IMPACT OF MINING ACTIVITY AT YACIMIENTOS CARBONÍFEROS FISCALES ON THE WATER RESOURCES OF THE RÍO TURBIO SYSTEM, SANTA CRUZ PROVINCE, ARGENTINA

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INTRODUCTION

Mining operations at Yacimientos Carboníferos Fiscales (YCF), both open air and underground, are currently located in the basin of the Arroyo San José. The San José drains the mountainous headwater region of the cordillera from the Chilean border. Immediately downstream of the mine, the San José and the Arroyo Prima Vera converge to form the north-south flowing Río Turbio. Open air strip mining has been practised for one year. It occurs above the 300 m contour along the side slopes of the valley of the arroyo Santa Flavia, above where it feeds into the San José. The area of excavation cut into the hillslope is about 80 m by 400 m. The coal is mined by 'truck and shovel', which permits the selective handling of spoils since spoils may be transported, dumped and even compacted in areas specifically allocated for spoil with specific compositions. However, this is not done and spoils are dumped immediately below the cutting on the hillslope of the Santa Flavia in an ad hoc manner. The waste rock pile extends almost to the edge of the Santa Flavia. Underground mining occurs in the valley of the San José and has been practised in the region for about 50 years.

Since 1970 waste rock has been deposited along the hillslopes of the San José valley from almost the river's edge up to the 270 m contour. The waste rock dump consists of rock fragments greater than 0.5 mm. Finer waste products are discharged to the river. It is estimated that about 70% of total waste products end up on the dump.

Estimated accumulation of coarse waste in the waste rock dump is about 250 000 tonnes per annum, with an average density of about 1.6 g/cm^3. The weight of overlying waste rock has resulted in compaction of the underlying fluvio-glacial sediment and a corresponding uplift in the surrounding valley bottom sediment. This has resulted in a 2 m rise in the level of the valley floor.

Current gross excavation projections are about 800 000 tonnes per annum, of which about 50% is waste product. However due to production problems, production of coal has been about 250 000 tonnes per annum. A further 70 000 tonnes is used by the mine for power generation. Estimated water use from the San José averages about 400 m^3/h, or about 1.8 m^3 per tonne of coal produced. About 1 kg of magnetite per tonne of coal is also consumed in the processing plant, which is lost to the refined coal, the coarse waste rock and the fine slurry discharged to the river.

CLIMATE

The region falls under the classification of Subhúmedo Magallánico, however, orographic effects result in a higher rainfall than commonly encountered on the Patagonian Steppes. The region can be classified as dry, with a mean annual precipitation of 411 mm and a mean annual temperature of 5.7 ºC (Sosic and Huidrobo). Minimum precipitation during drought years is probably in the order of 300 mm. Due to the low temperatures, evapotranspiration is low and probably does not exceed 65% of precipitation.

RUNOFF

No adequate runoff data exists for the catchment. Numerous estimates exist for runoff at specific moments in time (Salso, 1982), however, without a continuous record these data are useless for establishing a water balance. In addition, none of these data state where the measurement was taken, making it impossible to define the catchment area generating the runoff. This makes a comparison of the data impossible.

Data from YCF indicates that the mean runoff from the San José basin from mid September 1972-end September 1973 was about 12 205 m^3/h and ranged from 2 196-44 280 m^3/h. A.y. E.E. measured flows between 1958-1961 (Salso, 1982). They estimated a flow of 1609 m^3/h in March 1958 and a flow of 29 650 m^3/h in October 1958. Peak flows occur in spring between mid-September to the end of November. Low flows occur towards the end of winter. Estimates of mean annual runoff range from 23.8-47 hm^3/year. The lower value is probably more realistic. Based on a catchment area of 160 km^2 for Alto Turbio, this corresponds to 148 mm/year of runoff, which is 36% of precipitation. Recharge to the aquifer is unknown, but as base flows appear to be quite a significant proportion of runoff, recharge is probably quite high. Assuming an average annual base flow of 1600 m^3/h, recharge is of the order of 87 mm per year, or 21% of rainfall. Since the phreatic water table in the valley bottom sediment is in hydraulic connection with the river, direct rainfall-recharge to this aquifer is not a limiting factor on groundwater abstraction.

GEOLOGY AND HYDROGEOLOGY

The coal being mined occurs in a monocline of Eocene age, with about a 6-7º dip to the east in the vicinity of Río Turbio. The coal beds are found in the Río Turbio Formation, which consists of a series of sandstones and conglomerates with a thickness of about 600-650 m (Scalabrini, Spikermann, and Medina). Impregnations of calcite veins and granules of pyrite can be seen in the rock. These sediments outcrop on the hillslopes of the region. Due to diagenesis and compaction, the original sediments have been heavily silicified. They have therefore lost their primary permeability so that permeability is low and restricted to cracks and fractures. Little or no groundwater occurs on the hillslopes so that mining excavations are dry.

The valley bottom deposits consist of 30-40 m of Quaternary fluvio-glacial sands and gravels and form an aquifer of moderate permeability. Permeability tests indicate that permeabilities range from 10^{-4}-10^{-6} m/s. The average transmissivity of the aquifer ranges from 25-35 m^2/d above the town of Río Turbio and from 35-45 m^2/d below the town.

PRESENT WATER SUPPLY AND INFRASTRUCTURE

Río Turbio contains 7000 people and currently posseses infrastructure for both surface and groundwater supplies. The town of Río Turbio was previously supplied by water from a dam (Dique San José), which received water from the Valley San José. The catchment area for this dam is upgradient of the present day mining operations, hence water quality is not affected by mining. Due to water shortages during drought years and algae problem is attributed to contamination by nitrates, phosphates and other nutrients, two wellfields were established in 1994. These have now superseded the dam as the source of water supply for Río Turbio. The wells consist of newly drilled boreholes and older rehabilitated boreholes.

The two wellfields tap the fluvio-glacial aquifer in the valley San José upgradient of the mine. One wellfield is located immediately above the dique and the other immediately below. The total volume pumped from groundwater appears to be about 5000 m^3/day. Dynamic water levels are well below the ground surface and the level of the river, indicating that surface water probably recharges the aquifer in the vicinity of the wellfield.

Given the estimated transmissivity and the hydraulic gradient of 0.002, boreholes located below the dique are expected to have a radius of influence of 1400-1500 m. This can be attributed to the localised gradient reversal caused by pumping. As the wellfield is about 1500 m upgradient of the edge of the waste rock dump, it is unlikely that any groundwater contamination emanating from the waste rock dump would be drawn to the boreholes due to a localised groundwater gradient reversal.

WASTE PRODUCTS DERIVED FROM THE COAL TREATMENT PROCESS

The processing plant treats the bulk coal produced by the mine to separate coal from the waste rock. The process uses a dense medium with magnetite. It produces wastes for disposal consisting of washing plant fines (fine discard) and plant reject (coarse discard). The fine discard is slurried to the Arroyo San José while coarse discard is sent to a surface dump.

The method used results in three products:

- Coal of various grain sizes;
- Coarse sterile waste which is discharged to the waste rock dump; and
- Fine sterile waste of clay and coal suspended in water which is discharged as a mud to the Arroyo San José.

Coarse sterile waste

This product consists of two components: waste products from the mine and processing plant, which consists of rock from 20-200 mm in size and makes up over 35% of the coarse sterile waste; and washed sterile waste rock larger than

0.5 mm. The coarse waste consists of: 1) intercalated clay and silt; 2) sandstone; 3) coal (50%); and 4) intercalations of coal and clay. The washed sterile waste contains a lower coal and sandstone content but more intercalations of fines.

In total, the coarse waste contains about 43% silica, 14% aluminium oxides, 6.5% iron oxides, 6% carbonates, 2% sulphates, and 12% coal. The low sulphur content and the carbonate content are important in controlling acid-base reactions, which determine the quality of the leachate.

The washed sterile waste is between 0.5-20 mm and coal fragments makes up only 9% of the product, coal intercalations 15%, clay and silt intercalations 57% and sandstones 20%. The total coal content is about 7.5%, sulphates are 1.7%, carbonates 5%, silica 47%, iron and aluminium oxides are about 6% each.

Fine sterile wastes

This material contains particles finer than 0.5 mm which are discharged to the San José as mud. About 70% of the material is less than 13.6 microns in size. It is produced from an espesador Radial-Dorr 250, where fine particles are concentrated. A component of the waste mud from processing is discharged to the arroyo San José while another is returned to the coal washing process. The composition of the mud discharged to the river is as follows:

Solids content	200-250 g/l
solids > 44 microns	50-78% (75% average)
solids > 44 microns	22-50% (25% average)
waste (>44 microns fraction)	51.9%
waste (<44 microns fraction)	78%
magnetite	8-1 g/l

This discharge of magnetite implies that approximately 400 000 - 500 000 m^3 of waste water are flushed to the river each year in order to eliminate 400 000 kg of magnetite. At an average of 225 g/l of sediment, the sediment load is about 101 250 tonnes per year. At an average discharge of 3 000 m^3/h, a sediment load of about 3.9 g/l would be expected in the Río Turbio, with a sediment load of 5.5 g/l during low flows of 2100 m^3/h. After dilution with the Prima Vera which has approximately the same discharge, sediment loads would be halved (2.0 - 2.8 g/l).

The granulometric composition of the mud varies greatly, however the long term average indicates that sulphates generally make up less than 1% of the waste. In total about 40-45% of the waste is coal, which gives an annual load of 41 000 - 46 000 tonnes of coal to the river. The composition of mud and the presence of many charged particles in colloidal suspension makes it very difficult to separate the solids from water hence coagulation and flocculation to remove sediment is difficult.

CONTAMINATION FROM COAL MINING ACTIVITY

The hydrochemical impact of coal mining can be divided into short and long term impacts. Short term impacts are related to base and cation exchange between water and the mine material, and to the dissolution of soluble salts, which results in a rise in the total dissolved solids content of the receiving water. The expected short term impact of the open air mining operation is that the exposed rock will be subject to rain and snow melt water, hence any soluble salts present will be dissolved.

Mining operations also result in the exposure of sulphide bearing rock to oxygen and water. The long term impact of mining is related to the generation of acid mine drainage by another series of reactions. Acid mine drainage describes water of low pH emanating from mine spoils due to the chemical and bacteriological oxidation of pyrite.

Acid mine drainage is characterised by a low pH and a high iron and sulphate content. It is produced by the oxidation of pyrite (FeS_2) by a combination of abiotic and microbial reactions when pyrite bearing rock is exposed to oxygen. Recorded pH of leachate from coal mine dumps can be less than 3.

The following reactions are involved in the development of acid mine drainage:

- $2\ FeS_2 + 2\ H_2O + 7\ O_2 = 2\ FeSO_4 + 2\ H_2SO_4$
- $4\ FeSO_4 + O_2 + 2\ H_2SO_4 = 2\ Fe_2(SO_4)_3 + 2\ H_2O$
- $Fe_2(SO_4)_3 + 6\ H_2O = 2\ Fe(OH)_3 + 3\ H_2SO_4$
- $FeS_2 + 14\ Fe_3 + 8\ H_2O = 15\ Fe_2 + 2\ SO_4^{2-} + 16\ H^+$

Total sulphur gives little indication of the final pH of water as low sulphur rock may still give acid drainage if neutralising constituents are absent. These constituents are predominantly carbonates and their reaction with oxidation products produces metal salts. As a result, pH changes are buffered in leachates containing carbonate. However, water quality will still deteriorate as a result of the increased salinity produced by this process.

The Río Turbio mining system can be considered open, meaning that the system is aerobic and products of a chemical reaction are immediately removed as leachate and have no further influence on the chemical reactions within the system. Hence short term effects are the predominant contamination mechanism with little time for the oxidation of pyrite to occur by equation 1 and 2. Any acids formed are diluted to such an extent that they do not greatly influence the pH of water of the receiving water body. In addition, the sulphur content of the waste products is low, while the carbonate content is high, suggesting that acid generation will be buffered by carbonate. This suggests that leachate will have neutral pH but elevated levels of hardness and sulphate salts.

WATER QUALITY

Surface water quality

A survey of surface water in the Río Turbio system was commissioned by the Gerente de Producción in 1994

(Figure 1). Analytical results of filtered samples are shown in Table 1. Water from the dique San José (1) and the Arroyo Prima Vera (9) can be considered as background values. Samples 2, 4, 6 and 7 all indicate some degree of contamination. The slight reduction in pH and corresponding large increase in alkalinity, calcium, magnesium and sulphate indicate that pyrite oxidation has occurred but has been buffered by the dissolution of carbonate material, resulting in an increase of total dissolved solids.

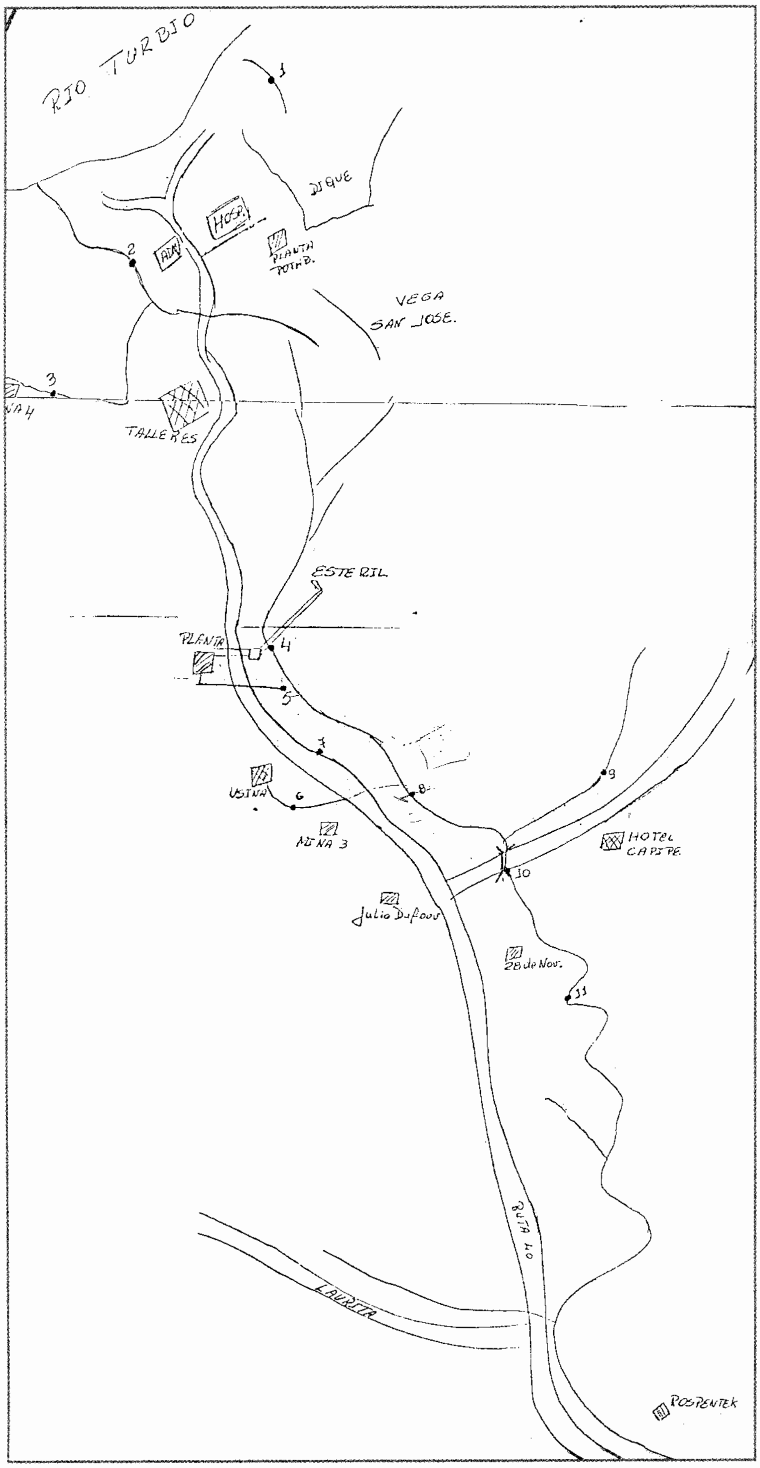

Figure 1. Location of sampling points of surface water survey.

From the low chloride concentrations, the dissolution of sodium, potassium and chloride bearing minerals, which represents the first interaction rock and water following mining activity, appears to be insignificant in Río Turbio. The slight increase in chloride observed in samples 2, 4 and 7 can be attributed to domestic waste as these samples are taken from the main river system.

Water from the Prima Vera contributes greatly to diluting the concentration of dissolved salts as seen by the large decrease in most constituents in sample 10.

Groundwater quality

Groundwater quality from production boreholes is monitored regularly by the Servicios Públicos S.E., Distrito Río Turbio. The water quality from selected boreholes is given in Table 2.

Boreholes 12, 6 and 8 can be considered as background as they are above the dique and not affected by mining activity. However, they do contain nitrates, ammonia and phosphate, indicating some organic pollution by domestic waste or livestock. Levels are within those acceptable for human consumption.

Borehole 1 is below the dique and no evidence of contamination from mining can be seen. Unfortunately the analysis does not include sulphate, which could indicate mine leachate. The Mina 3 borehole is down gradient of the mine and also does not exhibit any contamination.

Heavy metal contamination

A study of heavy metals and suspended solids was performed by the Fundación Patagonia Natural (1995). The study examined concentrations of zinc, copper, cadmium, lead and mercury in the Río Turbio system. Samples were taken from the Prima Vera to provide a background, and from Julia Dufour, Glencross, the Río Gallegos confluence, Bella Vista, Guer Aike (Toma agua), Río Gallegos and Punta Loyola to determine heavy metal transport downstream (Figure 2). Composite samples taken on 3 different days (1-3 March 1995) were filtered at 1 um and metals in suspension were determined. In addition, a sample from Julia Dufour was centrifuged due to the difficulties encountered with filtering the highly turbid water. Results are shown in Table 3.

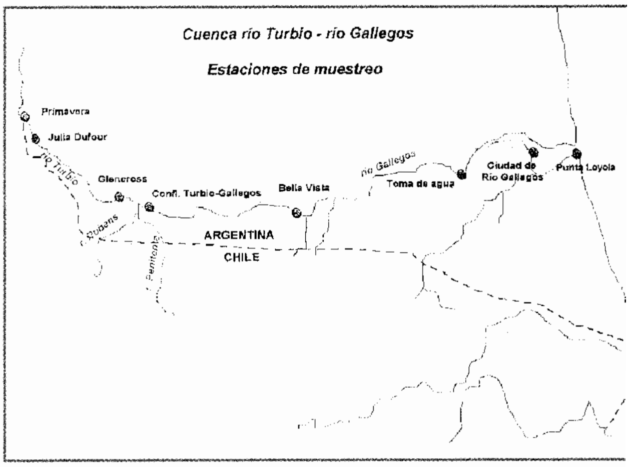

Figure 2. Location of sampling points for heavy metalsurvey (source: Fundación Patagonia Natural).

Parameter	Sample									
	1	2	3	4	6	7	9	10	11	12
pH	7.2	6.9	7.8	6.8	10	6.7	7.5	7.6	7.1	7.3
Color	75	30	15	40	40		70	100	50	120
Aspecto	amarilla	amarill. clara	clara	turbia	turbia	turbia	clara	marrón	amaril. clara	marron
Alcalin. tot. $CaCO_3$	60	144	228	187	100	492	6	60	131	81
Dureza tot. $CaCO_3$	65	133	262	58	110	804	70	80	126	104
Dureza cálcica $CaCO_3$	48	92	204	117	51	540	37	51	65	53
Dureza magnésica $CaCO_3$	17	41	58	41	59	264	33	29	61	51
Cloruros	10	20	15	15	10	15	5	10	10	5
Hierro	0.64	0.48	0.16	0.24	0.16	0.8	0.12	0.15	0.4	0.32
Nitritos	0	0.25	0	0.1	0	0	0	0.02	0.02	0
Amonio	0	10	0	1	0	0	0	0	0	0
Sulfídrico	0	0	0	0	0	0	0	0	0	0
Sulfatos	vestigios	vestigios	200	160	<50	2400	<50	75	<50	<50
Conductividad	94	246	74	377	126	1251	90	171	155	138
Sólidos totales	11	24	80	68	155		20	589	29	70
Sustancias solubles	0	32	30	0	41	0	0	0	0	0

1. Agua del Dique San José; 2. Efluente del Arroyo Santa Flavia a 100 m de la Administracion YCF; 3. Arroyo que baja de la Mina 4, tomado en forma superficial; 4. Arroyo San José que pasa por debajo del puente de cinta de estériles de planta depuradora; 5. No se realizaron por la gran cantidad de sólidos en suspensión; 6. Efluentes de usina, central termoeléctrica, en Mina 3, tomado del caño de desague, son aguas de apagado de cenizas; 7. Chorillo frente de usina, muestra superficial; 8. No se realizaron por la gran cantidad de sólidos en suspensión; 9. Arroyo Primavera; 10. Bajo puente Julia Dufour. Unión de los efluentes industriales con el arroyo Primavera; 11. Efluentes de 28 de Noviembre; 12. Pasando Rospentek

Table 1. Surface water quality in the Río Turbio system in mg/l.

	Well							
Parameter	1	12	6	8	10	Mina 3	ACEP.	TOL.
Fecha	8/5/97	2/6/97	8/5/97	2/6/97	2/6/97	8/5/97		
pH	7.5	7.5	7.5	7.1	7.5	7.9	6-9	
Alcalin. Tot. $CaCO_3$	210	204	124	248	202	190	400	800
Amoniaco	0.025	0.05			0.15	0.075	0.2	0.5
Nitrato	0	0.37		2.24	0.64	0	6	10
Dureza tot. $CaCO_3$	186	162	118	434	248	230	200	400
Calcio	51	45	29	109	61	58	32	80
Magnesio	14	12	10	38	23	20	30	70
Sodio							100	400
Hierro	0.3	0.2	0.1	10	0.1	0	0.1	0.2
Cloruros	13	20	18	18	24	14	250	700
SDT	245	225	163	597	295	368	1000	2800
Cond. Esp. (uS/m)	350	360	121	620	375	440		
Sílice	0.5	0.5	0.5		0.5	0.5		
Turbiedad (unt)	0.4	0.5	0.4	48	0.4	0.2	1	3
Sulfuros	0		0		0	0		
Color (unt)	10	2	2	10	2	2	5	12
Índice de Riznar (IER)	7.6	7.7	8.3	7.3	7.6	7.2		
Nitritos		0.55	0	0	0.01	0.008	0.1	0.16
Arsénico	0.009	0.072	0.048	0.041	0.023	0	0.01	0.1
Fosfatos	0.12	0.302	0.014	0.298	0.02	0.088		
Sulfatos							200	600
Fluor	0	0	0	0	0	0	1.2	2
Coli. Tot. NMP.en 100 ml	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	0	5
Coli. Fec. NMP en 100 ml	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	0	
VFC Heterotrof. Tot. en 1 ml	<30	<30	<30	<30	<30	<30	0	100

	Mat. en suspensión	Cobre	Cadmio	Plomo	Zinc	Temp.	Conduct.	Oxígeno	disuelto
	mg/l	ug/l	ug/l	ug/l	ug/l	C	uS/cm	%	mg/l
Prima Vera	3	0.16	0.02	1.3		14.8	61.8	106.2	10.76
J. Dufour	3100	119	0.38	38		21.2	438.5	84.9	7.52
Glencross	41	2.3	0.07	6.7		16.7	238.5	88.4	8.6
Confluencia	11	0.47	0.03	2.5		13.6	56.9	92.9	9.66
Bella Vista	17	3.3	0.05	5		15.2	60	95.4	9.58
Toma Agua	29	0.2	0.05	5		15.2	108.94	94.4	9.49
Gallegos	33	0.43	0.03	3.3		11.6	36320	85.1	7.57
Loyola						11.8	37290	98.6	8.69
Centrifugada	13300	638	0.67	116	652				

Table 3. Heavy metals in the Río Turbio system.

Metals such as mercury, cadmium and lead are highly toxic to aquatic species, whereas copper and zinc are essential metals but toxic in excessive quantities. These elements can enter the aquatic environment either in solution, as precipitates in suspension, or adsorbed onto sediment. Table 4 provides recommended target water quality criteria for waters of medium hardness (60-120 mg/l $CaCO_3$) for cold water adapted fish species. Also included is the pH level at which the constituent is no longer soluble.

	pH	Target range	Chronic effect	Measurement
Cadmium (ug/l)	8	≤0.1	0.19	Total
Copper (ug/l)	6	≤0.8	1.5	Total
Lead (ug/l)	6	≤0.5	1.0	Dissolved
Mercury (ug/l)	7	≤0.04	0.08	Total
Zinc (ug/l)	8	≤ 2	3.6	Dissolved

Table 4. Guidelines for heavy metals in aquatic ecosystems.

Results in Table 3 show that turbidity associated predominantly with mining activity extends to below Glencross. Turbidity is measured as 3.1 g/l at Julia Dufour, however, the discharge is not recorded so a total sediment load cannot be calculated. The sediment concentration agrees well with the estimated sediment load of 2.0-2.8 g/l from direct plant discharge calculated in 6.2.

Cadmium held in suspension and bound to organic substance presents a contamination problem. By Glencross cadmium declines to acceptable levels. Copper and lead held in suspension by organic substance cause levels to remain toxic to aquatic life to below Glencross. The lead probably originates from hydrocarbon contamination from Río Turbio. The presence of these contaminants is confirmed by existence of alcohol soluble contaminants (Table 1) in the Río Turbio area. The source of copper could be the increased oxidation of chalcopyrite due to mining activity. It appears to originate naturally from weathering rock as it is also present in the Prima Vera. Only by dilution with water from the Río Rubens and Penitente is water quality ameliorated to acceptable levels.

Excessive organic matter at Julia Dufour can be attributed to organic wastes and sewage originating from Río Turbio and to the high content of coal in plant discharge. The organic content is the cause of the large mass of sediment held in suspension.

Unfortunately the study did not include manganese. Since this metal does not precipitate at neutral pH levels as other heavy metals, it would be a useful indicator of acid rock drainage in rivers some distance from the source areas. The elevated electrical conductivity, however, indicates that dissolved salts produced from the leaching of mine waste and neutralisation reactions can be detected down to the confluence. Once in water these salts can only be reduced by dilution.

WATER SOURCES TO WASTE ROCK DUMP AND LEACHATE GENERATION

Leachate generation

Unrehabilitated waste rock constitutes almost all the disturbed area since no compaction, levelling or rehabilitation has been attempted at Río Turbio. The area of excavation of the strip mine is about 32 000 m^2, while the waste rock dump is about 19 531 m^2, giving a total of about 51 531 m^2. Using the above figures, expected leachate generation is 17 500 - 18 500 m^3/year (82-97% of rainfall), of which 6500 - 7500 m^3 originates from the waste rock dump. Assuming that about 3% of the annual waste load is soluble in water (based on a weighted mean calculated from the analyses in 6.1), a total dissolved solid load of between 1000-1150 mg/l can be expected.

CONCLUSIONS

Contaminant sources

Based on the results of this study, contamination in the Arroyo San José and further down the Río Turbio system originates from seven sources:

- Untreated liquid effluent from sewage containing nitrates, and pathogenic viruses and bacteria originating from the Río Turbio. This contamination also reduces dissolved oxygen in water due to the breakdown of bacteria and contributes organic colloids. These assist in adsorbing cadmium but hinder the precipitation of copper, which results in extensive copper contamination downstream.
- Nitrates, and pathogenic bacteria and viruses originating from livestock which grazes in the valley bottom in the vicinity of the water supply boreholes and the river. These probably are the cause of trace faecal contamination in shallow groundwater but its dispersed nature results in little risk to surface water.
- Muds consisting of fine coal, clays, magnetite and waste rock disposed of in the river by the industrial processing plant. These are the dominant cause of the high level of turbidity, which is the most severe contamination problem in the river system. The resulting clays and colloids are the dominant transport mechanism for metals and pathogenic bacteria.
- Oils, hydrocarbons and metals as surface runoff from roads and communities. This contributes a variety of organic contaminants which utilise dissolved oxygen for their breakdown and is probably the dominant source of the lead contamination.
- Oils, hydrocarbons and metals from industrial processing entering the river as surface runoff or in the discharge mud. These complement the problem from 4 above.
- Dissolved salts leached from the waste rock dumps. Due to the high carbonate content of the rock the formation of acid by the oxidation of pyrite is neutralised by carbonate, resulting in an increase in sulphate and carbonate salts, which raises the hardness and total dissolved solid content. This process also increases the availability of metals by releasing them as salts.
- Surface runoff of suspended fine coal and waste rock from the mine property. This provides contaminants similar in nature to 3 and 6.
- The location of these sources is shown in Figure 3.

Surface water quality in the Arroyo San José shows a typical pattern associated with mining activity. The general rise of sulphates, carbonates, heavy metals and electrical conductivity indicate the by-products of oxidation and acid neutralisation by carbonates. An associated increase in ferric iron is also evi-

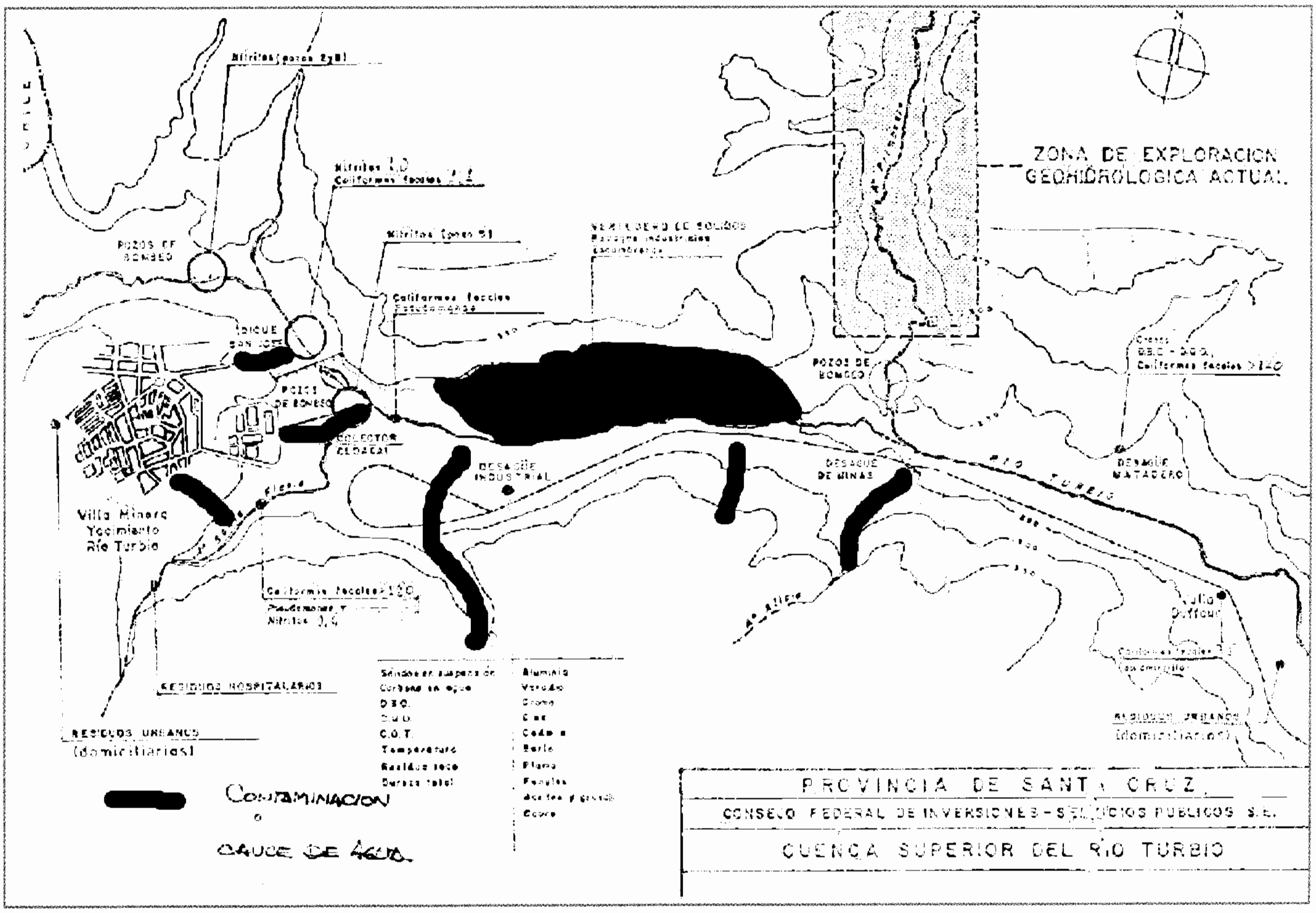

Figure 3. Sources of contamination in the Río Turbio System (source: Unknow).

dent, but due to the high pH, most of the iron is expected to be in suspension and would not be evident in the analysis of a filtered sample. It is not possible to determine the degree to which sulphate dominates the ion chemistry as none of the analyses have determined the full ion balance. However, it is likely that sulphate dominates the anion balance in the contaminated reaches of the river, whereas in the Prima Vera and upstream of the dique San José, carbonate is the dominant anion.

Actual and potential water use

The communities of Río Turbio, currently uses about 5000 m^3/d of groundwater respectively from the valley bottom fluvio-glacial aquifer. About 1.9 hm^3 of groundwater are abstracted annually from the basin of the San José. Based on storativity of about 0.15 and a recoverable fraction of 50%, the exploitation potential of groundwater is about 3.8 hm^3/year. However, only about 1.7 hm^3/year can be abstracted without having an impact on baseflow. Increased abstraction beyond current levels will, therefore, have a detrimental effect on water quality due to the lower volume of water available for dilution of pollution.

The mine uses about 700 000 - 800 000 m^3 of surface water from the San José annually at a consumption rate of 400 m^3/h during production. Available water in the river is therefore not a limiting factor on processing.

Impact on water resources

Current groundwater abstraction for domestic supply is expected to deplete baseflow in the river by about 23 m^3/h. The mine currently returns about 400 000 - 500 000 m^3/year of water to the river, albeit at a significantly lower quality. Net annual water consumption by the mine is about 30 000 m^3, or 34 m^3/h. The total reduction in flow in the San José is about 57 m^3/h.

No detectable impact on groundwater quality from mining activity is observed, however, no suitable monitoring piezometers exist to determine whether a local contamination plume exists.

A significant impact on surface water quality is seen, to the extent that dissolved constituents could not be analysed in the vicinity of the mine due to the degree of turbidity. Below Julia Dufour and after dilution with Prima Vera water, the water is of acceptable quality in terms of dissolved constituents, however, the suspended matter poses a significant problem. Suspended matter introduced primarily by mine waste disposal practice, but also by domestic sewage, only approaches acceptable levels at the confluence of the Río Gallegos. Copper, cadmium, lead and zinc contamination are also significant. Copper remains at chronic levels for aquatic ecosystems to below Glencross, effectively poisoning the river. Cadmium remains at chronic levels for fish to below Julia Dufour. Lead and zinc appear in high levels down to the confluence of the Río Gallegos.

No significant water users exist immediately down gradient of the mine, except environmental water requirements. Dissolved constituents below Julia Dufour, except for lead levels, are of acceptable quality for human consumption. However turbidity caused by the matter in suspension has an impact down to the Río Gallegos confluence and poses a severe health risk. Turbidity causes an unpleasant dark colour in the water, results in the transport of pathogenic bacteria, viruses and heavy metals, and greatly reduces the efficiency of chlorination of drinking water. Turbidity is also expensive to remove, resulting in the water being unfit for human consumption.

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