shut down for 8 years, but which used to dispose of their mine waste directly into the river) to evaluate the risk of development of ARD in the river bed after mine closure.
- Maintain the river monitoring programme to follow dissolved Cu levels and to check the predictions of the CSIRO geochemical model (in addition to dCu, include ASM-Cu and copper complexation capacity measurements).
- If current investigations show that the dCu spikes are indeed real, then it will be important to determine (i) what causes short-term copper variability, and (ii) how copper speciation varies during such "events".
- Test the toxicity of copper to aquatic species that are indigenous to the Ok Tedi / Fly system.
- Improve the link between the CSIRO geochemical model and the ARD model.

3.0 Review Comments

This section summarizes the PRG's detailed review comments (from the Fifth PRG Report [04/02/2000]) on both the "Final" Screening Level Risk Assessment (SLRA) and the "Final" Detailed Level Risk Assessment (DLRA) documents.

As noted in our Fourth Report (20/07/99), the SLRA has been previously subjected to review twice in draft format. However, the DLRA has previously only been subjected to one review, and only as an incomplete draft. Our review of this "final" SLRA document only considered whether our previous comments had been adequately addressed. In contrast, our review of the "final" DLRA document considered not only whether our previous comments had been adequately addressed but also involved a complete review of the document.

Our review comments are provided in the context of OTML's July 1999 cut-off date for information to be included in the HERA. In other words, per OTML's instructions, neither the HERA nor this report consider new information provided after that date. However, we are aware of some of the results of post-July 1999 studies and believe that those findings are of direct relevance to ultimate decision-making. Further, those findings could well change some of the DLRA results for comparisons between options. We expect that review of post-1999 study findings will be the subject of a future PRG report.

3.1 Screening Level Risk Assessment (SLRA)

The SLRA is set out within the standard risk assessment (RA) format. Many (but not all) of its shortcomings do not arise from the document itself but rather from the terms of reference and the sometimes glaring data gaps. The terms of reference effectively limited the SLRA (and the DLRA) to a comparative RA format; the PRG were asked to identify potential fatal flaws common to all options. Our review of the HERA (Human and Ecological Risk Assessment) consultants' replies to our previous comments indicates that not all of our comments or concerns have been adequately or completely addressed. However, given the above limitations and time constraints imposed by OTML, we do not believe that there is anything to be gained by further changes to the SLRA. Instead, we focus our attentions on the more important DLRA.

3.2 Detailed Level Risk Assessment (DLRA)

The PRG finds the "Final" DLRA document to have a number of major gaps and deficiencies. The major gaps are due to either limitations on the scope and timing of the DLRA imposed by OTML or due to remaining uncertainties. Deficiencies are due to errors or omissions that could have been addressed in the document.

The major gaps and deficiencies as identified from our detailed review comments (Fifth PRG Report [04/02/2000]) are provided below in bulleted format. After the narrative for each bullet we provide one or more numbers explaining the context of the major gap or deficiency: (1), (2), or (3). A (1) indicates limitations on the scope and timing of the DLRA; a (2) indicates remaining uncertainties; a (3) indicates errors or omissions.

- ***The risk of ARD is not resolved and is essentially not considered in the DLRA***. This potential risk should have been considered in more detail in the DLRA. The actual risk of ARD could not be resolved within the DLRA timeframe, but must be resolved expeditiously post-DLRA, i.e., is ARD likely and if so is it or is it not controllable, and what are the risks? Considerably more work is required to resolve this issue, including a well-planned field program to determine the capacity of river and floodplain sediments/soils to resist acid generation in the future. Note in this regard that “river bank” samples are not appropriate. Since “river banks” can be composed of bedrock, sediment that is hundreds of years old, or sediment deposited yesterday, such samples are virtually uninterpretable. Furthermore, the assumption that the increased sulphide content of the mine waste can be buffered by addition of limestone appears to be wrong. Sulphide-bearing minerals will tend to segregate because of specific gravity differences. Other alternatives to avoiding ARD should be sought. (1), (3)

- ***The risk of chemical changes in the floodplain environment as the sediment-water system evolves is unexplored***. This issue is related to the point above, but could occur in the absence of ARD. Wetting and drying cycles on the floodplain could release pulses of copper and possibly other contaminants to the aquatic environment. The possibility of this risk both with and without ARD must also be resolved expeditiously post-DLRA. (2)

- ***The causal linkages between the sediment and the fish decline are not determined.*** This is a critical issue that should have been addressed by investigative studies when fish declines first became evident in the late 1980s, rather than continuing to monitor the declines. Studies related to this determination were planned as part to the HERA but proved impossible due to the intervention of El Niño. These studies must be completed expeditiously post-DLRA. (2)

- ***The relative risk of aggradation and tie channel closure in the lower Middle Fly is unknown but is potentially very serious.*** This is a real issue that should have been discussed in the DLRA and which needs to be investigated post-DLRA. Lack of discussion regarding tie channels is particularly surprising given that this issue was discussed in detail at the July 1999 workshop attended by the HERA consultants. This is a risk which, if widespread and persistent, will have devastating effects on the ecosystem. (2), (3)

- ***The loss of biodiversity due to forest dieback is unknown and could be large***. This issue is not resolvable within the DLRA timeframe and was not adequately discussed in the DLRA. Evidence for losses of genetic diversity is lacking, true. But the reasons for this are twofold. First, there are insufficient data to make a conclusion; in other words, there is also scant evidence for discounting likely losses of genetic diversity since we have poor documentation of the species composition in the tropical forests (as acknowledged in the DLRA). Second, even if our knowledge of the vast array of species was much improved, we would still not have empirical evidence of genetic diversity effects since the system has not had time to readjust to post-mine conditions yet. Only after many decades will we know for sure whether genetic diversity was impacted in the long-term. (2), (3)

- ***The potential benefits and risks of dredging are not well understood***. This is a result of a rapid and continuing increase in our knowledge base as the dredging trial programme continues. (2)

- ***The risk to humans is poorly examined given that the DLRA is a human, not just an ecological risk assessment.***. Risks due to chemical contaminants were the only risks assessed in the DLRA; OTML chose to assess social risks via a different mechanism. However, potential human risks are inadequately addressed in the DLRA, even though the DLRA states that these have been qualitatively considered. For instance, the possibility that increased flooding could increase the incidence of disease and increase the risk of food rotting should have at least been mentioned in the DLRA. Data on risks to humans are available but outside the DLRA. These data were not provided to the PRG for their review. (1), (2), (3)

- ***A reliable prediction of the likely extent of dieback and vegetation conversion is not available for the entire Fly River***. This is not a fault of the DLRA but rather of the state-of-the-science of modeling. (2)

- ***The present condition of the lower Middle Fly is very poorly documented and has not been adequately modeled; its future state may lead to great ecosystem decline***. Same comment as the previous point. (2)

- ***Presently, dissolved copper (dCu) modeling can only provide average dCu concentrations on an annual time frame***. This must be improved post-DLRA so that dCu concentrations can be predicted at various locations on a weekly or daily time-frame. (2)

Our review of the HERA consultants' replies to our previous comments indicates that many of our previous comments (including some they had agreed to address) have not been addressed, and factually incorrect material is still included in the DLRA. In particular, **it appears that most previous comments regarding the state of knowledge of the physical system have been ignored.** Key points related to our disagreements or reservations include the following:

- ***The ecological differences between the mine waste management options are not as small as indicated by the HERA consultants***. As a general example, the benefits of closure on the aquatic system are understated. The DLRA proposes that there may be some threshold that degradation has to go below to make things better, but there are no data to support this hypothesis. One could just as well, and perhaps more strongly, argue that closure would greatly reduce the exposure time to high aggradation and suspended sediment loads and it is the duration of high exposure that really influences the rate of recovery. Recent surveys suggest that dredging is lowering the bed and that there may be a vegetation response. Also, surely closure must reduce the risk of ARD. Further, the dieback model does not apply for a large proportion of the floodplain. Reduced aggradation may have a large effect on the middle and lower parts of the Middle Fly which cannot be accurately predicted. In too many cases the DLRA relies inappropriately on modelling efforts. More specific examples are provided by the bulleted points on page xviii of the DLRA. Statements here regarding there being little difference between the options have a fatal flaw: the model does not accurately predict the lower Middle Fly aggradation. There has been dieback but the model predicts none because no aggradation was predicted there. The swamp grass reach has forested areas that are at risk but these are not even considered in the model. The only data for the lower Middle Fly suggest that some meters of aggradation have occurred there. Dredging or mine closure that reduces the total aggradation in the lower reach may have large consequences for dieback there. The third bullet states that Option A (early mine closure) dieback is "only" 20% less than Option C (no dredging), and there is stated to be "little difference" from any of the other mine waste management options. **Given that the majority of the tailings pulse is already unstoppable, the 15-20% impact that could be made represents a significant intervention relative to what we have control over**. If management intervention is compared only to the "no-action" baseline, this will always lead to a conclusion that management invention will have little impact, since the baseline impact is so large. However, **the key issue is in fact whether the differences between mine waste management options are sufficient to warrant intervention (i.e., do the benefits of intervention outweigh the economic benefits associated with the mine). If we view the problem as a question of whether we can successfully mitigate *further* damage, this changes the interpretation entirely. In other words, if the ecological damage associated with the *incremental* tailings input is large, this may warrant intervention irrespective of the damage that we cannot control.**

- ***Interpretation of percentage changes in isolation is not always appropriate for comparisons between mine waste management options.*** It is true that there will be large impacts irrespective of the mine waste management option chosen. However, it is still appropriate to consider ***the absolute value of the differences between mine waste management options***. In the DLRA, "comparative risks" are frequently evaluated in the context of percent differences. However, depending on the endpoint, percent differences may or may not provide a good measure of risk. For example, the percent difference between mine waste management scenarios for sediment chemical contaminants is useful, since we do not know the precise site-specific threshold for effects. A 10% increase in a contaminant such as chromium is unlikely to exert substantial ecological change. However, for other endpoints, small percent differences may imply very large ecological implications. For example, a 10% increase in forest dieback (on a scale as large as the watershed under consideration) is potentially very significant given that we already have a strong weight of evidence that forest dieback produces a major adverse effect on time scales of decades or more. Therefore, the interpretation of percentage changes is not always the same. For this reason, **consideration of absolute values of differences between mine waste management options is indeed important**.

- ***The PRG has consistently recommended a summary table stating the estimated risks for each endpoint and mine waste management option.*** Such a table would have addressed many (but not all) of the PRG's comments and concerns, and would have provided a readily understandable integration of the DLRA findings. The DLRA authors' statements about assumptions, uncertainties (which also need to be acknowledged as operating in both directions), predictions, etc. associated with these risk estimates are all valid. However, presenting this information in a table was not intended to assign a greater degree of certainty. The present document contains so much information and so many qualifications, that it is extremely difficult for the reader to get a clear view of the major risks and just how serious they are at present and will be in the future under the various waste mitigation options. A summary table would have allowed the reader to more easily compare the relative magnitude of change associated with each endpoint and option, as well as seeing which endpoints could not be quantified.

Our detailed review of the "final" DLRA document indicates the following additional major deficiencies:

- ***The text on the geomorphology of the river contains a very large number of inaccuracies and incorrect statements, and does not report the data on, for instance, sediment loads, river aggradation, channel slope***. The reporting is qualitative when it should be quantitative (there are a great deal of data available but not used in the DLRA), and also repetitive and overly simplistic. In too many cases the text refers to the wrong modeling predictions. Page 59 of the DLRA provides a good example of the level of errors contained in the DLRA. Scour of the Harvey Walls is CAUSED by the mine waste dumping, not "exacerbated". Dietrich and Parker have forecast that the Harvey Walls area will slowly stabilize as the bed aggrades. The statement in the third paragraph about Reach 1 (the Ok Mani) is wrong. The valley bottom was transformed from a relatively narrow clear flowing creek flowing over bouldery sediment and lined with forest to a broad, braided channel in which the forest was first eroded away due to channel bank migration due to growing bars and then buried by massive amounts of sediment. On Reach 2, channel widening occurred where the banks were not of bedrock, consuming what floodplain there was. The effect systematically declines downstream. The DLRA authors were provided by Bill Dietrich, with a paper providing information quantifying the increased channel migration rates due to mine sediment loading on the upper part of the Middle Fly. However, this information is not contained in the DLRA. **Given that physical "stressors" are a major factor, the loads and physical changes should have been more adequately and correctly reported and explained.**

- The method used to assess the risk of possible Cu toxicity was to combine the acute toxicity probability distribution (based on best available dCu toxicity information) with the modeled annual average Cu concentrations (i.e., single values). We continue to have concerns about a number of aspects of this method and its application. For example, the risks to aquatic biota were assessed using modelled bioavailable Cu concentrations compared with laboratory bioassay dCu data that (as best we can tell) have been hardness normalised only (to 50 mg/L as $CaCO_3$). ***The PRG has continuing concerns about whether the "dissolved" Cu data used in the toxicity distribution curves include the same Cu fractions as the bioavailable Cu fraction modelled by Apte et al.*** The DLRA consultants have stated that "all (toxicity) tests were conducted in low DOC, low TSS waters" and thus "that this (dCu concentration) is not exactly bioavailable copper, but it is close" (Memo to Don Carroll from Brix/Reagan, 8 Dec 1999, p27). However, note that dissolved Cu (dCu) includes the following species:

  dCu = free Cu + hydroxo-complexes + carbonate complexes + Cu-NOM

  where

  free Cu = Cu^{2+}
  hydroxo-complexes = $CuOH^{+} + Cu(OH)_2$
  carbonate complexes = $CuHCO_3^{+} + CuCO_3$
  Cu-NOM = Cu complexed with natural organic matter

  The above expression for dCu assumes no colloidal species present. According to the "Free-Ion Model", copper bioavailability is best predicted in terms of the free Cu^{2+} concentration. Thus it seems that the dCu used in the effects distribution curves would overestimate Cu-bioavailable concentration by including Cu-hydroxo, Cu-carbonate and Cu-NOM species (assuming that these species are NOT directly bioavailable, i.e. that they cannot pass directly through biological membranes by passive diffusion).

  In addition, the PRG has previously noted the problems associated with using modelled **annual average** bioavailable copper concentrations for the risk assessment. Such an approach takes no account of short-term higher Cu concentrations (spikes) that may be sufficient to cause problems. Thus, the effects distribution curves are likely to have **overestimated** the bioavailable Cu concentrations while the modelled data are more likely to have **underestimated** the bioavailable Cu concentrations.

- ***There was little use of algal toxicity data in the assessment of toxicity risk to the aquatic biota of the Fly River***. However, these data are likely crucial to predictions of survival of the fisheries since algae appear to be the most Cu sensitive biota (see data in Appendix G) and are arguably the most important part of the aquatic food web in the Fly River system.

- We remain concerned that ***the consequences of forest dieback (and of potential changes in the swamp grass reach) are not dealt with appropriately and that a far more positive outcome is suggested than is likely***. As presently presented, the wording of some of the statements in the document is misleading. There can be no "available evidence" of the long-term transition to the original vegetation community <u>before</u> the mine-related stressors are ameliorated. The assumption that affected areas will be eventually reestablished (to original condition) is a critical one. It may be that if the level of disruption is severe enough, the "retardation" could be more or less permanent. Since so much of the organic carbon and nutrients are tied up in the vegetation, the loss of forest canopy could have dire consequences for the long-term reestablishment of forest communities. The physical effects of burial, low nutrients, and possibly chemical stressors could exacerbate this situation. At the very least, the pattern or distribution of the various vegetation types will be different from what they are or were. In some cases, a type of post-disturbance "primary" succession on new (different from pre-mine) sedimentary surfaces will be involved. In other cases, it will involve secondary succession in the area concerned. Even in areas where re-establishment of the same general vegetation type occurs, the secondary equilibrium produced (climax community) is often quite distinguishable from the primary mature equilibrium of an area. This is presumed to be the result of the changes in microtopography, physicochemical substrate conditions, microclimatic factors (e.g., drainage, light), chance differences in the genome of the colonising individuals, and new *in situ* selection pressures arising from this complex of factors. Commonly the secondary equilibrium vegetation is less diverse than the original. Therefore, extreme caution must be used when asserting that reestablishment to the original community types will successfully occur.

- Following from the above comments, ***there are several statements in the Executive Summary (as well as later in the text) concerning the eventual state of the terrestrial vegetation that are incorrect and likely to be misleading to readers who are non-scientists***. Specifically, these statements may convey the impression that after mine closure the vegetation will eventually revert to the pre-mine state, and/or that replacement of one vegetation type by another that is functioning normally, represents a new state of acceptable normality in the system. For example, page xiv, last line:

  "Available evidence suggests that plant communities in most affected areas will eventually be re-established once mine-related physical stressors return to normal levels."

  And later (page xvii):

  "At the scale of the regional ecosystem, most effects at most locations are likely to be transient over a period of several decades…."

  "Current evidence does not suggest permanent changes in patterns of ecological organisation at the scale of the regional ecosystem."

  These statements suggest that eventually a pre-mining equilibrium in the vegetation will be restored. Yet the international ecological literature on secondary (i.e., post-disturbance) successions and secondary mature equilibrium communities (once referred to as climax communities), indicates that re-established communities are commonly different from, and often less diverse than, those of the primary colonisations of new bare areas. In addition, the patterns and relative areas of the various vegetation types in this river system cannot be predicted, which is a point made later in the text of the DLRA.

  In addition, the statement on functional integrity carries some implication that not only will a newly established "conversion" vegetation type be identical with the primary succession for this community, but that, since it will therefore have a normal pattern of functional organisation, no great harm will have been done. **This implication, whether intended or not, is unwarranted.**

It is in general clear from the DLRA that considerable human and ecological disturbance and harm have been caused by the mining operation, and that the effects will be very long-term, whatever mine option is adopted. However, although any ecological risk assessment will by definition contain uncertainties, in this case some of the uncertainties are vast indeed. This is partly because of the complexity of the system and disturbances being evaluated, but also partly because of the absence of data, some of which could have been acquired by field and laboratory investigations, had more time and resources been available for the purpose. In this regard we note that constraints on the HERA consultants included the fact that many past investigations were not appropriate to the focus of the HERA, and problems with some commissioned studies (timeliness and/or acceptability). However, as noted above, the DLRA still contains serious errors and omissions that should have been rectified.

The DLRA has narrowed the risks to the aquatic ecosystem from the OTML operations to three stressors - Cu toxicity, TSS (total suspended solids) and habitat changes (aggradation). These stressors remained after consideration of the SLRA and available data. Unfortunately, the conclusions from the detailed assessment of the risks from each of these key stressors are largely qualitative. It was disappointing that the DLRA did not provide a more quantitative assessment.

In summary, although the DLRA comprises a great deal of work and is also a useful piece of work, it is not as useful as it should be as either a benchmark document or for decision-making. However, despite the shortcomings, it can still be used by OTML as part of their decision-making process provided the major data gaps and deficiencies noted above (and in more detail in the Fifth PRG Report) are taken into account.

4.0 Summary

The evidence clearly shows that OTML's activities have to date caused major aggradation and flooding in the river valley which, among other effects, have resulted in extensive forest dieback (>500 km^2) which is likely to spread further, possibly exceeding 2,000 km^2. There has therefore at the same time been some loss of biodiversity, at the genetic (i.e., intra-specific) and ecosystem levels, in at least the rainforest system. Based on international comparisons, some loss of species biodiversity is also likely to have resulted already from the mining activities, however this cannot at present be assessed, because of a lack of detailed data on the New Guinea biota as a whole.

The forest dieback has been accompanied by replacement (or conversion) to swamp grasslands and other wetland communities, which are more flood-tolerant. Effects of mine-related activities on diversity, abundance and productivity of these wetter communities are also largely unknown. As the wave of mine-derived sedimentation passes down through the river system, it can be expected that secondary rainforest will be re-established in some areas. Present predictions suggest that no general vegetation type will be lost from the Ok Tedi/Fly valley. However, this is not certain. Further, the patterns of distribution of the dominant vegetation types, their relative abundances, and their exact species compositions cannot be predicted. This is again partly the result of a lack of detailed information on the flora of New Guinea, and partly because the details of the current and future topography and physico-chemical composition of the sediments in this river system are also uncertain.

In addition to widespread adverse effects to the terrestrial environment, the aquatic environment has also been adversely affected over a large area. There are very few fish to be found in the Lower Ok Tedi (an approximate 90% decrease in fisheries biomass). In the middle Fly River, there has been an approximate 75% decrease in fisheries biomass and some species are no longer found in this stretch of the river. Further decreases and possibly even a total collapse of the fishery are possible, however the likelihood of this possibility is unknown because the reason(s) for the original decline are unknown. The primary suspect is aggradation and associated habitat loss in the main river channel. Continued aggradation may threaten the ecologically critical tie channels in the Fly River system. The other major threat to the fisheries is ARD that, if it occurs on more than a localised basis, has the potential to totally eradicate the fisheries either through direct toxicity or indirectly by toxicity to sensitive food chain components (e.g., algae).

ARD also poses a threat to the plant communities living in the floodplain. Surface floodplain sediments presently include tailings and waste rock. Although preliminary modelling and predictions indicate that ARD is not an issue on the floodplain, the work is not definitive and future tailings and waste rock will have a greater ARD potential than was the case in the past.

There are no easy solutions. Closing the mine is arguably the best option environmentally but not necessarily the best social option. However, decisions must be made. And these decisions require the best possible and most up-to-date information. Post-DLRA work must focus on the key uncertainties noted in the DLRA and in the PRG's present report, related in particular to what can be done to minimize or prevent further environmental damage should the mine either continue to the natural end of its life or shut down earlier. In this regard, the positive effects of dredging need to be fully assessed. So too do the possibility of ARD and methods to prevent this, as well as reason(s) for the fisheries decline (which may provide insights into how to ameliorate this or at least prevent a catastrophic collapse).

The PRG recognizes the social value of OTML's presence in PNG but are not in a position nor do we have the expertise to evaluate social benefits compared to environmental harm. We commend OTML for the very valuable environmental studies done to date, but caution that more work is needed and almost certainly must continue post-mining if further environmental harm is to be avoided or minimized.