27

Science, governance and environmental impacts of mines in developing countries: lessons from Ok Tedi in Papua New Guinea

IAN C. CAMPBELL

27.1 Introduction

The construction of the Ok Tedi mine in western Papua New Guinea (PNG) began in 1981, with the first production commencing in 1984. The mine is operated by Ok Tedi Mining Limited (OTML), a company jointly owned in the 1990s by the Australian mining company BHP, the PNG government, and Inmet Pty Ltd, a Canadian mining company. In 2002 BHP, which by then owned 52% of the shares, withdrew from OTML, passing its shareholding to PNG Sustainable Development Program Limited, a company established solely for the purpose of administering the 52% share in the company and using any returns to undertake development work in PNG, particularly within the Western Province. The remainder of the shares are held by the PNG government (30%) and Inmet (18%). However, in 2009 Inmet commenced negotiating with the PNGSDPL to exchange its 18% equity interest for a 5% net smelter return royalty (Inmet, 2010).

The mine has been a major contributor to the economy of PNG. In 2007 it achieved a record pre-tax profit of K2.7 billion (approximately US$1 billion) and contributed 32% of PNG's export earnings (OTML, 2009). It is also a major employer within the Western Province, and PNG as a whole, with a directly employed workforce of about 2000 people, of whom 95% are PNG nationals, and an additional 1500 or so people employed through contractors working for the mining operation.

The environmental impact of the mine has been controversial. A proposed tailings dam on the neighbouring Ok Ma was never completed after a landslide impacted the early construction works in 1984. Waste rock is dumped directly into the local creeks via failing dumps. From 1984 to 1987 the mine operated principally as a gold mine using a cyanide leachate extraction process. Wastes from this process were detoxified before release to the rivers. From 1987 until 2008, when a tailings processing plant commenced operation, the tailings from the copper concentration process were released untreated to the rivers. The mine area creeks drain to the Ok Tedi, a tributary of the Fly River. In 1994 landowners along the Ok Tedi and Fly Rivers sued BHP, as the majority owner of OTML at the time, in an Australian court over environmental damage. The litigation was settled out of court

Water Resources Planning and Management, eds. R. Quentin Grafton and Karen Hussey. Published by Cambridge University Press.

in 1996 for payments of K150 million (about US$113 million) over the remaining life of the mine.

This chapter provides an overview of the present environmental impact within the Fly River system and raises concerns about long-term impacts. It also reflects on the governance issues that have contributed, and continue to contribute, to the environmental impact of the mine.

27.2 The geographical setting

The Ok Tedi Mine is located in the Star Mountains near the headwaters of the Ok Tedi ('ok' is the word for river in the local language). The geomorphology, hydrology, and climate of the Fly River basin have been described in detail by Pickup and Marshall (2009) and are only briefly summarised here. The Fly River catchment is about 75 000 km^2 and is drained by three major tributary branches, the Ok Tedi which drains the Hindenburg Ranges, the Upper Fly which drains the southern part of the Victor Emmanuel Range, and the Strickland which drains the Victor Emmanuel and Central Ranges (Pickup and Marshall, 2009). The Upper Fly and the Ok Tedi meet at D'Albertis Junction, and the river then flows to meet the Strickland River at Everill Junction just upstream of the Fly River delta. The section of the Fly River between D'Albertis and Everill Junctions is referred to as the middle Fly (Figure 27.1).

The Ok Tedi catchment has a heavily dissected ridge and ravine topography. For the most part, ridges rise to 200–800 m although there are areas in the north where they rise to over 2000 m. Igneous rock is exposed on some mountain tops, but the geology largely consists of shales, limestone, and sandstones. Although the vegetation cover is dense, slopes are unstable and landslides are frequent, and landslide debris and old flow deposits are common.

From just upstream of Ningerum, the Ok Tedi emerges on to the floodplain of the middle Fly. This is an extended area of flat topography about 400 km long through which the river meanders. Here it was formerly fringed with rain forest on the higher ground, although this has now virtually all died off. The river is characterised by a large number of off-river water bodies (ORWBs) of various types, including blocked-valley lakes as well as oxbow lakes (billabongs), many of which are linked to the river by tie channels.

The delta itself is extensive. According to Pickup and Marshall (2009) it extends a further 400 km from Everill Junction to the Gulf of Papua, occupying an area of about 10 000 km^2. However, from Everill Junction to at least 200 km downstream it flows through a single, well-formed channel and is not particularly deltaic. Downstream from Sturt Island it forms a funnel-shaped system with a tidal range of about 3.5 m at the seaward end and about 5 m at the inland apex (Pickup and Marshall, 2009).

The area is tropical and humid. Average rainfall varies with altitude, with falls in excess of 10 000 mm yr^{-1} at the Ok Tedi mine site and 8000 mm yr^{-1} at the mine settlement at Tabubil (Pickup and Marshall, 2009). Down river, near D'Albertis Junction, the annual rainfall is about 5200 mm and near Everill Junction about 1800 mm. Heavy rain can fall at

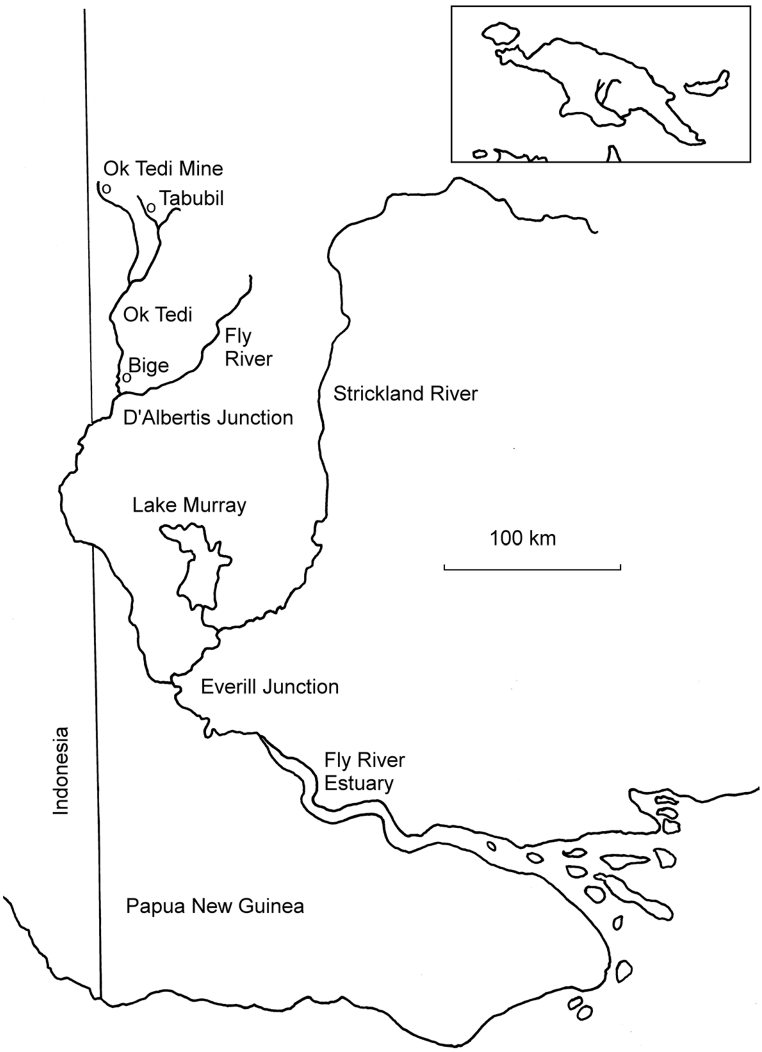

Figure 27.1. Map of south-western Papua New Guinea showing the locations of the rivers and the Ok Tedi mine.

any time of year, but rain is more consistent for the first three or four months of the year, and less from September to November. Around 70%–80% of the rainfall is estimated to run off in the catchments of the Upper Fly and Ok Tedi (Pickup and Marshall, 2009). As a consequence, those two rivers are flashy with rapid changes of water level occurring throughout the year. On the Fly River the rapid variations in water level are moderated due to flood wave attenuation and to the storage capacity of the floodplain and ORWBs; these store water when river levels rise, and release it back to the channel when levels fall.

27.3 The mine operation

The mining operation is an open cut which essentially removed the top of Mount Fubilan and is now forming a large pit. Owing to the nature of the ore body, the early operations were focused on gold, which was present in comparatively high concentrations in oxide ores near the top of the ore body. After three years, copper processing began with gold and silver remaining valuable by-products. The main copper ores are sulphidic, mainly monzonite, porphyry and skarn. The concentration of skarn increases towards the lower parts of the ore body. Skarn is the richest ore in terms of copper mineralisation but also the highest in sulphur, which raises particular environmental management difficulties.

The ore is processed on site to produce concentrate, which is piped as a slurry to Kiunga, a port on the Upper Fly River some 130 km south of the mine. The ore concentrate is dried, transported by barge down the Fly River, and then transferred to larger ocean-going vessels either in the Gulf of Papua or at Port Moresby (depending on the time of year and prevailing weather conditions). Overburden, waste rock, and (until 2008) mine tailings are dumped into one of three creek valleys: Harvey Creek or Sulphide Creek (via failing dumps) and the Ok Kumiup (via a pipe). Since 2008, a mine tailings treatment system has operated to remove the sulfides from the tailings. These are now piped to pits on the Ok Tedi floodplain at Bige, about 25 km upstream of the junction between the Ok Tedi and the Fly River. Following the completion of the mine waste management project risk assessment in 2000, OTML began adding additional limestone to the dumped material in an effort to neutralise the acid-forming potential of the sulfide ore wastes. Currently about 10 million tonnes of limestone a year are added.

27.4 Environmental consequences and environmental management responses

The major environmental impacts of the mine have arisen as a consequence of the dumping of waste rock and tailings into the river system. The impacts have led to a number of environmental management responses by OTML in an attempt to mitigate the impacts in the short term, and in some cases to attempt to predict long-term changes.

27.4.1 River sedimentation

The most obvious impact is river bed aggradation as a result of the large volumes of sediment which has been dumped into the system. Currently about 90 million tonnes of material including waste rock, output from the mine waste treatment plant (MWTP), and additional limestone are dumped into the river each year. Within the mine area creeks, the Ok Mani and the Ok Tedi, the stream morphology is completely altered from relatively deep, narrow streams flowing through boulder-strewn channels to broad, shallow streams meandering across floodplains hundreds of metres wide (Figure 27.2). The sedimentation impacts on the Ok Tedi were to some extent anticipated in the original environmental impact assessment (Maunsell and Partners, 1982), but impacts on the Fly River were not.

Figure 27.2. Photograph of the junction of the Ok Mani (left) and Ok Tedi (right). The Ok Mani receives the waste rock pushed into the Harvey Creek valley. The large volume of sediment, completely burying the original valley floor, has altered the morphology of both rivers. (Photo by Ian Campbell.)

Within the middle Fly River the increased sediment delivered from the Ok Tedi has caused substantial aggradation of the river bed. There is a sediment 'slug' down to about the 300 km point of the river, with reduced channel capacity in this section of the river (Pickup and Marshall, 2009). There is also a smaller sediment slug further downstream in the backwater upstream of Everill Junction.

Reduced channel capacity in the Middle Fly has had both operational and environmental consequences. The operational consequences arose from an increase in the amount of time that the ore concentrate barges were unable to pass up and down the river because of insufficient water depth. It is likely that, had the phenomenon continued, passage by the existing barge fleet would have become impossible.

In response to both the operational and environmental consequences, from 1998 OTML began dredging operations in the Ok Tedi at Bige. Dredged material is stockpiled on the floodplain with the intention that the piles will be capped and vegetated as they are completed. Capping is necessary to prevent oxygen penetrating the sulfidic material, forming acids, and giving rise to acid mine drainage – acidic water rich in dissolved toxic metals which can leach into the groundwater and/or the river (see, for example, Morin and Hutt, 1997). As a consequence of the dredging, which will continue until mine closure, the sediment delivery to the Fly River has been reduced, leaving the sediment slug to move down the channel of the middle Fly, a process which is expected to take 40–50 years (Pickup and Marshall, 2009).

It is unclear what will happen to sediment delivery once the mine closes and dredging ceases. The river is excluded from the mine closure and cleanup plan. It may be that the sediment delivery rate will drop because the sediment delivery from the tailing dumps will begin to decrease once material addition ceases. Much of the sediment presently stored within the river channels of the mine area creeks and the Ok Tedi will be relatively rapidly colonised and stabilised by vegetation, and the stream will commence to downcut new channels through the accumulated sediment. But the issue does not appear to have been given much attention. Pickup and Marshall (2009), who act as consultants to OTML, do not provide a long-term prognosis.

27.4.2 Changed floodplain hydrology

The hydrology of the middle Fly floodplain has been altered as a result of the deposition of sediment within the channel. Some of the tie channels that connect the ORWBs to the main river channel have become blocked by sediment, although most have sufficient water flow to scour them out (Pickup and Marshall, 2009). Aggradation caused by sediment deposition within the channel has resulted in higher water levels on the floodplain during high flow events, thus increasing the frequency, duration and extent of floodplain inundation. Furthermore, since smaller flow events in the channel now cause floodplain inundation, the frequency of inundation has increased, and over much of the floodplain the water is being retained longer. This in turn has ecological consequences, and is probably the main cause of forest dieback on the floodplain, discussed below.

27.4.3 Acid rock drainage

Acid rock drainage (ARD) or acid mine drainage (AMD) occurs when minerals rich in sulphides are exposed to atmospheric oxygen. The sulphides oxidise to sulphate, producing sulphuric acid – which is not only toxic but which also dissolves other materials, including toxic metals such as aluminium, copper, lead, cadmium, etc. The phenomenon has been known for many years and numerous case studies have been documented (see Morin and Hutt, 1997; Parker and Robertson, 1999). It is a major source of environmental concern associated with mining; it is known that the oxidation continues over many years, so that toxic drainage may cause environmental damage and require treatment for decades – long after the mine, and the mining company, which was the source of the problem, has ceased operations.

In the case of the Ok Tedi mine, there was an initial belief that the naturally alkaline river water would neutralise ARD; however from about the year 2000 concern about the problem grew and monitoring commenced (Bolton *et al*., 2009). As previously noted, after the risk assessment in 2000, OTML began to monitor the acid-forming potential of the material being deposited in the waste dumps and began adding extra limestone to increase neutralising capacity. While this appears to have had some success, the sulphide-rich sediment particles and the limestone particles (which have differing specific gravities) tend to segregate as they are transported downstream, so patches of ARD are becoming common along the river and on the levees and the floodplain.

Figure 27.3. An area of acid rock drainage at the back of the Fly River levee, upstream of Everill Junction, showing dead vegetation. (Photo by Ian Campbell.)

There is no ARD risk while mine-derived sediment is under water, because of lack of oxygen, but on exposed sandbanks and levees, and in areas of the floodplain that dry out, ARD becomes evident. The characteristic signs of ARD are areas of red-brown leachate, through mobilised iron and manganese, and dead vegetation (Figure 27.3).

As previously noted, deeper within the orebody the ore becomes richer in sulphur compounds (and copper). Thus the potential for ARD from the tailings also increases. In response to this, OTML have established the mine waste tailings project at a budgeted cost of over $200 m (Breen, 2008). The project has installed a treatment plant near the pit to extract the sulphur-rich component of the tailings. This component is piped to an area near Bige where it is buried below groundwater level in a pit several hundred metres from the river. Storing the waste below groundwater level is intended to maintain it in anoxic conditions, thus preventing acidification.

To obtain government approval for the mine waste tailings project (MWTP), the project was subjected to an independent technical assessment by a panel of experts appointed by the PNG government. The *a priori* criterion that the government requested the panel to use for evaluation was that the storage solution would safely contain the waste for at least 500 years. The panel reported that 500 years was an unrealistic time frame, and that they could only realistically consider whether a storage solution would be viable for 300–400 years. They judged that the dredge piles would be viable in the long term, and that there was no risk from groundwater leaching from the buried sulphides.

However, the panel’s assessment failed to consider one major risk: the possibility that the river channel would migrate, causing release of waste from the storage pit. A separate assessment conducted for OTML suggested that there was a ‘limited risk of the Ok Tedi channel reaching the storage containment wall by either channel migration or avulsion in the next 50–100 years' and 'the West Bank storage might fail at some time in the next 100–1,000 years' (OTML 2006).

The failure of the storage pit would be catastrophic, releasing large volumes of potentially acid-forming material into the river just upstream of the junction between the Ok Tedi and the Fly River. Formal risk assessment procedures would rate the overall risk as 'high' simply because the consequences are so severe. Evaluating the likelihood is difficult because the geomorphology of the Ok Tedi has been so altered by the mine sediment that past history is a poor guide to future behaviour. OTML tends to focus on the upper limit of the expert predictions about how long it may take for the river to erode through to the pit (Breen, 2008), but it is the lower figure which needs to be considered by management agencies – the pit may be breached in as little as 100 years (OTML, 2006).

It remains to be seen how extensive ARD problems will become in the Ok Tedi, but a bigger issue may be acidification of the floodplain.

27.4.4 Vegetation dieback

The change to floodplain hydrology, and the increased frequency and duration of inundation, has triggered large areas of forest dieback, especially on the middle Fly River floodplain. An estimated 1200 km^2 of forest have been killed (Townsend and Townsend, 2004) and, although there has been some recent recovery, it is estimated that a total in excess of 1500 km^2 will eventually be affected (OTML, 2009).

Floodplain dieback has serious consequences for the local people who utilise the floodplain as a source of food. Sago (*Metroxylon sagu*) is the main staple of the lowland people. It is a water-tolerant floodplain plant, but there are concerns that its distribution has been affected or its even its abundance reduced. OTML are conducting a sago mapping project in an attempt to establish whether there have been recent changes in sago distribution, but results are not yet available. The floodplain forest was an important area for hunting and for non-timber forest products. The social system of land holding in PNG means that the people whose land is affected do not have the option of moving to, or using, the land of other clans.

27.4.5 Fisheries decline

For people living along the watercourses, fish have been the major protein source. Data show that since the operation of the mine, there has been a major decline in the fishery, with a number of fish species having their distributions reduced and others becoming apparently less abundant (Storey *et al*., 2009a).

The reasons for the decline are not clear. The fish stocks are undoubtedly variable, including, as they do, species such as barramundi (*Lates calcarifer*) which are migratory and breed in coastal wetlands (Blaber *et al*., 2009). They are affected by climate variability, changes in their breeding areas, and a number of other non-mine-related variables. However, the mine has obviously had a major impact on the fish. Whether the impact has been primarily through modification of their habitat – as has undoubtedly been the case in the Ok Tedi (Storey *et al*., 2009b) – or due to impacts on their food (either through habitat impact, toxic effects of metals, or chemical changes in the water that deter migratory fish from travelling up the Fly) is not known and would be very difficult to determine with any level of confidence.

27.4.6 Long-term acidification risk

The Ok Tedi mine has created another very serious long-term risk for the floodplain of the lower Ok Tedi and middle Fly River. The mine-derived sediment, deposited on the floodplain during river floods, is now extremely widespread.

While there appears to be no danger that ORWBs will be completely filled as a result of the deposited sediment, the sediment has dispersed over a surprisingly large distance via tie channels and tributaries (Day *et al*., 2009). Day *et al.* (2008) described this pattern as a depositional web. They noted that almost all ORWBs have large amounts of mine-derived sediment, that levee heights have grown significantly, and that sediment has travelled tens of kilometres up tributaries.

Sediment deposits are metres thick near the river channels (immediately behind the natural levees), but even 100 m from the levee there are deposits up to 0.2 m thick. With the high density of channels, this amounts to a very large area of potentially acid-forming material. While the area remains under water, this is not a serious problem; the sediment is not exposed to air and will not oxidise. However, in areas where the sediment might dry out at some time in the future, the vegetation would likely die and a substantial volume of low pH effluent, with toxic concentrations of metals, would leach into the river.

While the sediment slug continues to pass through the river, it helps to maintain high water levels on the floodplain. So the increased inundation, which is causing forest die-off, is preventing acid drainage problems. But until the deposited material is oxidised, it keeps its acid-forming potential, so should the area dry out at any time in the future (however long that may be), the deposited acid-forming mine-derived sediment will begin to oxidise. Alan Breen, managing director of OTML (Breen, 2008) points out that climate change models predict that ‘normal inundation (both in terms of frequency and duration) will increase over the next 200 years’, but there are many climate change models which make a range of predictions for particular regions, so, for any particular locality, modellers can only have a relatively low level of confidence in their predictions. But, regardless of the predictions about long-term general climate trends, climate varies from year to year and over decades. At some point in the future the middle Fly floodplain will inevitably dry out, and there has been no attempt so far to determine the probability of that happening within the next 50 or 100 years.

With the new process, from late 2008, reducing the pyrite content of the tailings, much of the sediment passing down the river, from now until mine closure, has reduced potential to cause acid rock drainage. Much of this ‘clean’ sediment is dredged from the river at Bige and used to cap the stores of acid-forming sediment previously dredged from the river. As a consequence, it will not pass downstream to bury mine-derived sediment already deposited on the floodplain.

27.4.7 Estuarine risk

In addition to the floodplain, mine-derived sediment deposits have also been recorded within the Fly River estuary (Walsh and Ridd, 2009) and are probably widespread. The ecological consequences are not known. Monitoring is being conducted to assess whether high metal concentrations are appearing in selected marine species, and so far this does not appear to be the case. So the risk of food chain contamination does not appear to be high, but there is insufficient ecological monitoring to determine whether there are more subtle effects.

27.5 Governance and the Ok Tedi mine

From the preceding, it is clear that the Ok Tedi mine has created severe environmental impacts, some of which OTML has responded to, and some of which are likely to continue to cause problems for the river for decades or even centuries to come. Any environmental decision involves both technical and value judgements (Campbell, 2007). The technical component identifies the nature and extent of likely impacts, while the value judgement is a decision about the tradeoff – do the benefits of the project outweigh the impact costs? Governance processes are critical both to management of the technical processes and to decision-making; it also affects value judgement decisions, which, one hopes, represent the views of the community. In the case of Ok Tedi, many of the initial technical judgements were seriously flawed, in many cases because they were based on incorrect assumptions about the project. The environmental impacts have been far more extensive and severe than predicted in the original EIA (Maunsell and Partners, 1982).

The economic benefit to PNG from the Ok Tedi mine has been very large and positive so far. However, the risks to the Fly River floodplain from the stored pyrite waste and the extensive mine-derived sediment deposits make it quite likely that, over the long term, the project will be a net economic cost to the country. The failures of the project arise from a failure of governance.

The original environmental impact assessment for Ok Tedi was based on some very different project designs. Most critically, the original concept was based on a large tailings dam being built in a neighbouring catchment, the Ok Ma, where much of the sediment generated would be retained. The assessment estimated that, over the life of the project, 200 million tonnes of sediment would be released into the Ok Tedi (Maunsell and Partners, 1982); in fact about 80–90 million tonnes are being released each year (Bolton *et al.*, 2009).

The planned tailings dam was never built. Construction commenced, but following an earthquake and landslide at the construction site in 1984, construction was abandoned and government permission was eventually obtained to dump all waste rock and tailings from copper processing in the river. The abandonment of the tailings dam is controversial. It has been argued that the likelihood of its collapse at some future time was too high and the consequences for the people living downstream were too great for the dam to continue.

However, it has also been passionately argued that the landslide provided a convenient excuse for the company to reduce costs (Townsend and Townsend, 2004).

Whether or not the abandonment of the proposed tailings dam was justified on engineering terms, it was obvious from the time the decision was made that it would have major implications for the environmental impacts of the mine. At that time it is obvious that there should have been a requirement for a further full environmental impact assessment. So a major failure in governance was the failure of the PNG government to require a completely new Environmental Impact Assessment of the project when the project changed so profoundly.

The PNG government was under pressure, partly of its own making, during the early development of the Ok Tedi mine. In May 1989, the Panguna mine on Bougainville was closed because of violent local opposition. The closure left the PNG government with a substantial financial shortfall at a period when the large-scale environmental impact of Ok Tedi was becoming evident. The PNG government could not afford to lose the income from OK Tedi at that time. As a result, its regulatory leverage was small while the significance of the income from the mine at a critical period of PNG history was very large.

Present environmental monitoring of the impacts of Ok Tedi are conducted under the auspices of an environmental regime initially proposed in 2001 (OTML, 2001). The regime has been passed by the PNG parliament as the Mining (Ok Tedi Mine Continuation (Ninth Supplemental) Agreement) Act 2001; however, variations to the 2001 regime, subsequently implemented by OTML, have been forwarded to the PNG government for approval but never formally accepted. Under the regime, the company provides an annual environmental report to the PNG government. Within those reports, OTML has proposed modifications to the monitoring regime – which have now been implemented – but it has never received any response from the government to either the supplied data nor to the proposed monitoring changes. From a governance point of view this is clearly unsatisfactory, and the reason for the lack of government response is unclear. The company has not received any indication that government agencies are unhappy with the monitoring program, and the absence of any response may simply reflect a lack of agency capacity. So the second governance failure is a failure by the PNG government, for at least the past 10 years, to effectively monitor the environmental impact of the mining operation.

OTML have subjected the environmental monitoring regime of their mining operation to a number of high-level evaluations. An early evaluation was conducted by NSR to evaluate whether the correct scientific programs were being conducted. In 1999, environmental and human health impacts of the OTML operations were subject to a risk assessment process – the HERA (Human and Environmental Risk Assessment) (Parametrix, 1999a; 1999b). In turn, OTML set up the Peer Review Group (PRG), a panel of independent specialists, to review and report on the HERA (PRG, 1999; 2000).

While the engagement of high level independent reviewers is admirable, there were two shortcomings. The first is that many of the key recommendations by the PRG were either ignored or not appropriately implemented. For example, although the PRG (1999) recommended that one of the questions needing addressing in the OTML environmental investigations was 'What mine-related issues most affect algae and other important bases for the food chains?', and repeated the point in their later report (PRG, 2000: 7). Apart from a one-off survey by Stauber and colleagues in 1995 (Stauber *et al.*, 2009), no studies to directly investigate algal abundance or diversity, or the impact of the mine in the field, were commenced until 2007, some eight years after the initial recommendation. Even then, the work done was extremely limited, and abandoned when it failed to confirm the opinions of management. The only algal monitoring work was a toxicity testing program which evaluated the impacts of water collected at a series of locations along the river on the growth and survival of a species of *Chlorella*, isolated from Lake Aesake on the Strickland River and maintained under culture in Australia. Unfortunately, the controls for this work used synthetic river water rather than Fly River water collected above the source of contamination.

Perhaps a more basic problem was the absence of any quality control procedures for environmental consultancy work at Ok Tedi. Although the need to have consultancy reports independently reviewed was repeatedly stressed to the company by members of the PRG and others, no such review process was ever implemented. The high-level reviews simply assessed whether the appropriate kinds of studies were being conducted; they did not review the actual consultancy reports. OTML lack the in-house technical expertise to conduct such reviews, and the reports are not sent out for review. While many of the consultants reports are excellent, there are a disturbing number that are technically inadequate.

The annual environment report produced by OTML for the government (e.g. OTML, 2005) should presumably be reviewed by government agencies, but that does not appear to happen. The reports are comprehensive but have had a number of weaknesses. One obvious weakness is the complete lack of any statistical analysis of any of the water quality and sediment data prior to 2007. In addition, much of the sediment data in particular is of such low statistical power that it is unlikely to be able to detect any changes.

The overriding governance issue is the presence of the government of PNG as a part owner and board member of OTML. Thus the government is both a promoter of the mine as well as the regulator. Most governments regulating mining operations tend to have some conflict of interest if they also receive royalties from the operation. That conflict is more acute when any particular mine contributes a large proportion of government income, as was the case with the Ok Tedi mine in PNG, especially after the closure of the mine on Bougainville Island following civil disturbance.

However, the case of Ok Tedi becomes more extreme because the PNG government is also a 30% shareholder and board member of OTML. That promotes an unhealthy relationship for the government's regulatory role. It is difficult to see how the selective terms of reference for the government evaluation of the mine waste treatment project could not have been influenced by the government's knowledge of, and participation in, the board discussions of OTML's own evaluation of the project. Had more appropriate terms of reference been implemented, a far more vigorous debate could have occurred about the long-term advisability of the project.

27.6 Conclusions

The two major constraints on environmental management that have led to the large-scale environmental impacts at the Ok Tedi mine are poor governance and a lack of agency capacity. These constraints are not unique to Ok Tedi, but are widespread through developing countries, and not unknown in developed countries

Poor governance is occurring at both the government level and within OTML. At the government level, it has resulted in a failure to require a revision of the environmental impact assessment when the mine project changed substantially after 1984 (the decision not to construct the tailings dam). Poor governance continues to allow the mine to remain operating without effective oversight, fails to adequately evaluate the risk of future failure of the mine waste treatment storage facility, and fails to respond to annual environmental reports. At the company level it has resulted in a failure to review the technical content of consultancy work.

Lack of capacity also impacts both the PNG government and OTML. At the government level it is almost certainly a contributing factor to the failure of the government to respond to annual environmental reports. Within the company it has led to an environment department which for many years has been overly dependant on consultants and which struggles to manage technical outputs.

Finding appropriately qualified staff prepared to work in remote locations such as Tabubil is never easy. However, OTML does seem to have had a lack of appreciation of the need to employ senior qualified professional staff within the environment department. For the government of PNG there is both a limited pool of qualified environmental specialists, as well as a limited budget for staff. However, long-term environmental concerns also appear to trail well behind short-term financial gain in government priorities.

References

Blaber, S. J. M., Milton, D. A. and Salini, J.P. (2009). The biology of Barramundi (*Lates calcarifer*) in the Fly River system. In *The Fly River Papua New Guinea. Environmental Studies in an Impacted Tropical River System*, ed. B. R. Bolton, Burlington, MA, USA: Elsevier, pp. 411–26.

Bolton, B. R., Pile, J. L. and Kundapen, H. (2009). Texture, geochemistry, and mineralogy of sediments of the Fly River system. In *The Fly River Papua New Guinea. Environmental Studies in an Impacted Tropical River System*, ed. B. R. Bolton. Burlington, MA, USA: Elsevier, pp. 51–112.

Breen, A. (2008). Letter to Australian Broadcasting Commission, September 2008.

Campbell, I. C. (2007). The management of large rivers: technical and political challenges. In *Large Rivers*, ed. A. Gupta . Chichester, UK: John Wiley and Sons, pp. 571–85.

Day, G., Dietrich, W. E., Rowland, J. C. and Marshall, A. R. (2008). The depositional web on the floodplain of the Fly River, Papua New Guinea. *Journal of Geophysical Research*, **113**, F01S04. doi:10.1029/2006JF000627.

Day, G., Dietrich, W. E., Rowland, J. C. and Marshall, A. R. (2009). The rapid spread of mine-derived sediment across the middle Fly River floodplain. In *The Fly River*

Papua New Guinea. Environmental Studies in an Impacted Tropical River System, ed. B. R. Bolton. Burlington, MA, USA: Elsevier, pp. 113–52.

Inmet (2010). Inmet Mining press release. Available at http://www.inmetmining.com/default.aspx?SectionId=b89b8c3b-61ee-429a-9f47–560bf16f77ae&LanguageId=1&PressReleaseId=1d47b981–7afb-4fde-8a04–4bcb386cfaeb. Accessed 24 March 2010.

Maunsell and Partners (1982). *Ok Tedi Environmental Study*. Environmental Impact Statement. Maunsell and Partners Pty Ltd.

Morin, K.A. and Hutt, N.M. (1997). *Environmental Geochemistry of Minesite Drainage. Practical Theory and Case Studies*. Vancouver, Canada: MDAG Publishing, 333 pp.

OTML (2001). *Proposed Environmental Regime*. Report ENV 010914, Environment Department, September 2001, 57 pp. Available at http://www.oktedi.com/attachments/250_Regime%20Sept%20010909jv.pdf. Accessed 13 December 2009.

OTML (2005). *2005 Annual Environment Report*. Available at http://www.oktedi.com/news-and-reports/reports/environmental/env-annualreports. Accessed 20 December 2009.

OTML (2006). *Mine Waste Tailings Project. Change Notice, Supporting Document*. 8 September 2006, 94 pp.

OTML (2009). *OTML at a Glance*. Available at http://www.OTML.com. Accessed 1 November 2009.

PRG (1999). *Fourth Report of the OTML Environment Peer Review Group (PRG): Comments on the Science Underlying the Human and Ecological Risk Assessment (HERA*). Final Report (20/07/99). Available at http://www.oktedi.com/news-and-reports/reports/environmental/human-health-and-wellbeing. Accessed 13 December 2009.

PRG (2000). *Ok Tedi Mining Ltd (OTML) Environment Peer Review Group (PRG): Comments of Key Issues and Review Comments on the Final Human and Ecological Risk Assessment Documents*, 19 pp. Available at http://www.oktedi.com/news-and-reports/reports/environmental/human-health-and-wellbeing. Accessed 13 December 2009.

Parametrix Inc. (1999a). *Assessment of Human and Ecological Risks for Proposed Mine Waste Mitigation Options at the Ok Tedi Mine, Papua New Guinea*. Detailed Level Risk Assessment, Final Report. Prepared for Ok Tedi Mining Ltd, November 1999. 239 pp. Available at http://www.oktedi.com/news-and-reports/reports/environmental/human-health-and-wellbeing. Accessed 13 December 2009.

Parametrix Inc. (1999b). *Assessment of Human and Ecological Risks for Proposed Mine Waste Mitigation Options at the Ok Tedi Mine, Papua New Guinea*. Screening Level Risk Assessment, Final Report. Prepared for Ok Tedi Mining Ltd, November 1999. 222 pp. http://www.oktedi.com/news-and-reports/reports/environmental/human-health-and-wellbeing, accessed 13 December 2009.

Parker, G. K. and Robertson, A. (1999). *Acid Drainage*. Australian Minerals and Energy Environment Foundation, Melbourne, 227 pp.

Pickup, G. and Marshall, A. R. (2009). Geomorphology, hydrology, and climate of the Fly River system. In *The Fly River Papua New Guinea. Environmental Studies in an Impacted Tropical River System*, ed. B. R. Bolton. Burlington, MA, USA: Elsevier, pp. 3–49.

Stauber, J. L., Apte, S. C. and Rogers, N. (2009). Speciation, bioavailability and toxicity of copper in the Fly River system. In *The Fly River Papua New Guinea. Environmental Studies in an Impacted Tropical River System*, ed. B. R. Bolton. Burlington, MA, USA: Elsevier, pp. 375–408.

Storey, A. W., Yarrao, M., Tenakanai, C., Figa, B. and Lynas, J. (2009a). Use of changes in fish assemblages in the Fly River system, Papua New Guinea, to assess effects of the Ok Tedi copper mine. In *The Fly River Papua New Guinea. Environmental Studies in* *an Impacted Tropical River System*, ed. B. R. Bolton. Burlington, MA, USA: Elsevier, pp. 427–62.

Storey, A. W., Marshall, A. R. and Yarrao, M. (2009b). Effects of mine derived river aggradation on fish habitat of the Fly River, Papua New Guinea. In *The Fly River Papua New Guinea. Environmental Studies in an Impacted Tropical River System*, ed. B.R. Bolton. Burlington, MA, USA: Elsevier, pp. 463–90.

Townsend, P. K and Townsend, W. H. (2004). *Assessing an Assessment: The Ok Tedi Mine*. Available at http://www.maweb.org/documents/bridging/papers/townsend.patricia.pdf Accessed 22 November 2009.

Walsh, J. P. and Ridd, P. V. (2009). Processes, sediments and stratigraphy of the Fly River delta. In *The Fly River Papua New Guinea. Environmental Studies in an Impacted Tropical River System*, ed. B. R. Bolton. Burlington, MA, USA: Elsevier, pp. 53–76.