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Report to U K Overseas Development Administration

Proyecto de gestión
Integrada y Plan
Maestro de la Cuenca
del Rio Pilcomayo
BIBLIOTECA

REVIEW OF THE PORCO MINE TAILINGS DAM BURST AND
ASSOCIATED MINING WASTE PROBLEMS, PILCOMAYO BASIN, Bolivia

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MA - 049

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SUMMARY

1. A breach of a tailings dam for the Porco mine on 29 August and, 1 September 1996 released tailings and fluid into the upper reaches of the Pilaya catchment of the Pilcomayo river. Metal concentrations reduce rapidly in the first 200 kms. downstream from the Porco mine.
2. Severe and widespread metal pollution has occurred in the upper Pilaya and Pilcomayo rivers basin as a consequence of past and present mining activity. Immediate remediation is required for arsenic and lead pollution in the Tumusla-Pilaya system as far as at least 110km. downstream from the Porco mine. The Porco mine spill did give rise to serious contamination but other mines dumping metalliferous waste directly into the rivers are likely to constitute a more serious long-term environmental threat.
3. Population densities are low in the Pilaya catchment but a number of communities depend on river water for human and livestock consumption. Irrigation using river water is important in some areas, particularly between Tumusla and Villa Abecia. Riverine communities in the Pilcomayo downstream of the Pilaya-Pilcomayo junction also depend on fishing for a living and for food. Such populations are highly conscious of the possibility of contamination of river water and skilled at evasive action. They are still highly vulnerable, especially when no alternative water sources are accessible. People are aware of the sensitivity of different crops to contamination. Fishing communities are particularly vulnerable to contamination of river water since it affects both livelihood and income.
4. It seems likely that a 'spike' of sediment from the Porco tailings dam did reach as far as Villa Montes.
5. Fish, including those caught for sale [sábalo, dorado and surubi], are likely to be affected both by heavy sediment loads [giving rise to *borrachera* incidents] and cumulative ingestion of heavy metals.
6. Fish from the Pilcomayo, in the areas visited, are as safe to eat as they ever were. Immediate risks have not increased.
7. Heavy metal accumulation in fish can affect human health. Results of existing analyses of metal accumulations in fish show grounds for concern.
8. The existing risk from chronic river waste pollution needs to be properly assessed. The risk from fish is unlikely to increase for the next year, even following the Porco incident, but it needs to be closely monitored and assessed.
9. The Porco incident emphasises the potential present and future threats of the mine waste problem to major downstream infrastructural projects [e.g. the Provisa scheme in Villa Montes and the Proyecto Pantalón in Paraguay and Argentina].

no Pilaya al Pilcomayo

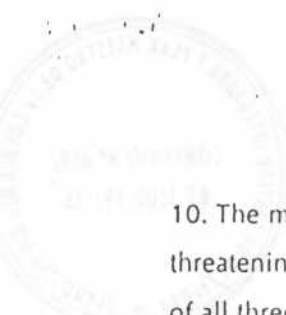
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SUMMARY
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10. The mine waste disposal problem in the headwaters of the River Pilcomayo is a time bomb threatening any future development of water resources within the river basin and requires the attention of all three riparian countries. This may now be facilitated by the Three Nations Commission.

1. Severe and widespread metal pollution has occurred in the upper Pilays and Pilcomayo river basin as a consequence of past and present mining activity. Immediate remediation is required for reasons and lead pollution in the Tumbes-Pilays system as far as at least 100 km downstream from the Porco mine. The Porco mine will give rise to serious contamination but other mines dumping metalliferous waste directly into the river are likely to constitute a more serious long-term environmental threat.

2. Population densities are low in the Pilays catchment but a number of communities depend on river water for human and livestock consumption, irrigation being of great importance in some areas, particularly between Tumbes and Villa Abasco. Riverine communities in the Pilcomayo downstream of the Pilays-Pilcomayo junction also depend on fishing for a living and for food. Such populations are highly conscious of the possibility of contamination of river water and called for early action. They are still highly vulnerable, especially when no alternative water sources are accessible. People are aware of the possibility of different crops to contamination. Fishing communities are particularly vulnerable to contamination of river water since it affects both livelihood and income.

3. It seems likely that a "spike" of sediment from the Porco mine will reach as far as Villa Montes.

4. Fish, including those caught for sale (barramundi, dorado and curupe), are likely to be affected both by heavy sediment loads (giving rise to barotrauma incidents) and cumulative ingestion of heavy metals.

5. Fish from the Pilcomayo, in the areas visited, are at risk as they may have been immediately affected.

6. Heavy metal accumulation in fish can affect human health. Results of existing analyses of metal accumulation in fish show grounds for concern.

7. The existing risk from chronic river waste pollution needs to be properly assessed. The risk from fish is unlikely to increase for the next year, even following the Porco incident, but it needs to be closely monitored and assessed.

8. The Porco incident emphasizes the potential present and future threats of the mine waste problem to major downstream infrastructural projects (e.g. the Pivaya scheme in Villa Montes and the Proyecto Pacion in Paraguay and Argentina).

RECOMMENDATIONS FOR ACTION PLAN

1. Initiate a survey of existing mine waste storage practices in corporate and small-scale mines around Potosí and in the Pilcomayo catchment with a view to defining improvements and investment costs for future protection for basin development.
2. Rapid implementation of improved practices and structures in mine waste storage recommended from item 1 above.
3. Conduct a baseline review of existing data and, with rapid field appraisals, define present status of the contamination problem for the river and its dependent peoples. This would include a preliminary categorisation of the people and places at risk. The review should be conducted within all three partner states; Bolivia, Paraguay and Argentina.
4. From the above review, finalise a detailed action and management plan for national governments as the *Three Nations Committee of the Pilcomayo Basin*.
5. Establish regional monitoring and information centres, based on existing universities or government institutions, to conduct initial intensive surveys of the status of metals in sediments and water with international collaboration. This intensive survey should answer the basic questions regarding the present and future distribution of heavy metals and other mining contaminants within the river basin, with or without future improvements in mine waste management. This appraisal should also identify basic, cost-effective indicators for long-term monitoring by the regional centres in order to provide the governments and the Three Nations Committee with details concerning the extent to which targets for control are being met. There may be five regional centres, three in the source country - Bolivia - and one each in Paraguay and Argentina.
6. A systematic determination of metal accumulation in commercial fish species in the basin with recommended actions for regulations on sale or consumption.
7. A survey of the migration routes and dynamics of the commercial fish species and also of the riverside fishing communities and their relative dependency on their fish. The degree of exposure to contaminants of these fishing communities must also be ascertained. This will provide details of the distribution of possible contamination within the basin.

8. A survey to establish impact of chronic exposure to mine pollutants on the health of the most vulnerable people through social appraisals and analysis of physical features such as teeth, hair, blood and urine.

9. Immediate protection measures to riverside communities through construction of simple wells and general improvements in water supply to the most vulnerable groups and areas.

10. Construction of a Geographical Information System [GIS] and a parallel Management Information System [MIS] to store data for regional monitoring centres and allow timely analysis into a form appropriate for basin management and improving decision-making by national governments and the Three Nations Committee.

11. Production of predictive models to show future distribution and impacts of contaminated sediments together with the interaction with economic activities such as fishing and infrastructure development projects including the Caipipendi Dam and Proyecto Pantalón. This will use the outputs from items 5, 6, 8 and 10 above.

12. A feasibility study should be carried out to look at engineering options for stabilising the river channel at key points or otherwise reduce the possibility of erosion of contaminant sediments.

13. The most vulnerable social groups need to be identified as per items 8 and 9 above. An appraisal of their social and decision-making structures should be carried out and appropriate NGOs identified to assist in the promotion of health protection improvements and alternative income generation activities where appropriate. The NGOs would also act as the communications link between the riparian communities and river basin management bodies

14. From items 5, 6 and 8 the legal limits of contaminants in sediment, water and food will be reviewed in all three partner countries.

ACTIONS REQUIRED

Schedule for Regional Action Plan

From Recommendation	Action	Responsibility	Start Date
1	Prepare TOR for mine waste storage survey	MDSMA/Comsur	March 1997
1	Conduct waste storage survey	To be appointed	April 1997
3	Prepare TOR for baseline reviews	MDSMA / Mision Britanica	April 1997
3	Conduct baseline reviews (field and literature)	MDSMA / International counterparts / National Counterparts (Paraguay , Argentina)	May 1997
4	Finalise Action Plan	MDSMA / International Counterparts (to be appointed) / National Counterparts	June 1997
5	Prepare TOR for regional centres	MDSMA / Mision Britanica / National Counterparts	March 1997
5	Prepare TOR for downstream sediment study and monitoring	MDSMA / Mision Britanica/ National Counterparts	March 1997
6 and 7	Preparation of TOR for fish surveys	MDSMA / Mision Britanica	March 1997
3 and 11	Conduct sediment and water metal survey	To be appointed	July 1997
6	Conduct fish bio-accumulation survey	To be appointed	July 1997
7	Conduct fisheries and fishing community survey	To be appointed	July 1997
8	Prepare TOR for health survey	MDSMA / Mision Britanica	April 1997
9	Prepare TOR for health protection measures	MDSMA / Mision Britanica / others	April 1997
8	Conduct health survey of vulnerable groups	To be appointed	June 1997
9	Construction of health protection measures	To be appointed	September 1997
10	Preparation of TOR for regional MIS and GIS	MDSMA / Mision Britanica	May 1997
11	Construction of regional MIS and GIS	To be appointed	August 1997
11	Produce predictive models of future sediment and areas of impact	National and International groups	November 1997
12	Conduct feasibility study on engineering options for stabilising river channels	To be appointed	August 1997
13	Preparation of TOR for socio-economic survey of vulnerable groups	MDSMA / Mision Britanica	April 1997
13	Appointment of NGOs to help implement findings	To be appointed	October 1997
13	Conduct socio-economic survey of vulnerable groups	To be appointed	May 1997
14	Review legal limits of contaminants in sediment, water and food	MDSMA / Leeds University/ MRAG / Imperial College London	June 1997
15	Appoint Project Technical Advisory Committee to Three Nations Committee / National Governments	National Representatives/ Co-opted in International Representatives	June 1997

1. Introduction

A team comprising staff from the University of Leeds School of Geography and the Marine Resources Assessment Group Ltd. visited Bolivia from 9-16 November 1996. The mission was invited to visit Bolivia following a proposal from Leeds Geography to the UK Overseas Development Administration that it would be of value to the Government of Bolivia if a short visit were made to sites downstream from the Porco mine in order to obtain data regarding the degree of contamination of sediments in the river system following the spill and its downstream social and economic effects.

The Terms of Reference of the Mission were 'to assess the extent of the environmental damage already done, the current risk and the likely future risks from seasonal changes in river flow rates' and 'to assess the effects on the fish population and possible consequent dangers to the human population'.

1.1 General background to the mission and the Porco incident

The incident, widely reported in the press following the publication of the government report on the impact of the dam burst on 14 October, excited considerable popular interest and disquiet. Reports of deaths associated with drinking of polluted river water and eating contaminated fish over 100 kms. downstream from the mine fuelled speculation that contamination could have spread much further than suggested by technical reports prepared by Bolivians experts. The Comité Cívico of Tarija, through whose department the lower course of the Río Pilcomayo runs, nominated a commission to press for further study and inform and support visiting missions. It also was able to collect samples of sediment for subsequent analysis as well as fish. The Trinational Pilcomayo Commission which considers matters of common interest to Bolivia, Argentina and Paraguay relating to the Pilcomayo river expressed interest in establishing a scientific basis for monitoring contamination of the river system, recognising it to be a longstanding and widespread issue of common interest.

1.2 Visit to Porco mine and downstream investigations

On 11 November the mission visited the Porco mine and were informed about the mining operations and the tailings dams construction and maintenance by COMSUR staff. The nature of the defects in the dam which burst were explained, the nature of the mine tailings which were released into the river and the cleaning-up operation which followed the major burst on 1 October.

The mission subsequently visited a site at Puca Puca about 10 kms. downstream to assess visible evidence of sediment accumulations and to take sediment samples. Part of the mission [Macklin and Sedgwick] visited the upper part of the Pilcomayo between Potosí and Sucre for collection of sediment samples for metal analysis in order to establish the degree and extent of contamination by mining in the uppermost part of the Pilcomayo, to the east and North of Potosí. Most of our sampling sites were the same as those previously sampled by the MDSMA immediately following the incident. Our emphasis was on the sediment associated metals rather than water quality.

appeared also to show a similar trend. The precise pattern and exact levels of heavy metals in the river sediment samples collected by MDSMA unfortunately could not be determined because of calculation error.

3. Downstream dispersal and concentrations of contaminant heavy metals in the Pilaya and upper Pilcomayo river basins.

Contemporary fine grained (< 2mm) river sediment, material from floodplain, river terraces, and mine tailing ponds were collected from 14 sites in the Pilaya and Pilcomayo catchments (Map 1 and Annex 1). Thirty five samples were taken, analysed in duplicate for As, Cd, Co, Cr, Cu, Ni, Pb, Sn, and Zn using Inductively Coupled Plasma Spectrometry (ICP) after digestion in nitric acid. Levels of river sediment contamination in the Tumusla-Pilaya system affected by the Porco mining spill, and in the Pilcomayo downstream of the major mining area of Potosí (Map 1), can best be assessed by comparing these with Dutch indicator values (Tables 3.1 & 3.2) of metal pollution. Indicator values have been developed by the Dutch government for environmental protection, monitoring and remediation programmes and we have used these because such standards for river sediments are to our knowledge not currently available in Bolivia or elsewhere in South America. Emboldened figures in Tables 3.1 & 3.2 are where contaminant metal and As concentrations exceed values where immediate remediation is recommended. Pb appears to pose the greatest threat to the environment and human health in both river systems with significantly elevated concentrations up to 200 km downstream from Porco in the Rio Pilaya, and extending at least 40 km downstream from the Potosí mining area. This would suggest that the length of the Tumusla-Pilaya system affected by the Porco mine spill was considerably greater than suggested by MDSMA. Metal concentrations in the Pilcomayo, however, in the upper 40 - 60 km of the river are in some cases more than 10 times higher than at sample sites located similar distances downstream of the Porco mine spill. Thus although the effect of the Porco mine spill was probably more widespread than originally believed, metal concentrations are at present generally much higher in upper reaches of the Pilcomayo. This is due to uncontrolled metal effluent discharges by small private mines in the Potosí area. Lower metal concentrations in the Tumusla-Pilaya system reflect more effective processing of metal ore and pollution control, prior to the August 1st 1996 accident, by the modern corporate Porco mine.

Our analyses indicate that severe and widespread metal pollution has occurred in the Tumusla-Pilaya and Pilcomayo river basins arising from present and past mining activity. Although the Porco mine spill did result in serious contaminations, innumerable privately-owned mines around Potosí dumping metalliferous waste directly into the Pilcomayo are likely to constitute a more serious environmental threat. In the long term heavy metals in river sediments and floodplain soils are stored for considerable periods of time, in some cases approaching several hundred years, but can be remobilised by a number of physical, chemical and biological processes and re-introduced back in the river system. In the case of

the Pilaya, it is very probable that metal contaminated river sediment will over a period of years or decades move slowly downstream in the form of an attenuating wave contaminating the middle and lower reaches of the system. A similar process is likely to be operating in the Pilcomayo but over a longer period of time. This has considerable implications for the development of the Pilcomayo basin as a whole, for example, dam construction in Bolivia, Paraguay and Argentina which may inadvertently trap large quantities of metal-polluted sediment. Samples collected during the November 1996 visit provide an important initial benchmark in this respect by which future changes in river metal concentrations can be monitored. It will be essential, however, to extend this survey to headwater tributaries of the Pilcomayo and to the middle and lower reaches of the basin.

TABLE 3.1 Mean and maximum metal concentrations in contemporary fine sediments in comparison with Dutch Indicator Values (DIVs).

River System	Mean Pb	Max Pb	Mean Cd	Max Cd	Mean As	Max As	Mean Zn	Max Zn	C* value Pb	C* value Cd	C* value As	C* value Zn
Pilcomayo	2500	7361	10.4	52	5055	17128	14747	46768	600	20	680	3000
Tumusla - Pilaya	929	2410	2.2	14	610	2446	2017	5958	600	20	680	3000

Table 3.2 Mean and maximum metal concentrations in floodplain sediments in comparison with Dutch Indicator Values (DIVs).

River System	Mean Pb	Max Pb	Mean Cd	Max Cd	Mean As	Max As	Mean Zn	Max Zn	C* value Pb	C* value Cd	C* value As	C* value Zn
Pilcomayo	381	560	2	4	226	364	621	1072	600	20	680	3000
Tumusla - Pilaya	611	1981	0.7	3	230	1839	1068	5336	600	20	680	3000

* Riparian land with metal concentrations exceeding the C value is considered to be severely contaminated by the Netherlands government.

12 November

Sites on the edge of Potosí city were visited. One part of the team [Payne and Preston] travelled by road towards Camargo and Tarija, interviewing rural people about their use of river water, their perceptions of risk from contamination by mining and other activities. Where the Río Chico is joined by the Río Tumusla evidence of reactions to the spike of contaminated water from Porco was gathered as well as more general commentary of variations in the quantity and quality of river water. At the junction of the Río San Juan de Oro and the Río Grande, at the point where the river becomes the Río Camblaya, further evidence was gathered about contamination by early season rains bringing waste from further upstream.

The second team [Macklin and Sedgwick] collected sediment samples at a series of sites that could be reached by road, downstream from the Río Jatun Mayo towards the Río Tumusla before continuing to reach Tarija late at night.

13 November

Two members of the mission [Preston and Payne] flew to Villa Montes in order to visit sites where the Pilcomayo enters the Chaco lowlands and where riverine populations are dependent on fishing for food and for income. They returned to Tarija on 14 November.

15 November

The mission returned to La Paz and met with the Chargé d'Affaires of Paraguay, a member of the delegation of the European Union and with the Under-Secretary for the Environment, Ministry of Sustainable Development and Environment [MDSMA] of the Government of Bolivia.

16 November

Members of the mission met with staff from COMSUR for further discussion of their work and to collect detailed data made available by the company.

1.3 Data collection in Pilcomayo basin

The members of the mission met staff of the mining company COMSUR and talked with them during the visit to the mine and tailings dams. They were also able to discuss with them the general context of the environmental protection work associated with mining in this part of Bolivia. We were able to meet informed members of departmental government from Chuquisaca and Tarija as well as concerned university staff and departmental elected representatives who explained their own work, shared relevant findings with us and expressed their concerns. We received samples of sediments taken weeks previously 200 kms. downstream of the Porco mine.

The mission visited a series of sites from the Porco Dam B downstream as far as Puerto Margarita, upstream from Villa Montes, in order to collect river sediment samples from representative locations to determine contamination levels at different points in the Pilcomayo catchment. A single sample was

taken at Puente Méndez, west of Sucre to estimate contamination in the uppermost part of the Pilcomayo basin.

Interviews with residents were carried out at Puca Puca, Cucho Ingenio, El Caserón, Puente La Palca, San Juan de Oro [near the junction of the Rfo San Juan with the Rfo Grande] and at Puerto Margarita upstream from Villa Montes. At each location residents were interviewed, both individually and in groups to listen to their views on access to water, use of the rivers, issues connected with fishing, water pollution and flooding and their recollections of specific events which might be connected with the Porco burst. We also invited their comments on changes in river water and resources during past decades. In several localities people were present from places upstream who were able to add their comments.

2. The Porco Mine dam burst

The Porco mine lies the head of the basin of the Pilaya river. Of the two basins which comprise the Pilcomayo in highland Bolivia, that of the Pilaya contributes about twice as much water to the Pilcomayo as does the upper Pilcomayo system [an average annual flow estimated as 4 million m³ compared with 2 million m³]. It is located at 4100 metres above sea level in an area with low and highly seasonal rainfall. At the time of the burst [29 August] the rainy season had scarcely started. The mine site area has been exploited since the first half of the 16th century and was one of the first important mines of the colonial period.

The present mine operation controls waste contamination by means of two tailings dams, designed by foreign consultants, constructed in the past five years. It was the lower of the two dams [Dam B] which was breached at the end of August. The damage was first noticed on 29 August when the topmost section of the dam allowed limited spillage. Following this, the main dam upper wall ruptured on the morning of 1 September and an estimated 235 000 m³ of tailings were released into the dry bed of the valley below. Rain and snowmelt water entering the dam is believed to have been a factor contributing to the failure. The downstream movement of the solids was checked by an older dam further downstream and a narrow-gauge tunnel.

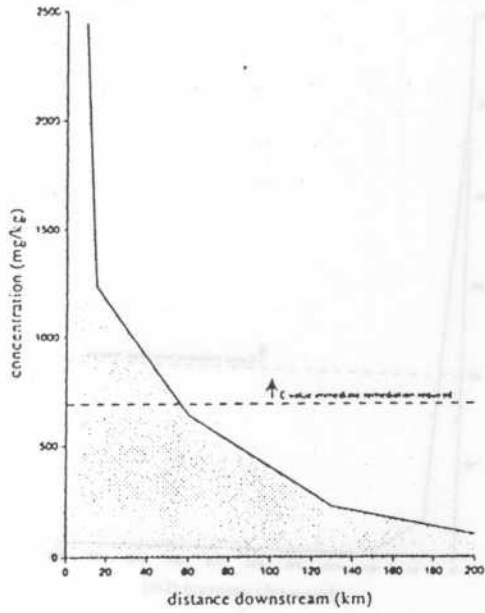
The cleaning operation undertaken by the mining company COMSUR had removed much of the trapped tailings by the time of our visit over 8 weeks later.

According to the report of the incident produced by the Under-Secretariat for the Environment, MDSMA, 87 per cent of water contamination occurs in the first 50 kilometres, largely in the first two kilometres downstream of the dam. Less contamination occurs the the section Chillma-Torcochi, 50-105 kms. downstream; and least in the third section Torcochi-Palca Higueras. Metal concentrations in river

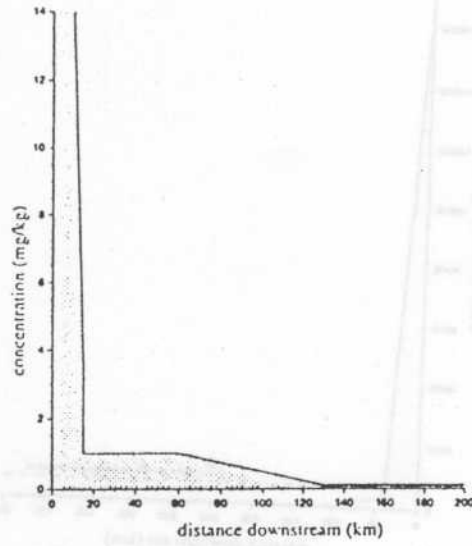
... the principal long term store of contaminant metals in the aquatic environment

Figure 3.1

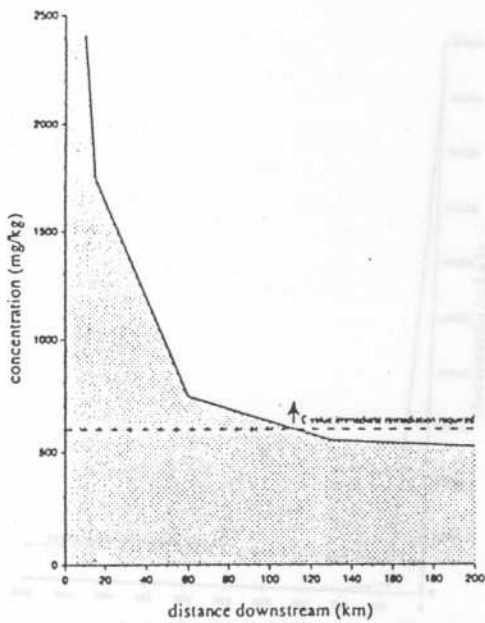
Arsenic concentration in the River Tumusla – River Pilaya



Cadmium concentration in the River Tumusla – River Pilaya



Lead concentration in the River Tumusla – River Pilaya



Zinc concentration in the River Tumusla – River Pilaya

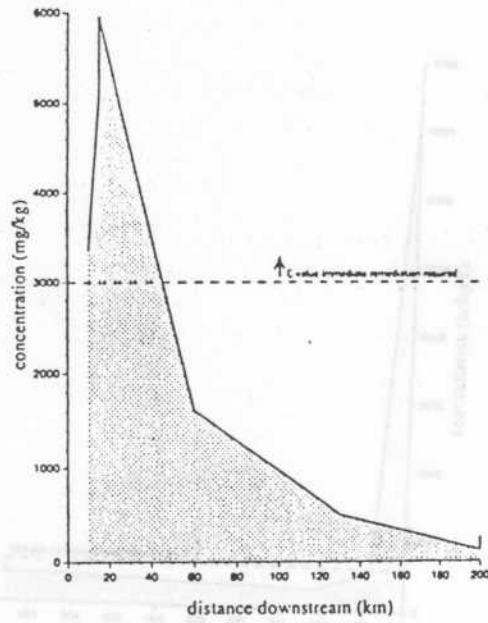
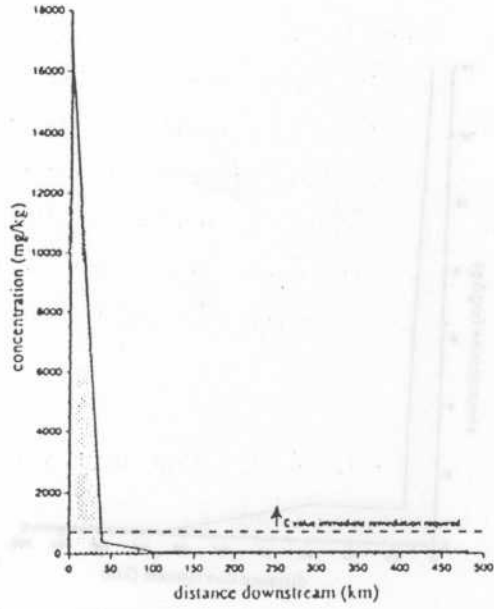
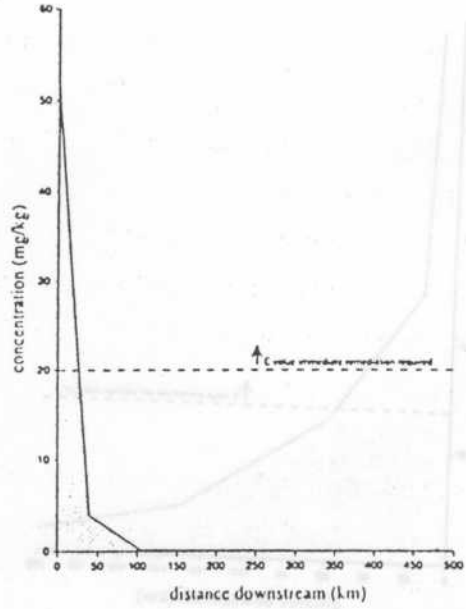


Figure 3.2

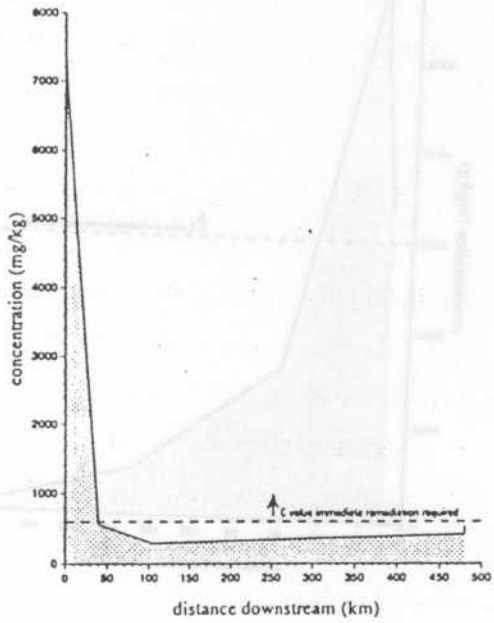
Arsenic concentration in the River Pilcomayo



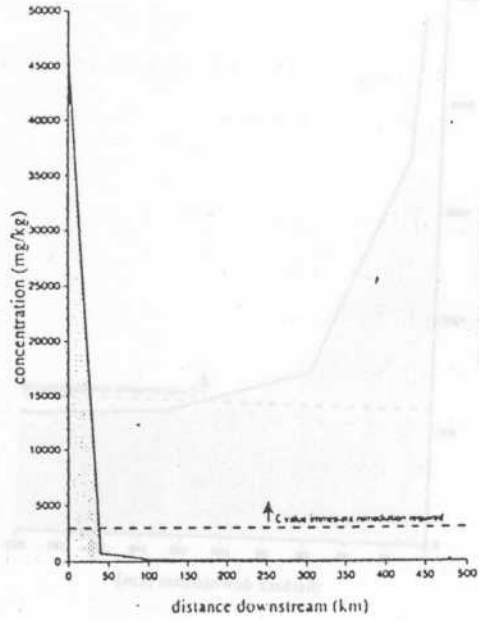
Cadmium concentration in the River Pilcomayo



Lead concentration in the River Pilcomayo



Zinc concentration in the River Pilcomayo



4. Downstream social and environmental effects

4.1 Riverine human populations and their exposure to and perceptions of hazard

The population of the area within the Pilaya catchment of the Pilcomayo system is estimated at 164,000 out of a total upper Pilcomayo catchment population of 424,000¹ [1992 Census]. The population is concentrated in small urban settlements and scattered communities. Population densities are low and the extensive uplands lying over 3000 m. altitude are used for livestock raising and agriculture, which is confined to areas having access to water from springs, or undulating surfaces with good soils. Cereals are grown, largely wheat and barley, as well as beans although maize becomes important at lower elevations. In the river valleys at lower levels irrigation is widely used and intensive farming of fruit and vegetables is practised. The area near Camargo is an important producer of grapes for wine and brandy. Downstream from the Pilaya once the Pilcomayo is joined, population densities are low but groups of native people use river resources particularly for fish although more use is being made of the near-level Chaco [300-400 m. above sea level] in some parts of Bolivia for commercial-oriented agriculture, particularly for soyabeans.

The highly seasonal rainfall means that river levels vary considerably and, during the dry season, sources of water are reduced and the upper parts of some river systems are virtually dry. With the first storms of the rainy season, rivers carry a very high sediment load and accumulations of waste from mines and urban centres are washed downstream. People in several localities spoke of flushes of sediment and waste of different colours, according to the geographical location of the storm which brought the material downstream. They commented that water during such flood periods was unsuitable for either irrigation or drinking. The *borracheras* which cause fish in the lower part of the Pilcomayo to exhibit distress by writhing and splashing on the surface [see 4.2.4] seem also to be associated with early season rains flushing accumulated material downstream.

The degree of dependence on river water which may be contaminated varies according to the site and the socio-economic situation of the people. Many riverine communities appear to have no alternative water source to the river and are thus unable to avoid drinking river water at times of high silt load and possible maximum toxicity. In Potosí and Chuquisaca departments 80 per cent of the rural population have no access to a piped water supply. The Guarani community visited at Puerto Margarita use the juice from the leaves of a local plant as a flocculant to speed the settlement of silt but this is not an adequate substitute for clean drinking water for people and animals. Children are particularly at risk when the river water is poor quality since they play and bathe in the river and do not necessarily obey parental injunctions not to drink the water. A child who drank the river water at Puente La Palca following the Porco incident and subsequent became ill had been told not to drink the water and was described as naughty the way some children are.

Exposure to risk may originate in diet as well as daily activity. While many informants commented that neither they nor the animals are so foolish as to drink river water at times of high sediment load, others have little choice. It is clearly a high priority that sources of clean water be provided for communities which have no satisfactory access to alternative supplies. People interviewed were highly conscious of the possibility of contamination of river water, very aware of diagnostic signs of contamination as well as the sources of contamination and well skilled in taking evasive action when necessary. Many are not able to take necessary evasive action for lack of alternatives.

River contamination and public health

The most common class of illness for many people, but particularly children, is gastro-intestinal. This is true for most areas where living standards are low. Some parts of the Pilcomayo basin, particularly in southern Potosí and Chuquisaca, have some of the highest incidences of poverty in Bolivia. 1992 data on child mortality show that in the Department of Potosí mortality is 74 per cent higher than the neighbouring department of Tarija. Interviews at Puerto Margarita revealed that stomach ailments were most common reasons for seeking help from the health clinic. In such situations not only are people particularly vulnerable to effects of contamination from water but also they are likely to be insufficiently robust to survive low levels of toxicity.

It will be difficult to demonstrate conclusively the contribution of contamination of water supplies to individual and collective ill-health for it will be one of multiple causes. In view of the findings of Part 3 of this report, it is clear that studies need to be set in motion to attempt to establish the role of heavy metal contamination in morbidity and mortality in this part of Bolivia.

4.2 Fish and fisheries

4.2.1 General Features

The fishery for the Pilcomayo sábalo (*Prochilodus platensis*) is one of the largest suppliers of fish in the country. Production is variable, but is generally between 1,000 mt to 2,600 mt per year with an average yield of 1,300 mt (Payne and Salas 1993). The principal markets are the major urban areas of Bolivia including La Paz, Tarija and Santa Cruz. For most centres, including La Paz, the major distribution route is by road, relying upon lorries with 5 and 10 ton ice boxes loading up with fresh fish at numerous sites along the Pilcomayo River and transporting the iced product to market, a journey which can take up to 48 hours.

The fishery has been documented through the monitoring of the previous Centro de Desarrollo Pesquería (CDP) and through a series of collaborative surveys of CDP with the ODA Misión Británica (Bayley 1973, Payne 1986, Payne and Fallows 1987, Payne and Harvey 1989, Payne and Salas 1993). The fishery is very seasonal with the migratory adults appearing in the Bolivian Sector in late April or early May. First fishing activity is therefore reported at the southerly centres such as Esmeralda.

4.2.2 The Fish

The sábalo migrate up the Pilcomayo in waves, reaching a peak usually in June or July. The smallest fish are around 18-19 cm and the youngest age group is almost 2 years old (Payne and Harvey 1989). The largest fish are over 50 cm and can be 6-7 years old. All the fish are adults with maturing gonads and do not include juveniles.

The fish are moving upstream to spawn. They pass through the gorges of El Chorro and appear to spawn in the flatter upland areas around Puerto Margarita (Bayley 1973, Payne and Salas 1993). Exactly how far up river the fish move or spawn is unclear. During these spawning runs the fish appear to feed little, if at all, with the gut being completely empty in most cases (Bayley 1973, Payne and Harvey 1989, Payne and Salas 1993). They subsist upon the large fat reserves which are seen at this time and which have been built up on the main feeding grounds downstream in Paraguay earlier in the year. Whether feeding commences again at or around spawning in the flatter areas at Puerto Margarita remains to be seen. In relation to exposure to toxic materials in the water or sediments, these are important issues.

The sábalo feeds by browsing over the surface of mud or sand deposits from which it extracts the fine organic particles or detritus as its main food source. Given the tendency of heavy metals to become selectively absorbed onto organic particles, feeding clearly represents a route of exposure.

Once the fish have spawned, probably around September, the adult fish start to move downstream with the first rise in water levels. At this time the fish do receive some protection, since the fishing season closes at the end of August and a veda or embargo is in place until the next April.

Sábalo, which are found throughout the La Plata basin, typically retreat to established floodplains for the remainder of the year, where they feed and grow in the abundant production of such areas. The fish disappear from Bolivian waters and probably go downstream to the extensive floodplains of the lower Pilcomayo towards Asunción in Paraguay (Bailey 1973).

The eggs and larvae are thought to be carried downstream passively by the current towards the floodplain as they are elsewhere. Eggs and larvae were found suspended in the water at Villa Montes by a Russian Academy of Sciences / CODETAR study at this time.

The juveniles spend the first two years on the floodplain growing to the size of around 18 cm before joining the adults in their first upstream migration. There is some evidence that, following a good flood year when growth and survival are expected to be high, there is a peak in fish catch two years later due to the high survival of young two years previously (Payne and Harvey 1989).

It is clear that a residual number of sábalo do remain in the river throughout the year at Puerto Margarita. These support a small domestic and subsistence fishery. The extent and significance of this residual population remains to be assessed.

4.2.3 Fishing Communities

The fishing season extends from April until the end of August, when a veda is imposed. There are three main groups involved in the fishery:

(i) the Matacos people, who fish from the border over the flat meandering river of the dry chaco, using large seine nets;

(ii) the trap fishermen of the torrential gorge region, who build stone traps into the boulder strewn river;

(iii) the Guarani people of the flat areas around Puerto Margarita who also use seine nets.

The Matacos fish on a communal basis. They stay in large fishing camps near the river during the fishing season, but move back towards mission stations in the closed season. They keep cattle and have

some agriculture. Fish is their major cash income. They may also make tourist artefacts for sale during the closed season. The fishing posts are all recognised and licensed.

The trap operators are a more mixed group. Each trapping post has its licence and a nucleus of experienced operators, but there is also a proportion of labourers. Again, there is a more or less fixed number of trapping positions. There is a Fishing Association based in Villa Montes which may have formal or informal links with the Matacos fishing groups. At the end of the fishing season the trap teams disperse to take up other occupations such as farming, or other forms of labouring. Some of the main licensees live in Villa Montes.

The Guaraní are in many ways the most completely dependent upon the fishery. Like the other groups, they catch fish commercially during the season, using large seine nets, but at other times they fish for domestic consumption using small gears, such as cast nets. At these times, each household "owns" or is given access to a hole in the river where they can always fish. The residual sabalo and other species are therefore very important to these people (see Section 4.2.2).

The Guaraní in this area eat fish virtually every day. The fish they catch during the commercial season is virtually their only source of cash. Only a few have livestock and otherwise they still rely upon plants or wild animals which they can find in the Chaco, or upon bartering fish for maize with other Guaraní groups over towards Entre Rios. Fish is an important barter item for a range of other commodities. The sabalo, therefore, is an essential source of both food and income. In this very arid area, the river water is also the only source of water, and is taken directly from the river.

During the fishing season large numbers of lorries with ice boxes find their way to all of these locations, where the access can be quite difficult. Here they will wait for up to a week whilst the boxes are filled directly from the river. When full, they depart for the urban markets. In the case of Santa Cruz, the ice boxes are carried by rail from Villa Montes station.

4.2.4 Impact of the Incident

Evidence at the sites

where?

Interviews conducted down the Pilcomayo river system consistently described how the water turned black with suspended sediment at some point after the Porco incident. Widely separated interviewees independently related that the "black water" came in three waves. This was also reported by the Guaraní people at Puerto Margarita. Whilst the Pilcomayo normally has a heavy silt load, this is mostly pale brown or pale grey and none of the communities remembered seeing black water before.

Evidence
⚡

Given the grey/black colour of the mine tailings, it does seem likely that the "spike" of sediment discharged from the tailing dam did reach Puerto Margarita and Villa Montes.

people said they haven't seen fish killed during period (Sept - Nov) 06

There have been reports in the press of mass fish kills in the lower stretches of the river, in the Matacos area, and of incidents of dogs dying after eating fish guts. These reports remain to be verified. Interviews with the Guarani stated that they observed no particular mortalities associated with the black water. What they did report were three incidents of the "borrachera" (i.e. drunkenness) phenomenon of fish in the river coinciding with the early rains. One was observed the day before our arrival and two fish specimens were obtained. *and what did you find?*

is quite normal when rains arrive.

see previous page

The borrachera syndrome is indicated by the fish splashing and writhing around at the surface of the water in large numbers. These includes not just sábalo, but also dorado and surubí. This response could be consistent with distress caused by the flushing out of debris and contaminants accumulated in the water courses in the dry season, which is a recognised event in highly seasonal systems.

Borrachera incidents have occurred spasmodically in the past, always with the first rains. The black water itself was not accompanied by such an incident. *The "borrachera" happened a month or more after the Perico spill.*

dates?

The Guarani community at Puerto Margarita tried not to drink the river water during the period of the black water. In this they were fortunate since a research compound of the University of Tarija has recently dug a 20 m well which, whilst it is close to the river, produces clear water. Some people were able to use this water.

An interview with the pharmacist at the recently opened pharmacy at Puerto Margarita suggested that it was difficult to say if the incident had any immediate impact on health, since diarrhoea and other gut ailments are common in the community, largely because they had to drink river water.

Potential Toxic Effects to Fish

The tailings contain a number of potentially toxic materials, most notably heavy metals, including arsenic. Toxic effects can be separated into:

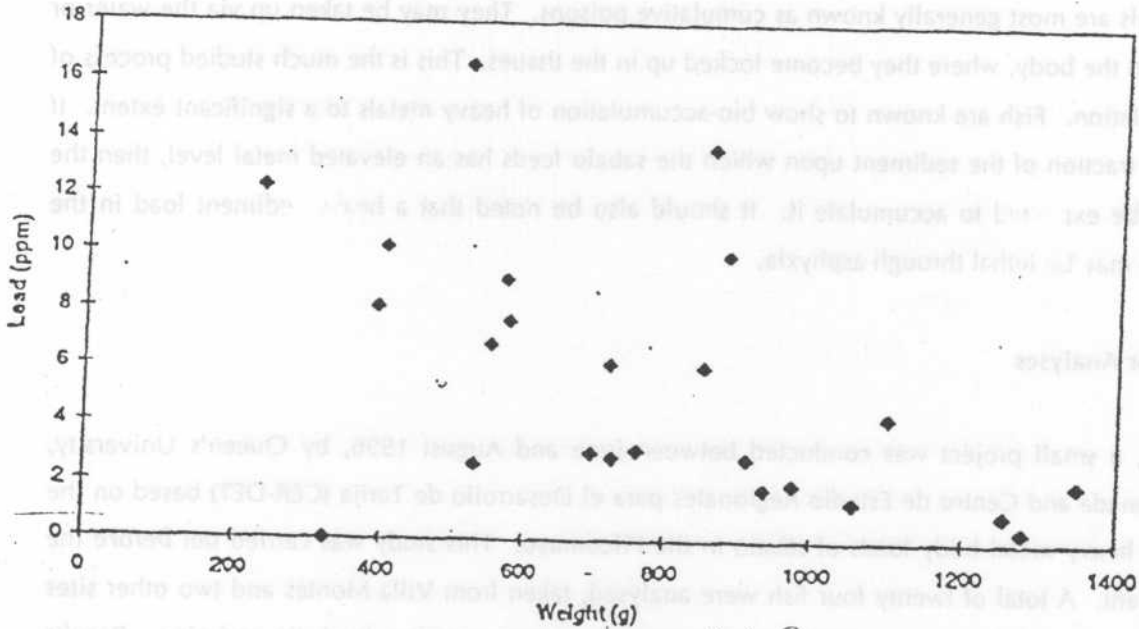
- acute - short-term and often lethal
- chronic - longer-term, lethal or sub-lethal.

Fish can be killed by acute incidents of heavy metal exposure, but by and large, dissolved concentrates need to be relatively high. This is not necessarily true of all mine waste contaminants. Cyanide, used in the processing of the tailings, for example, is a fast-acting metabolic poison that can kill in very low

The clearest case is that of lead (Figure 4.1)

Figure 4.1

LEAD CONTENT VS WEIGHT



The report points out that 92% of all the observations exceed the allowable limit and that the mean value of 5.5 ppm is eleven times higher than the allowable limit. The highest level is 30 times higher. There may be mitigating factors towards explaining this, but nevertheless, the lead levels are remarkably high. It can also be seen that the lead levels tend to be higher in smaller, younger fish (Figure 4.1), a feature which has been observed in other fish types.

The results of the lead determination are therefore, albeit on a small sample and without a control, sufficiently abnormal to urge further action.

The results for arsenic and mercury are less decisive. The means for arsenic and mercury (Figure 4.2) are less than half that of the allowable limit. It does depend, however, upon which tissues the metals are concentrated in and how appropriate the allowable limits are. There is no apparent trend for mercury to be concentrated in either younger or older fish (Figure 4.2).

It should also be borne in mind that heavy metals accumulate progressively at each point of transfer up the food chain. The metal concentrations in the predatory dorado and the catfish, surubí, and by inference, people, should therefore be of interest.

concentrations. It is, however, relatively readily broken down in natural systems. The main route for substances having an acute effect is from the water through the gills. Chronic effects may arise via the gut and / or the gills.

Heavy metals are most generally known as cumulative poisons. They may be taken up via the water or the food into the body, where they become locked up in the tissues. This is the much studied process of bio-accumulation. Fish are known to show bio-accumulation of heavy metals to a significant extent. If the organic fraction of the sediment upon which the sabalo feeds has an elevated metal level, then the fish would be expected to accumulate it. It should also be noted that a heavy sediment load in the water alone may be lethal through asphyxia.

Evidence for Analyses

Fortunately, a small project was conducted between June and August 1996, by Queen's University, Ontario, Canada and Centro de Estudio Regionales para el Desarrollo de Tarija (CER-DET) based on the analyses of heavy metal body loads of sábalo in the Pilcomayo. This study was carried out *before* the Porco incident. A total of twenty four fish were analysed, taken from Villa Montes and two other sites further upstream. Analyses were conducted for arsenic, copper, mercury, lead, tin and zinc. Results were expressed in parts per million (ppm) which is equivalent to mg kg^{-1}

Significant amounts of all metals were found in these fishes. However, no samples were available from clean, uncontaminated sites as a reference to judge the natural profile of these metals in uncontaminated sábalo. Some national background uptake will necessarily take place for some metals such as zinc and copper. Others, such as arsenic, mercury and lead are normally present in virtually negligible quantities unless in exceptional circumstances. All three of these metals occur in detectable quantities in the small sample of sabalo from the Pilcomayo. *Values?*

The Queens / CER-DET Report gives the Canadian limits allowable for human consumption of fish. These limits are expressed in terms of the fish flesh only, i.e. the part most universally consumed. These allowable limits are:

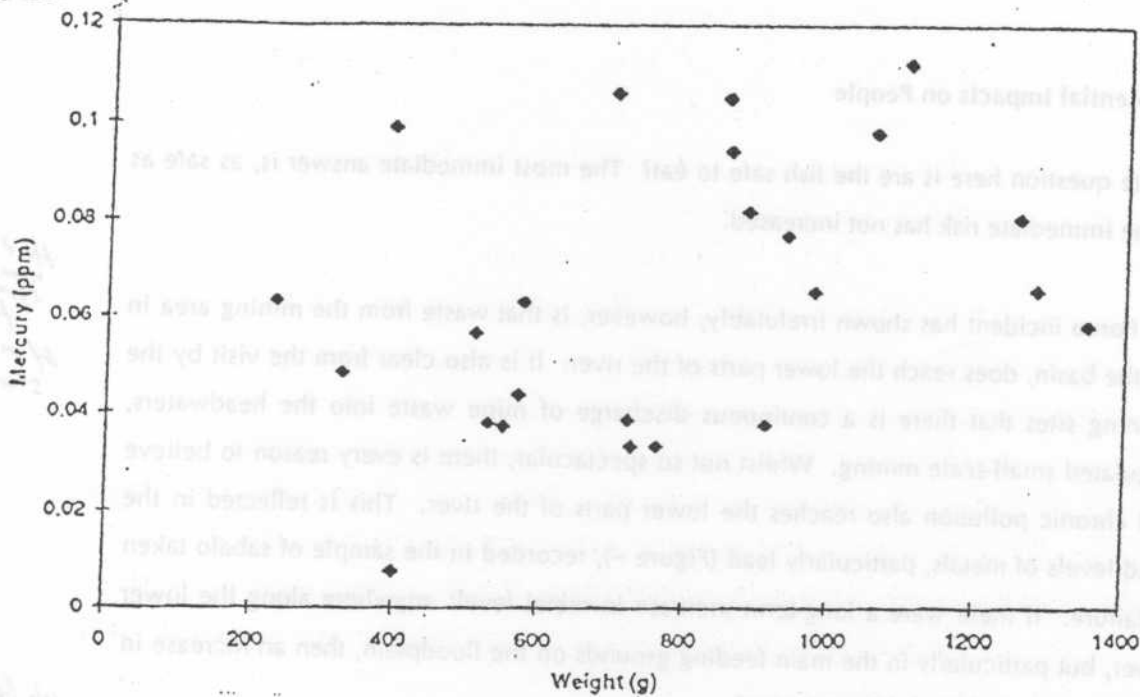
Lead	0.5 ppm
Arsenic	3.5 ppm
Mercury	0.5 ppm

what is the equivalence for a whole fish?

It should be borne in mind that values given in the present study are in ppm for the whole fish and that metals may be selectively accumulated in specific and different organs and tissues.

Figure 4.2

MERCURY CONTENT VS WEIGHT



P.L. > 0.5

4.2.5 Potential impacts on fish

The first question is whether bio-accumulation of lead or other metals is lethal to fish. The answer is not in the short term. There is, however, indirect evidence that accumulated levels of lead may increase general mortality rates within a population and also reduce growth rates.

The incident itself occurred at the end of August, just when all the sábalo would have been upstream and spawning. A dense spike of black, potentially toxic sediment may have interfered with spawning behaviour or have proved more lethal or damaging to the delicate eggs and alevins than to the adults. If this is true then recruitment of young fish into the fishery would be greatly reduced in two years time (see Section 4.2.2), resulting in a fall in annual catch at that time.

If the spike of sediment coming down the river ultimately resulted in an increase in metal concentrations in the sediments in flat areas, such as around Puerto Margarita and even down as far as the floodplains in Paraguay, this could readily lead to elevated rates of uptake and further increased body loads of metals by the sábalo. The results of the analyses do show clear evidence that the fish do accumulate heavy metals. Their feeding habits on the bottom sediments do predispose them to uptake from this source. Equally, uptake by their predators would also be expected to increase.

4.5. There is no graph for P.L., why?

The sábalo fishery is already under considerable pressure from a variety of sources, including intensive exploitation, water abstraction, engineering structures and low rainfall, and it may only require one more negative factor to eliminate this national resource.

4.2.6 Potential Impacts on People

The most immediate question here is are the fish safe to eat? The most immediate answer is, as safe as they ever were. The immediate risk has not increased.

The one thing the Porco incident has shown irrefutably, however, is that waste from the mining area in the headwaters of the basin, does reach the lower parts of the river. It is also clear from the visit by the mission to the mining sites that there is a continuous discharge of mine waste into the headwaters, mainly from unregulated small-scale mining. Whilst not so spectacular, there is every reason to believe that this low level chronic pollution also reaches the lower parts of the river. This is reflected in the apparently elevated levels of metals, particularly lead (Figure -), recorded in the sample of sábalo taken before the Porco failure. If there were a long-term increase in metal levels anywhere along the lower stretches of the river, but particularly in the main feeding grounds on the floodplain, then an increase in the metal content of the fish would also be expected.

How can you prove that if it shows at

Present and future risks to human health remain to be assessed. There is no doubt that heavy metals accumulated in the human system can be damaging. The most dramatic example was the Minamata syndrome where large numbers of people showed several neuronal disorders after eating mercury-contaminated fish. Similarly extensive research in Europe on the effects of aerosol lead in petrol fumes showed that it accumulated in the nervous system and was linked to low IQ results in children. These are extreme cases, but show the risks should not be disregarded.

We harm by pollution do this comparison is not appropriate

vs Pb in petrol

The sampling available at present is small and the analyses are too generalised to provide a clear indication of the risk. The results however, do show grounds for concern and also indicate how analyses should be focused in future.

Nobody eating a single fish is likely to be harmed, nor is occasional consumption of fish likely to be a hazard. Those most at risk will be those who eat fish most frequently and also drink river water on a regular basis. It should be remembered, however, that much of the sábalo is actually marketed in the major urban centres, such as La Paz, Santa Cruz and Tarija.

The existing risk from chronic mine waste pollution needs to be properly assessed. This risk is unlikely to increase from fish for the next year, even following the Porco incident, but this will also need to be

closely monitored and assessed. Risks may increase in the short term if elevated levels in the sediment are ingested while drinking water from the river.

advised (not 10 years)

A precipitate closure of the fishery could not be recommended. For the next year the risks will almost certainly be the same as they have been for some time. The fishery provides a livelihood for some of the poorest people as well as being a significant part of the national food reserves. The impact of closing the fishery would, in the short-term, be far more damaging to the fishing communities.

The existing and future risks need to be assessed. These risks, however, would ultimately be removed if the mine waste was controlled.

4.3 Agriculture, livelihoods and migration

The most direct consequence of water contamination of farming is injury to crops and livestock. In many places the long-standing nature of contamination may ensure that farmers know well which areas are contaminated since livestock avoid them or become noticeable sick. In other cases crops will fail to grow where contamination is marked. Where contamination fluctuates during the year and where irrigation is an integral part of farming, such as in many riverine zones of southern highland Bolivia, crops can be endangered and thus domestic livelihoods. Second-hand evidence was provided at Puente la Palca of a farmer whose onions were recently affected by toxic water entering his irrigation channels. Precisely who was affected by the spike of contaminated water associated with the Porco spill would be difficult to establish. What is noteworthy is that most informants were well aware of the dangers inherent in irrigation at times when river water was carrying a heavy silt load, thus possibly highly charged with contaminants. They reported in San Juan de Oro that tomatoes were most sensitive to contamination; potatoes and pumpkins [zapallo] were less affected. Woody plants such as vines and fruit trees are little affected. The communities potentially most affected are therefore those growing vegetables, particularly for market, such as those downstream from Camargo as far as Villa Abecia.

How did you prove that?

*Not proved
crops don't grow in a couple of months*

Livestock were reported usually to avoid drinking water heavily charged with silt but are clearly vulnerable, just as are humans, where alternative water supplies are scarce or non-existent. In many of the dry highland areas livestock will move from one pasture zone to another on a daily and seasonal basis and thus their exposure to contamination may be reduced.

Livelihoods can only be assured in many of the poorer areas by seasonal movement of people and livestock, but an increasingly common strategy is migration to work in Santa Cruz or Argentina for prolonged periods. Some villages between Potosí and Camargo exhibited unmistakable signs of such migration with brightly-painted houses and garages for new [but used] vehicles purchased with migrant savings. Population here is falling, largely as a consequence of out-migration. Such migration will reduce the exposure of some people to the effects of contaminated water but, since farming in the

highland areas remains an important element in domestic livelihood strategies, such exposure is reduced rather than eliminated and the elderly and children will remain highly vulnerable. Higher incomes also lead to increased consumption of fish, much of which is brought during the fishing season by lorry from the Chaco, particularly Villa Montes. If such fish is contaminated and eaten regularly this may increase exposure to disease. Several informants reported buying fish both when visiting Potosí and from passing lorries.

Households such as those of the Guarani people in Puerto Margarita both depend on fish for their cash income during the season and consume fish on a daily basis. On the one hand they are vulnerable to contamination as a result of continuous ingestion of affected fish and, on the other, they are highly sensitive to fluctuating demand for fish as a consequence of changes in popular [market] perception of the advisability of eating fish from the Pilcomayo on health grounds.

4.4 Infrastructure projects

4.4.1 Background

There are a number of significant infrastructure projects downstream of the affected areas in the Pilcomayo basin and more are planned. The Porco incident has emphasised the potential present and future threats of the mine waste problem to major downstream projects. The incident has shown, above all, that mine waste does reach the lower parts of the river, although it does remain to be determined exactly how far that influence extends, including beyond the borders of Bolivia.

4.4.2 Irrigation Projects

Among existing infrastructure projects, the most significant are the Provisa (Proyecto Villa Montes) irrigation scheme near Villa Montes and water abstraction scheme Proyecto Pantalón, also believed to be mainly for irrigation, between Paraguay and Argentina. Irrigation schemes provide the most intimate association between water and soil and, as such, are particularly vulnerable to pollution incidents. A dense black sediment, even if it were inert would still have a very damaging effect upon the soil by clogging up the air spaces and generally degrading the soil structure. The mission found reported examples of smallholder irrigation where the channels were open during the black water period, one with a crop of onions and one with sugar cane, where a black sediment was deposited in the irrigation furrows. Samples from the sugar cane plants were brought for examination and proved to be of a black, highly glutinous nature. The onion crop, apparently withered and died. Fortunately, water was not circulating through the Provisa irrigation scheme at Villa Montes during the spike from the incident. The conditions in schemes beyond Bolivia in Paraguay and Argentina are unknown. A rapid survey of indicators of the incident in these two countries, if they have not already been carried out, would be extremely valuable in determining exactly how far downstream mine waste is actually carried. The "black water" has provided a good marker.

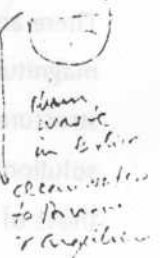
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What is the
relation w/ P.

In fact the sediment from mine waste is not inert. It carries with it concentrations of a variety of heavy metals (see Section 3). If such sediment is left in the soil, then crops will absorb the metals and accumulate there. Experience downstream of a zinc smelter in India showed that wheat crops grown alongside downstream channels concentrated both lead and zinc several times above that in the water, and that horticultural crops such as tomatoes and cucumbers concentrated the metals to the highest degree. This is not just true following a one-off incident. It is equally true of low-level continuous pollution of the type continuously discharged from the mining areas of the headwaters. Such continuous pollution can have an insidious effect upon crops and soil structure within irrigation schemes.

4.4.3 Dam Projects

A number of projects involving dam or barrier construction across the Pilcomayo have been proposed. Provisa have plans for a dam across the steep gorge region of the river at El Chorro (Payne and Salas 1993). Most recently there was a proposal for the construction of a major dam at Caipipendi, which would flood most of the flat upland areas of the river basin around Puerto Marguerita, including the settlement itself (Payne and Salas in ERM 1994). The major purposes of these dams was to provide hydroelectric power and water for extensive irrigation development. The Caipipendi development was of interest to the Three Nations Committee because of the increased ability to regulate downstream water supplies amongst other attributes.

Need to be reconsidered!



Dams are essentially sediment traps. Continuous low-level discharge of mine waste with its associated heavy metal content would accumulate in the reservoir sediments. These would eventually get into the food chain and the water. This would have deleterious effects in downstream irrigation schemes, increase corrosion rates on turbine blades and other HEP structures, and present a risk to people dependent upon the water of the reservoir.

A one-off effect of an incident such as the failure at Porco could have a tremendous impact. Observations in other areas, such as the North American Great Lakes, show that once heavy metals build up in lakes they take many years to disperse. In the case of Caipipendi, the whole sediment discharge would ultimately be retained by the dam with greatly increased chronic effects such as those mentioned above, and graphic acute effects such as fish kills and general negative impacts on the whole biodiversity.

5. The future

The mine waste disposal problem in the headwaters of the Pilcomayo is a time bomb threatening any future development of water resources within the river basin. Any development or investment in this and related sectors will always be at risk from the chronic long-term effects of continuous discharge or from acute effects of catastrophic one-off events such as the Porco failure. It is a basin-wide problem, since the downstream effects extend over considerable distances and it will require the attention of all three riparian countries. Fortunately, the tripartite Three Nations Commission exists as a forum for discussion of shared problems of basin management. Without some resolution of the problem, economic development of the basin will always be in jeopardy.

There are specific risks to health and agriculture which may increase in future as a result of Porco or similar events. There are also the existing risks from the present continuous discharge. This will require monitoring and assessment, followed by the creation of mitigation targets, and future monitoring to ascertain if these targets are being met.

There are, however, immediate practical measures to be taken. Clearly an immediate assessment of the magnitude of the continuous discharge from small-scale mining and of the stability of large storage structures needs to be accomplished, with designs for engineering solutions. Implementation of those solutions should be rapid. This will stop the problem at source and the remaining problems will be those of restoration and rehabilitation.

A further simple practical measure would be a programme of providing simple tube-wells for communities living along river banks which otherwise need to drink the river water. A simple well, even on the river bank, acts as a very effective filter. This programme would have the added advantage of also reducing the high levels of gastro-intestinal bacterial diseases.

With regard to monitoring and assessment measures, which should include sediment, water, fish and socio-economic indicators. Clearly each country would be concerned to assess the position in its national area through their respective environment and sectoral ministries, but there would be a need for international co-ordination.

It is suggested that the monitoring be conducted through a series of Regional Monitoring Centres, based around universities or research centres. There could be five in all, three in Bolivia, being the headwater country, and one each in Paraguay and Argentina. In Bolivia these may include the Universities of Potosi and Tarija. These centres may require some reinforcement of capacity in terms of equipment or training to enable them to take in this task, which would be contracted to them by the national governments.

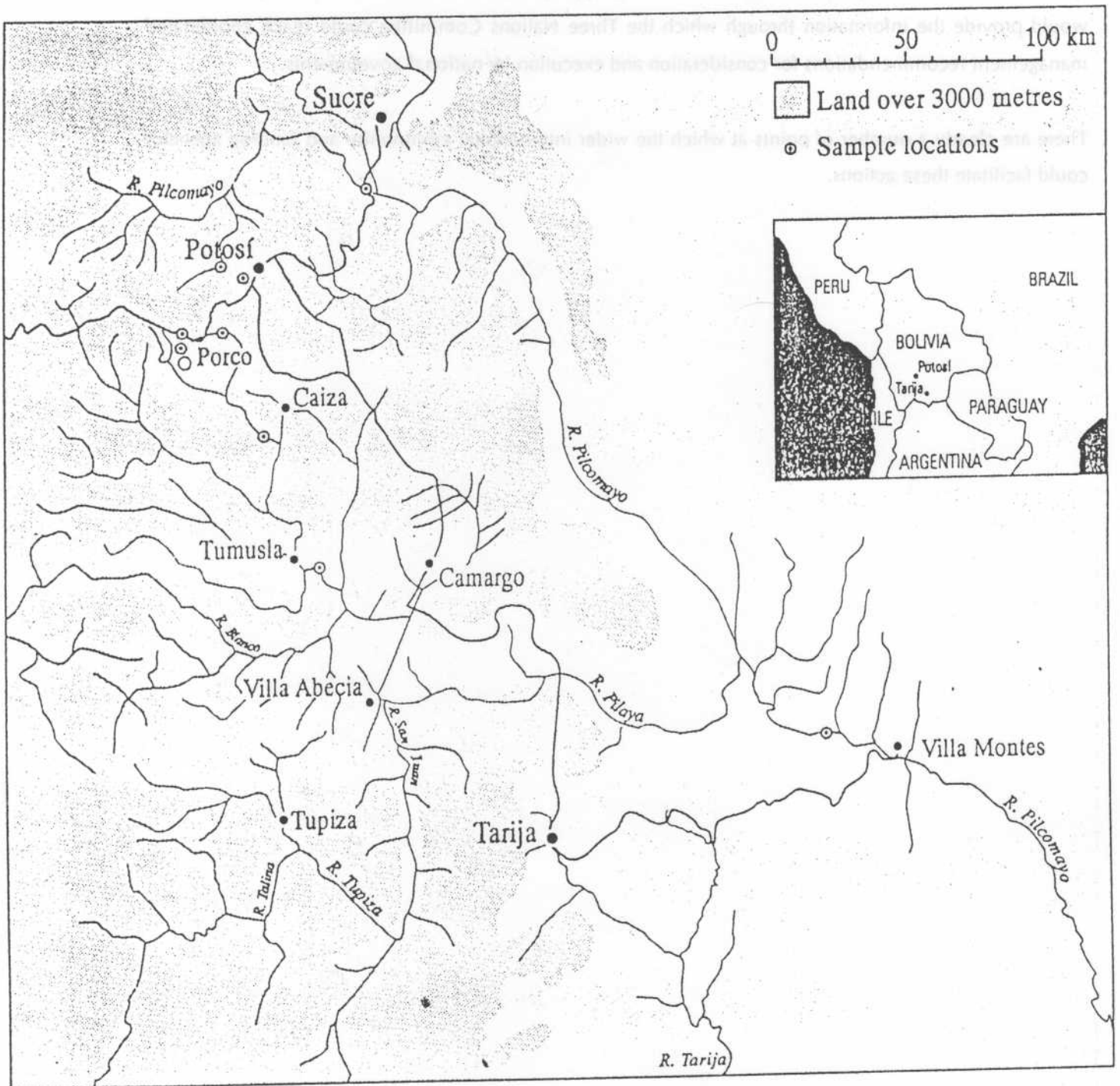
In many cases, coordinated management of international river basins is difficult due to the lack of an institutional forum or secretariat. This does exist for the Pilcomayo basin. The Three Nations Committee may need support from a Technical Advisory Committee drawn from the appropriate national environment ministries or the Regional Monitoring Centres. National or international specialists could be coopted into this committee as appropriate. The Technical Advisory Committee would provide the information through which the Three Nations Committee could reach coordinated management recommendations for consideration and execution by national governments.

There are clearly a number of points at which the wider international community and funding agencies could facilitate these actions.



Map 1

Pilaya and Pilcomayo catchments of the Upper Pilcomayo river



The Pilcomayo river in the Paraná-Paraguay river system



Annex 1 Results of analyses of sediments
The Pilcomayo river in the Paraná-Uruguay river system



690 3,000 670 20

Sample No.	Description	As mg/kg	Zn mg/kg	Pb mg/kg	Cd mg/kg	Cu mg/kg	Sn mg/kg	Cr mg/kg	Ni mg/kg	Co mg/kg
1	R. de la Ribera - 0km (edge of Potosi). Contemporary channel sediments. *	17127	46768	7361	52	436	310	7	34	394
2	R. Tarapaya - approx 40km downstream. Contemporary channel sediments.	6806	22473	3042	<1	183	134	5	23	208
3	R. Tarapaya - approx 40km downstream. Recent flood deposits banked against 3m terrace.	1165	4176	1148	1	71	120	7	11	111
4	R. Tarapaya - approx 40km downstream. 50cm below 3m terrace sediments	364	769	560	4	385	125	9	13	208
5	R. Tarapaya - approx 40km downstream. Topsoil on 3m terrace. *	304	1073	557	3	163	125	9	15	95
6	R. Pilcomayo - approx 104km downstream. Contemporary channel sediments	62	189	292	<1	<1	54	8	12	78
7	R. Pilcomayo - approx 480km downstream. Contemporary channel sediments	63	4	417	<1	<1	84	12	19	124
8	R. Pilcomayo - approx 480km downstream. Contemporary channel sediments	112	314	531	<1	12	99	14	35	170
9	R. Pilcomayo - approx 480km downstream. Surface 2m terrace.	10	22	25	<1	<1	35	5	5	38
10	Potosi - mine tailings sample	5614	257	2795	58	97	473	4	60	720
11	R. Agua Castilla - approx 10km downstream. Contemporary channel sediments. *	2446	3348	2411	14	83	74	7	9	107
12	R. Agua Castilla - approx 10km downstream. Overbank sediments.	1839	5336	1981	1	105	72	8	15	95
13	R. Agua Castilla - approx 10km downstream. 0.4m from surface of 2m terrace	117	1195	481	1	17	87	7	8	67
14	R. Agua Castilla - approx 10km downstream. 1.2m from surface of 2m terrace	29	129	154	<1	<1	43	6	11	40
15	R. Agua Castilla - approx 10km downstream. 4m from surface of 7m terrace.	20	56	229	<1	<1	59	9	21	113
16	R. Agua Castilla - approx 11km downstream. Pre - mining terrace	204	3455	1056	3	3	93	9	9	71
17	R. Agua Castilla - approx 15km downstream. Contemporary channel sediments.	1234	5087	1335	4	31	75	6	9	94
18	R. Agua Castilla - approx 15km downstream. Contemporary channel sediments. *		5959	1716	1	51	79	6	16	109
19	R. Jatun Mayo - approx 60km downstream. Contemporary channel sediments. *	642	1611	744	1	11	66	7	20	98
20	R. Jatun Mayo - approx 60km downstream. Vegetated point bar surface sediments.	70	550	432	1	7	80	9	37	142
21	R. Jatun Mayo - approx 60km downstream. Surface sediments of 1.5m agric terrace.	71	555	439	1	6	71	9	29	136
22	R. Tumusla approx 130km downstream. Contemporary channel sediments. *	225	500	551	<1	11	84	10	35	137
23	R. Tumusla - approx 130km downstream. surface of 0.5m vegetated point bar.	62	142	523	<1	11	90	11	48	188
24	R. Tumusla - approx 130km downstream. Base of 0.5m vegetated point bar.	54	172	421	<1	5	73	9	27	126
25	R. Tumusla - approx 130km downstream. Surface of cultivated low terrace.	68	154	513	<1	8	87	11	34	157
26	R. Tumusla - approx 130km downstream. Base of 1.5m agric terrace.	61	177	431	<1	4	81	10	36	141
27	R. Pitaya - approx 200km downstream. Contemporary channel sediments.	100	118	524	<1	7	128	20	24	173
28	R. Pitaya - approx 200km downstream. In channel sediments - fish trap.	99	192	527	<1	18	109	16	39	194
29	R. Pitaya - approx 200km downstream. Channel bed sediments	100	254	523	<1	263	98	11	14	64
30	R. Pitaya - approx 200km downstream. Irrigation channel sediments - floodplain.	73	121	468	<1	3	91	14	29	150
31	R. Pitaya - approx 200km downstream. Floodplain surface sediments.	161	887	666	1	26	95	14	24	145
32	Porco - mine tailings sample	2893	11516	3393	4	183	94	11	13	132
33	Porco mine tailings sample	3260	10465	3277	3	179	91	11	11	135
34	Porco - mine tailings sample	2954	3993	2549	15	54	68	5	66	132

Annex 2
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Author	Title	Year	Page	Volume	Issue	Journal	Year	Page	Volume	Issue	Journal
1	Payne, I, S A Temple and C Curr	1993	86			<i>Final Report to ODA</i>	July 1993				
2	Payne, I and M J Harvey	1989	233 and 248	20		<i>Aquaculture and Fisheries Management</i>					