Japan International Cooperation Agency (JICA)

Republic of Bolivia
Ministerio de Desarrollo Sostenible y Planificación

THE STUDY ON EVALUATION OF ENVIRONMENTAL IMPACT OF MINING SECTOR IN POTOSI PREFECTURE OF THE REPUBLIC OF BOLIVIA

FINAL REPORT (SUMMARY)

Septiembre, 1999

MITSUI MINERAL DEVELOPMENT ENGINEERING CO., LTD.
UNICO INTERNATIONAL CORPORATION

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1 Preface

1-1 Background

Mining has been the main export industries for long time in Bolivia. More than one thousand mines, from small to large mines, concentrated on the Andes mountain range from La Paz city, the capital, to Tupiza city through Oruro city and Potosi city at the best mining days. However, worldwide catastrophe of Tin market and big scale labor strike in the middle of 1980 forced almost mines to quit mine activity.

On the other hand, environmental pollution caused by mining activity of more than 400 year long history is serious lacking of consideration for the environment. In particular, acid water from the waste rock piled in open-air by mines around the Potosi city and alkaline tailings discharged directly into the rivers by Ingenios around the Potosi city contaminate De la Ribera river which runs down through the Potosi city, Huaynamayu river etc, joining acid water spring out from abandoned mines.

Furthermore, this river contamination has raised export of pollution and international problems as the origin of the river contamination which has influenced on the down stream of the Pilcomayo river through neighbor countries of Paraguay and Argentina up to the La Plata river.

The Bolivian Government considered the situation serious and requested to Japan "The Study on Evaluation of Environmental Impact of Mining Sector in Potosi Prefecture of The Republic of Bolivia" through Ministerio de Desarrollo Sostenible y Planificación.

Japan International Cooperation Agency (JICA) has begun to execute the study with the Viceministerio de Medio Ambiente, Recursos Naturales y Desarrollo Forestal (VMMARNDF) as a counterpart (C/P). (The study area is shown in Figure 1).

2 Objectives of the Study, Study Policy and Abstract of the Study

2-1 Objectives of the Study, Study Area

2-1-1 Objectives of the Study

Objectives of the Study are based on the items mentioned below.

① to carry out the study the environment impact caused by mining activity at Potosi area

② to plan the environment monitoring and environment management program

③ to propose the political and technical recommendation relating to manage and to mitigate the mine pollution at the study area.

Concretely, to make sure the situation of heavy metal contamination etc. at main point of the De la Ribera river and the Pilcomayo river, and to make the pollution protection plans for pollution origin.

Furthermore, to execute the technical transfer to the counterpart that C/P will be able to carry out similar study, planning pollution protection program, reviewing of environment management plan (environment regulation) by themselves forming environmental monitoring system of the De la Ribera river. (See Figure 2)

2-1-2 Study Area

The study area of the Study The study is Potosi City area and 180km of the De la De la Ribera river basin which covers from the origin in the Potosi city to the Mendez Bridge changing the name, Aljamayu, Molino and Tarapaya, and finally joining into the Pilcomayo.

2-2 Field of the Study and Abstract of the Study

2-2-1 Field of the Study and Experts

The Study fields and the experts are as follows,

Team Leader	OOKI Hisamitsu
Water Quality/Hydrology	MORI Toshio
Mine Geology	NAKAMURA Kiyoshi
Mineral Processing	ITO Kenji
Waste Water Treatment (Chemical Analysis)	TANAKA Yoshiharu
Data Base/Statistic	Ricardo ORTIZ
Equipment Designing (Mechanical)/Estimation	KIMURA Soichiro
Economic/Finance	KOSUGI Yoshio
Environment Management Plan/Organization System	YAMAUCHI Ken

2-2-2 Abstract of the Study

(1) Water Quality/Hydrology

River water and sediment sampling at 25 sampling points, 2 monitoring points and 6 section points of the rivers through the year and main element analysis were carried out.

At the same period, hydrological study was also carried out.

(2) Mining Geology

Existing data of Geological and ore reserve related to the Cerro Rico de Potosi mine, newly obtained data from COMIBOL and related organizations were analyzed with site survey data. And, Cerro Rico de Potosi mine ore reserves were estimated.

(3) Mineral Processing

Study on the actual condition of Ingenios (the small scale mineral processing plant) was carried out picking out the problems. Mineral processing test for improvement of operation result aiming compatible of "production" and "environment" was also executed for raising income which contributes to environment cost.

Finally, study on the most appropriate processing flow for the Potosi mine ore to design model plant, integrated plant was carried out and recommended.

(4) Waste Water Treatment (Chemical Analysis)

Study the pollution origin at dry season and rainy season identifying 30 monitoring points was done. Collected data were analyzed. Clearing the pollution mechanism was done. Simultaneously, execution of the waste water treatment test. The result was analyzed and recommendation on the most appropriate treatment method was offered.

(5) Data base/Statistic

Data base for compiling monitoring data was constructed collecting and analyzing statistically the information and the data of water quality, hydrology, contamination origin, waste water treatment test, tailing, meteorology etc.

Furthermore, the software which contributes to construct example of future estimation model experimentation to form the simulation model.

(6) Plant Design (Mechanic)/Estimation

Data collection for the plant designing and estimation was carried out. Then, Equipment estimation and conceptual designing of model plant and integrated plant were executed.

(7) Economic/Finance

Financing analysis on the construction of the model plant and integrate plant was executed. Execution of economic evaluation with applying the improvement measure was done.

(8) Environment Management Plan/Organization System

Actual state of contamination, grade and sphere of impact, and environment related law and regulations were studied including commissioning work. As the result of analysis, environment management related recommendation, i.e. environment index, reformation plan of environment administration organization, construction of the monitoring system, was done.

3 Special Environment Outline

3-1 World Heritage

Cerro Rico Mountain for its geographic viewpoint and Potosi City for its historic viewpoint were nominated as world heritage for its nature and culture by UNESCO on December 7th, 1987.

Accordingly to the long mining history in the Cerro Rico Mountain, Potosi Citizen are anxious in general being explored the mountain again dramatically and modifying the shape of the mountain.

3-2 Mining in Potosi Prefecture

The mining activities in the Potosi Prefecture included in the scope of the study are mainly composed of the followings;

① Mines : The Empresa Minera Pailaviri R.C., a medium scale company in the COMIBOL group, and the Mining Co-operative Association composed of 30 small scale companies.

② Ingenios : Medium and small scale concentrators amounting to 42 in total.

4 Present State of Pollution

4-1 Grade and Sphere of Water Quality Contamination in the Tarapaya River Basin

4-1-1 Contamination origin

As the result of 30 points of contamination origin, acid water which spring out from the tunnel, permeable water which comes out through the waste rock and the Sucu, permeable water which comes out through the old tailing dam and alkaline tailing from the Ingenios were confirmed.

The Ph value of the acid water varies from less than 2 to less then 4, and instantaneous variation of those Ph value caused by the concentrated heavy metals precipitation. (See Figure 4)

4-1-2 Actual state of contamination

As the result of the study at 25 sampling points, 2 monitoring points and 6 section points of the rivers during dry season and rainy season, following acts were found. (See Figure 5)

Acid water from the tunnels of mines, waste rock and Sucu is poring into the Huaynamayu River which is the branch river of the De la Ribera River, upper stream of the Tarapaya River Basin.

As it runs down, alkaline tailing from the Ingenios comes into, and those pollute the water quality. The most influence origin is tailing which contains arsenic and heavy metals. Then, acid water from the tunnels and permeable water from the Sucu and tailing dam containing heavy metal ions has influence.

The De la Ribera River up to the conjunction with the Huaynamayu River shows chemical reaction zone where neutralizing reaction with acid water and alkaline water occurs. On the other hand, area between the Tarapaya River and the Mendez Bridge of the Pilcomayo River physical reaction with sedimentation and wash away of SS which contains arsenic and other heavy metals occurs. (See Figure 6)

Water from the tunnel, which shows strong acid of pH2.2-2.3 and contains 16-24ppmof Cd, 1,000ppm of Zn, 200ppm of Cu and 31,000ppm of SO_4, pores into up stream of the La Ribera River changing the water quality acid.

As it runs down through the Potosi City, alkaline tailing of pH 10-12 which contains 10-15 weight % fine particles of 25-200μm, which is discharged from small scale processing plant so called the Ingenios is mixed in to the De la Ribera River causing neutralization reaction and contaminating water quality.

The quantity ratio between acid water and tailing is approximately 1/30-100.

At the suburbs of the Potosi City, permeable acid water through old tailing dam (pH<2, Cd=4.6ppm, Zn=710ppm, Cu=112ppm, SO_4=19,600ppm) flows into at the rate of 40-50m^3/d.

Furthermore, when it rains, acid water through huge amount of old tailings of gravity separation which is called Sucu and covers the Cerro Rico de Potosi mountain foot flows into the river boosting water quality contamination.

SS value is observed more than 1,700t/d at San Antonio, 1,200t/d in the Potosi City, 950t/d at near Molino Village and lass then 400t/d at Mondragon village. Daily amount of tailing from the Ingenios is estimated 1,300-1,500t/d, therefore, it can be said that almost all of SS caused by the tailing.

Namely, the number indicates that large amount of sedimentation of SS and accumulation to the river bed occur at down stream from San Antonio.

The sedimentation and accumulation amount was calculated as around 750t/d between San Antonio and Molino, and around 550t/d between Molino and Mondragon.

Accumulated sediment is washed away and moves by intermittent heavy rain and flood in the rainy season. There is nearly 100 times of SS differences between dry season and rainy season. Clear accumulation is observed along the stream in dry season.

As the study result, 300kg/d of As, 80-100kg/d of Cd, 20-30t/d of Zn and 2-4t/d of Sn were estimated to be discharged into the Tarapaya River as the heavy metal contaminants.

4-2 Damages Impact Data

Location	Comments	Pb (ppm)	Zn (ppm)
Villamontes	Near Argentine	2.11	13.31
Puerto Margarita	Between Villamontes and Yukimbia	7.76	35.64
Yukimbia	Near Potosi	6.82	33.48

4-3 Summary of Pollution Impact

Taking the above facts into the consideration, the main impacts caused by the Pilcomayo River Basin can be classified as follows:

4-3-1 Social Impact:

- Poverty caused by the difficulty or the impossibility to maintain traditional productive activities.
- Migration caused by poverty, particularly during winter and spring when there is a scarcity of good water resources, and the risk of catching sickness, the frequent disease mainly related with digestion, which could eventually be serious.
- Migration and poverty are damaging the structures of the traditional social organizations.

4-3-2 Economic Impact:

- Decrease and destabilization of the production capacity of fishing, agriculture and livestock raising.
- Decrease of economic activities due to decreasing human resources.
- Reduction of the economic and political importance of the farming sector in the Pilcomayo region economy.

4-3-3 Environmental Impact:

- The accumulation of, heavy metal, toxic chemical elements in rivers, soils and food chain.
- Increase of the suspended solids in the Pilcomayo River.
- Increase of the ecosystem sensitivity in the face of disturbing factors (human or natural).

5 Sources and the Mechanism of Water Pollution

5-1 The Source of Water Pollution

As the study result, the contamination sources of river water quality contamination of mining sector in the Potosi Prefecture were identified as follows. The study points of contamination sources are shown in Figure 7.

5-1-1 Mine drainage (Mine water)

Typical wastewater is from sampling point No.12. When water quality from the rainy and the dry seasons are compared, the pH was 2.28 and 2.22, and they are low values for either season. The concentrations of Cu are 182mg/L and 198mg/L, Zn 1,050mg/L and 1,110mg/L, Cd 16.4mg/L and 24.0mg/L and concentrations of heavy metals were higher than the other sampling sites. The concentration of SO_4 is 31,000mg/L that is the highest among all samples. The ratio of Fe^{3+} to T-Fe is high, so one can surmised that the wastewater is oxidized inside of the mine. The high concentration of As was detected during the dry season. This stream flows into Rio Huaynamayu River.

5-1-2 Infiltrating water from low grade ore stockpile, tailings

This is the infiltrating water from a stockpile of waste rock that was mined out and left.

The representative sample is No.13. The wastewater quality has almost same characteristics as the mine drainage. The pH value of 1.86 was the lowest value among all samples. The concentration of Cu is 112mg/L, Zn 710mg/L and Cd 4.6mg/L and concentrations of heavy metals were high.

The concentration of SO_4 was 19,600mg/L that is the second height, so one can guess that the wastewater was oxidized. After raining, this water flows into Rio Huaynamayu River.

5-1-3 Infiltrating water from waste ore, called Sucu, which was generated from gravity concentration ore dressing .

The typical wastewater samples are no.1 and No.18. The value of each parameter is not as high as No.12 or No.13. For No.1 and No.18, pH are 2.58 and 3.09, Cu 60.0mg/L and

4.40mg/L, Zn 144mg/L and 916mg/L, Cd 14.0mg/L and 45.0mg/L, and Sn 43.3mg/L and 21.9mg/L, respectively. The wastewater quality has almost same characteristics as No.12 or No.13. These streams flow into Quebrada Jayajmayu River.

5-1-4 Infiltrating water from tailings dams which was generated from the gravity concentration of tin processing plant

The typical pollution source is the tailing dams of San Miguel. The typical wastewater is No.26. a spring flows during all the seasons. This stream flows into Rio de La Ribera, directly.

The values of each parameter during both the rainy and the dry season are pH 3.14 and 2.99, Cu 5.20mg/L and 6.20mg/L, Zn 60.0mg/L and 75.0mg/L, respectively. The concentration of SO_4 during the rainy season was 1,290mg/L.

5-1-5 Infiltrating water from tailings dams which was generated from the flotation of lead and zinc

The typical pollution source is the tailing dams of San Miguel. The typical wastewater is No.16. There is no water during the dry season.

The value of pH is 2.38, Cu 96.0mg/L, Zn 529mg/L and Cd 1.50mg/L, and SO_4 is 9,690mg/L.

5-1-6 Infiltrating water from the idled heap leaching pad for silver.

The PLAHIPO silver leaching plant is located on the area of Potosi. This sampling point is No.27, but it is difficult to take a sample because of the shutdown. On the other hand, COMCO is located south of Potosi. Since the water system location is different from the Potosi area, this problem was excluded from our consideration.

5-1-7 Tailing of Ingenios (SS, Alkaline Water)

All the Ingenios (42 in total) discharge all of their mineral processing tailings without any treatment into all the rivers, to begin with the De la Ribera river, which belong to the four fluvial systems in the Potosi city area. This causes serious water pollution in these rivers. The said tailing is composed of SS (solid portion) and alkaline water (aqueous portion). Both of these components of the tailing, SS and alkaline water, are the sources of fluvial water pollution caused by the Ingenios. The said pollution associated with the mineral processing sector as well as that associated with the mining sector are the major sources of the fluvial water pollution.

Following more than 400 years mining activity, in recent years, the fluvial water pollution brought about by the Ingenios grows worse due to the reasons mentioned below.

As a tin (Sn) quotation took a sudden big drop in 1985 as a result of a collapse of the ITC, the Ingenios in Potosi City changed their operational processes from conventional gravity concentration to flotation. Up to that time, gravity concentration was used to recover tin oxide mineral (Cassiterite: SnO_2), and after that, flotation was employed to start to recover lead sulfide mineral (Galena: PbS) and zinc sulfide mineral (Sphalerite: ZnS). The said conversion of their operational processes resulted in the following four items of alteration;

① Grain fining: Grain size of the tailing turned to be fine because the grain size for ore treatment was switched from coarse and medium size (several mm-0.5mm) in conventional gravity concentration to medium and fine size (0.3-0.05mm) in newly employed flotation.

② Start of flotation reagent use: In accompany with excessive addition of flotation reagents, residual reagents left in the tailings, such as frother, collector (xanthates etc.,) and depressor (cyanide etc.,) were discharged into the rivers without any treatment.

③ Rise of pH: The pH of the tailing turned to high alkalinity because a raise of pH in flotation is an optimum condition for recovery of lead sulfide and zinc sulfide minerals.

④ Insufficient technology: The majority of Ingenios have empirically conducted their operations. Therefore, it is hard to say that they have employed the optimum process flow and operational conditions to the treatment of current ore out of the Potosi Mine. As a result, they came to discharge the tailings containing great quantities of unrecovered heavy metals due to insufficiency of their recovery.

Summarization of upper mentioned items are shown in Table below. (See Figure 8)

Classification	Contaminant Sources		Contaminant
Source characteristics	Mine originated effluents	Acid drainage from mines	Acidity and solved heavy metals
		Infiltrated water drainage form waste rocks	Acidity and solved heavy metals
		Infiltrated water drainage form tailings deposits	Acidity and solved heavy metals
	Ingenios waste originated effluents	Alkaline effluents contained in tailings	Alkalis and flotation reagents
		Solids contents in tailings	Solid particles containing heavy metals
Phenomenon occurred in rivers	Chemical phenomena	Neutralization reaction (decrease of acidity, neutralization or light alkalinization)	Microscopic particles of heavy metals hydroxids
		Generation of precipitants caused by neutralization	Heavy metals SS and sediments
	Physical phenomena	Precipitation of solids	Accumulation of heavy metals sediments
		Transport of SS and sediments caused by hydraulic force	Transport of heavy metals SS and sediments

5-2 The Mechanism of mine pollution

5-2-1 The Mechanism of the pollution origin

The rivers in Potosi are polluted daily by three types of water discharge: mine drainage, household wastewater and ore processing plant wastewater. On the other hand, the infiltrating water from both tailing dams and low-grade ore stockpiles in the Cerro Rico Mountain also pollutes the rivers in the rainy season.

Since mainly sulfide ores are extracted at the metal mines, minerals such as pyrite, chalcopyrite, sphalerite and galena still remain at the mining site even after closure of the mine. They react with the oxygen in ground water or air and generate acid water containing heavy metals.

The tailings carried out of a mine also become a source of mine pollution because the metals dissolve in rainwater. Moreover, tailings flow out or are scattered by winds and cause environmental pollution.

Of Cerro Rico mountain, there are three Sucu at the west, the northwest and the southwest. Their extents are 32,000m^2, 400,000m^2 and 90,000m^2, respectively. Many stockpiles of waste rock and low-grade ore are in close on slopes of mining sites. In case of Cerro Rico mountain, oxide ores are stockpiled at above 4,400m height, and sulfide ores below. Outside of Real Socavon at the foot of Cerro Rico mountain, the presence of mine drainage can be seen all year round. There is the PLAHIPO silver leaching plant at the east of Cerro Rico mountain that is idle now. The San Miguel tailing dams is located at the west of the urban area, at the north of which there is a spring, and from where water is flowing out into Rio De la Ribera River all year round. The wide rainfall streams run both, on surface and underground of these stockpiles, and springs and infiltrating water may flow into rivers again.

5-2-2 The Mechanism of Water Pollution in Rivers

The worst polluters are acid mine water which contains heavy metal ions, acid infiltrating water from waste ore stockpiles, Sucu, and tailing dams which also contain heavy metal ions and untreated discharged tailings which contains SS and alkaline from Ingenios to Rio De la Ribera and other river streams. This SS includes As and other heavy metals.

On the other hand, concentration ratio of As, Cu, Pb, Cd etc. decrease as pH raise. However, tend to show increase again in high pH value zone. It can be said that those metals are amphoteric elements, therefore they begin to dissolve forming compounds at pH 8-9.

Heavy metal contents in the sedimentation of riverbed are higher than those in the SS. It is considered that sedimentation includes precipitation, which occurred with neutralization reaction.

6 Study on Countermeasures

6-1 Mine Pollution Control Plan

6-1-1 Countermeasure items

The proposal of countermeasures for environmental improvement is shown below, which is made from the standpoint of mine pollution control plan.

① Stoppage of discharge tailing direct into the river

② Improvement of process flow of the Ingenios

③ Treatment of water from underground and permeable through waste dam

④ Plan for Education, Enlightenment, Foster of human resources

⑤ Tailing treatment in tailing dam and discharge water treatment

⑥ Introduction of Tailing Re-treatment Plant

⑦ Introduction of Model Plant

⑧ Recovery of valuable minerals from waste rock and the Sucu

⑨ Installation of Monitoring System

⑩ Construction of Integrated Plant

⑪ Establishment of Environment and Safety Research Center

6-1-2 Basic Flow of Mine Pollution Control Plan

Basic flow for executing mine pollution control plan in each countermeasures discussed in clause 6-1 are shown in Table below.

Mining Sector	Direct Countermeasure	([1]) ········ [1] → [2]
Mineral Processing Sector	Direct Countermeasure	[3] →
	Indirect Countermeasure	[4] → [5] → [8] [4] → [6] → [8] [4] → [7] →

Note: The items above in time series are shown as follows;

[1]: Treatment of mine water and seepage water from waste rock dump

[2]: Vegetative stabilization on waste rock dump and old tailing dam

[3]: Treatment of tailing and waste water control at tailing dam

[4]: Study on production process improvement at Ingenios

[5]: Introduction of tin recovery concentrator out of Ingenios tailings

[6]: Introduction of model concentrator

[7]: Recovery of valuable metals from waste rock and Sucu

[8]: Construction of integrated concentrator (Industrial estate)

The basic idea of pollution mechanism and mine pollution protection are shown in Figure 9.

6-2 Environment Management Plan

6-2-1 Environmental Improvement Based on the Environment Management Plan

From the view point of the environment management plan, the principal action items are listed below.

① The establishment of the monitoring system to collect the environmental systems continuously.

② The rearrangement of administrative rules, regulations and laws regarding the environment protection, to control any discharging materials to proceed the environment management actually.

③ To form a joint system setting every members participation, administrations enterprises and peoples to protect the acceptable environment.

④ To establish the environment indexes acceptable by peoples to encourage them to participate in the environment self-control system.

⑤ To promote the environment education and training of people for the environment issues.

⑥ The itemized targets, each of them have short term, middle term and long term strategies, can start from the most implementable strategies.

7 Education, Enlightenment, Human resources

7-1 Points of problem

Problems related to environment contamination of mining Potosi prefecture are pointed out as follows.

① Mining pollution is not considered serious in inhabitant

② Owner of mine and Ingenios have slight knowledge about mining pollution

③ Owner of mine and Ingenios are pushed to keep productivity and have less space to consider pollution protection

④ There is not enough organization, system in the administration organization. This causes insufficient monitoring.

⑤ Unsatisfactory administration power

⑥ Lack of environment management technology and experiment

⑦ Lack of monitoring technology and monitoring system (include hard)

7-2 Plans for Enlightenment, Education, Human resources

It is very important that staffs of organizations related mentioned below have enough knowledge of mining pollution, pollution protection and environmental protection.

Furthermore, these plans should be executed steadily and sustainable way aiming to spread the target for long time span.

① Environmental staffs of MDSP-VMMARNDF and environmental administration

② Environmental staffs of VMMARNDF and environmental administration

③ Environmental Division Staff of the city

④ UATF Mining Faculty, Chemical Faculty, professor and lecturer.

⑤ Owner of mine, engineer, key person of union.

⑥ Owner of Ingenios, engineer, key person of union.

⑦ Representative of NGO

⑧ Others, staff of environmental division of other prefecture

8 Financial and Economic Analysis

8-1 Financial Analysis

The effect of the project case is measured by comparing "with" case and "without" case.

Contents of Each Project Case

Each content of the project case is as follows.

Contents of Project Case

Case No.	Project Case	Range of Plan
A	Process improvement of existing Ingenios	Short
B	Construction of the tailing re-processing plant (tin recovery plant)	Middle
C	Construction of the integrated plant	Long

Analysis result of each case is shown in the table below.

Results of Analysis (Unit: %)

FIRR	Case A	Case B	Case C
before tax	46.72	0.22	14.26
after tax	36.66	0.22	12.59

8-2 Economic Analysis

8-2-1 Opportunity loss calculation of field of agriculture

Opportunity loss concerning to the field of agriculture was calculated comparing to the data of the prefectures which are under similar conditions.

Those conditions and the result are shown in table below.

Opportunity loss calculation of field of agriculture

	Potosi Prefecture	Chuquisaca Prefecture
(1) Pilcomayo River wide area		
-Area of agriculture (10^3ha)	116	149
-Productivity differences comparing to the country (Bs/ha)	370	434
-Area of agriculture along the Pilcomayo River area (10^3ha)	42.2	89.1
-Opportunity Loss(10^3Bs, 1993)	15,623	38,669
-Opportunity Loss(10^3\$, 1993)	3,659	9,056
-Opportunity Loss(10^3\$, 1998)	4,240	10,496
-Net Opportunity Loss (10^3\$, 1998)	1,060	1,312
(Ratio of Contribution)	(25%)	(12.5%)
(2) Pilcomayo River limited area		
- Existed Area of agriculture (ha)	1,537 (81%)	3,246 (81%)
-Possible Area for agriculture (ha)	361 (19%)	761 (19%)
Total area in the basin	1,898 (100%)	4,007 (100%)
- Opportunity Loss (1993)		
-Existing (10^3Bs)	569	1,409
-Possible (10^3Bs)	622	1,311
- Total Opportunity Loss (10^3Bs)	1,191	2,720
-Opportunity Loss(10^3\$, 1993)	279	637
-Opportunity Loss(10^3\$, 1998)	323	738
-Net Opportunity Loss (10^3\$, 1998)	162	185
(Ratio of Contribution)	(50%)	(25%)

8-2-2 Opportunity loss calculation of field of stock farming

Opportunity loss concerning to the field of stock farming was also calculated comparing to the data of the prefectures which are under similar conditions.

Those conditions and the result are shown in table below.

Opportunity loss calculation of field of stock farming

(1) Pilcomayo River wide area

	Potosi Prefecture	Chuquisaca Prefecture	Tarija Prefecture
-Annual production by stock farming (10^3Bs, 1993)	33,807	95,904	59,526
-Area in the basin (10^3km^2)	43.0 (36.4%)	30.8 (59.8%)	24.6 (65.4%)
Rate of un-contaminated area	21.5 (18.2%)	15.4 (29.9%)	12.3 (32.7%)
Rate of contaminated area (productivity 1/2)	21.5 (18.2%)	15.4 (29.9%)	12.3 (32.7%)
-Area out of the basin (10^3km^2)	75.2 (63.6%)	20.7 (40.2%)	13.0 (34.6%)
- Possible Area for stock farming (10^3km^2)	96.7 (81.8%)	36.1 (70.1%)	25.3 (67.3%)
- Average productivity of stock farming (Bs/km^2)	350	2,657	2,353
- Opportunity loss (10^3Bs, 1993)	7,525	40,918	28,942
- Opportunity loss (10^3\$, 1993)	1,762	9,583	6,778
- Opportunity loss (10^3\$, 1998)	2,042	11,107	7,856
- Net Opportunity Loss (10^3\$, 1998) (Ratio of Contribution)	511 (25%)	1,388 (12.5%)	982 (12.5%)

(2) Pilcomayo River limited area

	Potosi Prefecture	Chuquisaca Prefecture	Tarija Prefecture
-Contaminated area (10^3km^2) (20% of item 1))	4.30	3.08	2.46
- Average productivity of stock farming (Bs/km^2)	350	2,657	2,353
- Opportunity Loss(10^3Bs, 1993)	1,505	8,184	5,788
- Opportunity Loss(10^3\$, 1993)	352	1,917	1,356
- Opportunity Loss(10^3\$, 1998)	408	2,221	1,571
- Net Opportunity Loss (10^3\$, 1998) (Ratio of Contribution)	204 (50%)	555 (25%)	393 (25%)

8-2-3 Basic case: Effect when all the water quality improvement would have been completed

The basic case (effect when all the water quality improvement would have been completed) has been evaluated to determine its feasibility by using economic internal rate of return (EIRR).

No.	Project Case	Overall Case (EIRR 1) %	Single Case (EIRR 2) %
C	Integrated Plant	14.26	—
D-1	Wide area of Pilcomayo river in Potosi prefecture	13.83	11.42
D-2	Limited basin of Pilcomayo river in Potosi prefecture	11.79	Negative
E-1	Wide area of Pilcomayo river in all the prefectures	19.29	48.77
E-2	Limited basin of Pilcomayo river in all the prefectures	13.69	9.12

Note that Case C means the integrated plant as used in financial analysis.

Regarding two cases, i.e. in case each project case including the integrated plant (call as Overall case) and in case each project case not including (call as Single case), the analysis was roughly made.

In case of Single case, in Potosi prefecture, the result of Case D-2 indicates that the project is not feasible, however, that of D-1 indicates that the project has effects more than 11%, while in all the prefectures, that of Case E-1 indicates that the project has effects more than those in Potosi prefecture.

In case of Overall case, in Potosi prefecture, the result of Case D-2 as a worst case indicates that the project has effects more than 11%, while in all the prefectures, the result indicates that the viability of D-1 is slightly less than that of Case C.

Finally, though the analysis is roughly made based on the only quantitative available data in agriculture and stock-breeding as benefits as mentioned above, it is presumed that the project has great benefits brought to Pilcomayo river basin.

Furthermore, the effect of investment in Overall case reveals the integrated plant has a prominent position. It is anticipated that Ingenios play an more important part from view-point of particularity in Potosi prefecture.

9 Recommendation for the Future Steps and the effect

9-1 Recommendation for the Future Steps

As the study result, the Team has proposed twelve recommendations mentioned below to improve mining sector environment contamination in Potosi Prefecture.

Those items are recommended to carry out classifying into three terms, short (urgent), middle and long according to their property, urgentness, effectiveness, sustainability of the effect, etc. (cf. Table 1, Table 2)

9-1-1 Items which should be executed in a short term

- To quit discharging tailings of Ingenios to the river [①]
- To introduce efficient mining technology
- To renovate the process of Ingenios (processing plant) [②]
- To arrange the enlightenment and education, fostering (leader fostering)[④]
- Education, Enlightenment, Fostering human resources [④]

9-1-2 Steps to be taken in the Middle Term

(1) Items which should be executed in the first half of the middle term

- To treat acid water [⑤]
- To arrange environment management system and to review law, regulation (⑦)
- Forestation of old tailing dam (⑧)
- Education, Enlightenment, Fostering human resources [④]

(2) Items which should be executed in the last half of the middle term

- To install tailings reprocessing plant (⑨)
- To introduce waste water recycle system

9-1-3 Steps to be taken in the long term

- Mineral processing test
- Tailing treatment (Re-inject into under ground etc.)
- Installation of integrated mineral processing plant [⑩]
- Treatment test of waste rock and Sucu (⑪)
- Construction of monitoring system of the Pilcomayo river basin (⑫)
- Education, Enlightenment, Fostering human resources [④]

9-1-4 Establishment of Environment and Safety Research Center

The main purpose of the center is targeting to carry out twelve recommendations mentioned above connecting each recommendations from ① to ⑫ systematically.

9-2 Effects when the recommendations are completed

Estimated effect when the recommendations are completed when the recommendations are completed are as follows. (See Figure 10)

Actually, 36t/y of cadmium load was observed by the Study in the Tarapaya river basin. Under the application of countermeasures presented in this study, cadmium loading can be decrease up to 4 ton per year (89% reduction).

Similar results can be obtained with other heavy metals. Additionally, pH can be estimated to be in neutral range and SS to be nearly zero (bellow environmental standards).

① Efficient exploitation and mine life extension applying appropriate modern mining method to Potosi mine.

② Improvement of mineral processing and lowering operation cost applying appropriate process technology (improvement of operation of Ingenios).

③ Squeeze out environment cost and completion of mine pollution protection by improving operation result.

④ Improvement of water quality of the De la Ribera River.

⑤ Arrangement of laws, regulations and environment management system fitting to the Bolivian mining pollution protection.

⑥ Arrangement the environment law which is appropriate to the Bolivian environment condition and is easy to sustain

⑦ Obtain and maintain the better scenery of the Potosi City, improvement of the quality of life.

⑧ Recovering and utilization of resources remained (minerals remained in waste rock, Sucu, etc.)

⑨ Reduction of origin of acid water treating waste rock, Sucu, etc.

⑩ Mitigation of mine pollution in the Pilcomayo River basin establishing monitoring system and completion of environment management system (protection of pollution export).

⑪ Execution of better environment making recognition of environment protection on inhabitant consciousness (improvement of total environment quality)

⑫ To be the model case of environment protection to other area where the similar pollution exists.

⑬ Technological acquisition applying the third countries training

Acknowledgement

The Study that has begun in September 1997 will complete in October 1999.

Plans in connection with mitigation of mine pollution and environment protection, which should be executed in short, middle and long term, are recommended based on the result of the study and analysis for 25 months.

In particular, as the result of establishment of the Environment and Safety Research Center and its activity, it is recommended that the integrate plant should be constructed finally at upper part of San Antonio tailing dam transferring and uniting 42 "Ingenios".

The concept and the objectives of the former recommendations are shown in Table-1 and Table-2. The latter is proposed that foreign aid of technology and fund.

Furthermore, twelve recommendations for environment protection and mining pollution protection that should be carried out in short, middle and long term is proposed.

Most of those proposals will be and should be executed by Bolivian side.

Finally, the Study Team wishes to express sincere thanks to Counterpart, the staff member of the Ministry of Sustainable Development and Planning, Vice Ministry of Sustainable Development and Environment, Environment Department of the Potosi Prefecture, Autonomous University of Tomas Frias related, Mining Association and owners, Ingenio Association, Foreign Experts, members of NGO and Inhabitants of the Potosi City who have given heartfelt and fruitful cooperation during study for 25 months.

Meanwhile, the Study Team has been led many times by Mr. Nagata: manager, Mr. Chiba: sub-manager, Mr. Kobayakawa in charge of the Study and Mr. Mizuguchi: technical expert of JICA to prepare this report.

The Study Team also wishes to express that the Study report has completed owing to those JICA members.

Table 1. Proposals Execution Plan

Proposal		Short Term	Mid Term	Long Term
1. Mining pollution prevention plan	① Tailings drainage suspension	→	→	→
	② Process improvement at ingenios	→	→	→
	⑤ Acid effluents treatment (mines and waste deposits)	→	→	→
	⑧ Minerals waste deposits forestation		→	→
	⑨ Tailings (from ingenios) treatment plant			→
	⑩ Integrated concentration plant			→
	⑪ Value metals recovery from mineral wastes	→	→	→
2. Environmental management plan	③ Monitoring system organization			
	⑦ Environmental laws and regulations review			→
	⑫ Pilcomayo basin monitoring system			→
3. Research Center activities	④ Training and instruction program	→	→	→
	Activities related to mining pollution prevention plan	① Technical and financial analysis on tailing treatment plant and water recycling system	① Follow up and consulting	
		② Technical and financial analysis on mineral process items	②Follow up and consulting	
		⑤ Technical and financial analysis on effluents treatment	⑤Follow up and consulting	
		⑧Technical and financial analysis on forestation items	⑧Follow up and consulting	
			⑨ Technical and financial analysis on tailings treatment	⑨Follow up and consulting
			⑩ Technical and financial analysis on integrated plant construction	⑩Follow up and consulting
			⑪ Technical and financial analysis on value metals recovery from mineral wastes	⑪Follow up and consulting
	Activities related to environmental management	③ Introduction of monitoring system and simulation techniques (progressive improvement)		
		⑦ Environmental law and regulation review, environment white paper formation, environment indexes application, environmental executive organization improvement, training and instruction program execution (progressive improvement)		
		⑫ Establishment of policy and progressive improvement of Pilcomayo basin integral monitoring system		

	Origin	Source	Mechanism	Contaminant	Flow	Cd Charge	Cd form	pH	Measurement
1	Concentration plants	Tailings	Non liberated miner:	Sludge with metals	6.000ton/d*1	67,5Kg/d*2	SS	11 a 12	1.Process improvement
			Flotation reagents	Reagents and alkali	69lit/s				2.DCSA (KfW)
									3.Environment analysis equip.
									4.Monitoring equipment
									6.Research center
									7.Tailings treatment
									8Effluent recycling
									11.Integrated plant
2	Mine galleries	Rain, filtration	Generation of acids	Solved metals	777ton/d*3	7,8Kg/d*4	ion	1 a 2	5.Acid effluent treatment
			Metal leaching	Acid water	9lit/s	(10mg/lit)			2.DCSA (KfW)
									3.Environment analysis equip.
									4.Monitoring equipment
									6.Research center
3-1	Waste rocks	Rain	Generation of acids	Solved metals	Estiaje:4.320ton/d*5	9,5kg/d*6	ion	2 a 3	5.Acid effluent treatment
			Metal leaching	Acid water	50lit/s	(2,2mg/l)			9.Afforestation
3-2	Old tailing deposits	Rain	Generation of acids	Solved metals	Rain				10.Filling mines/tailings
	Gravimetry of Sn		Metal leaching	Acid water					2.DCSA (KfW)
3-3	Old tailing deposits	Rain	Generation of acids	Remanent metals					3.Environment analysis equip.
	Flotation of Zn, Pb			Alkaline water					4.Monitoring equipment
									6.Research center
									12.Metal recovery plant
4	Population	Modus vivendi	Waste	Organics, bacteria	13.478ton/d				x.Effluent treatment (KfW)
				Ammonium, etc.	156lit/s				
	Total (San Antonio)					99Kg/d*7	Principal. S.S.	6 a 12	
						(2,53mg/l)			
	Environment standart					(0,005mg/l)			

Table 2. Pollution Situation at Potosi and its Solution Measurements

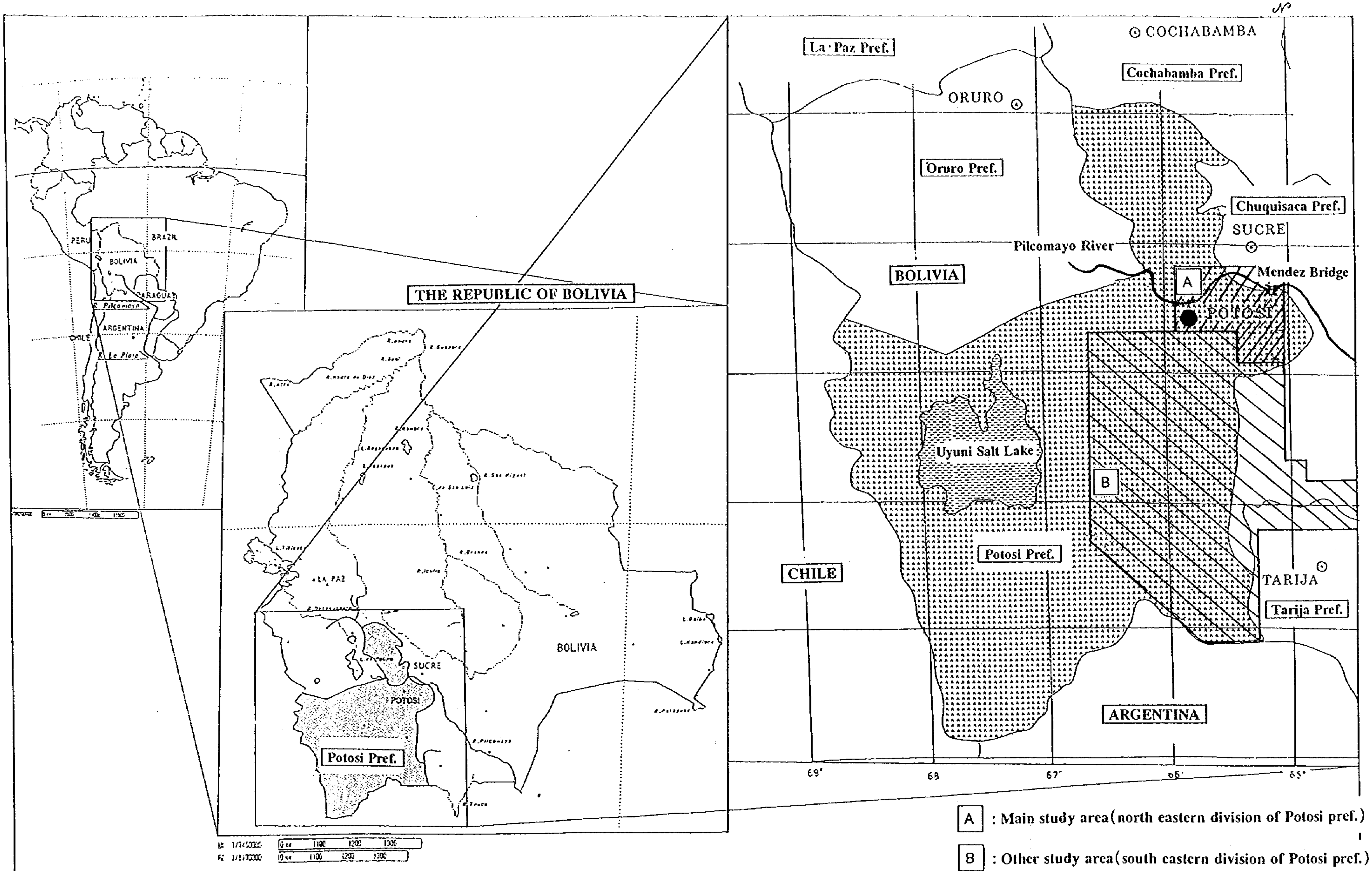


Figure 1 Location Map of The Study on Evaluation of Environmental Impact of Mining Sector in Potosi Pref.

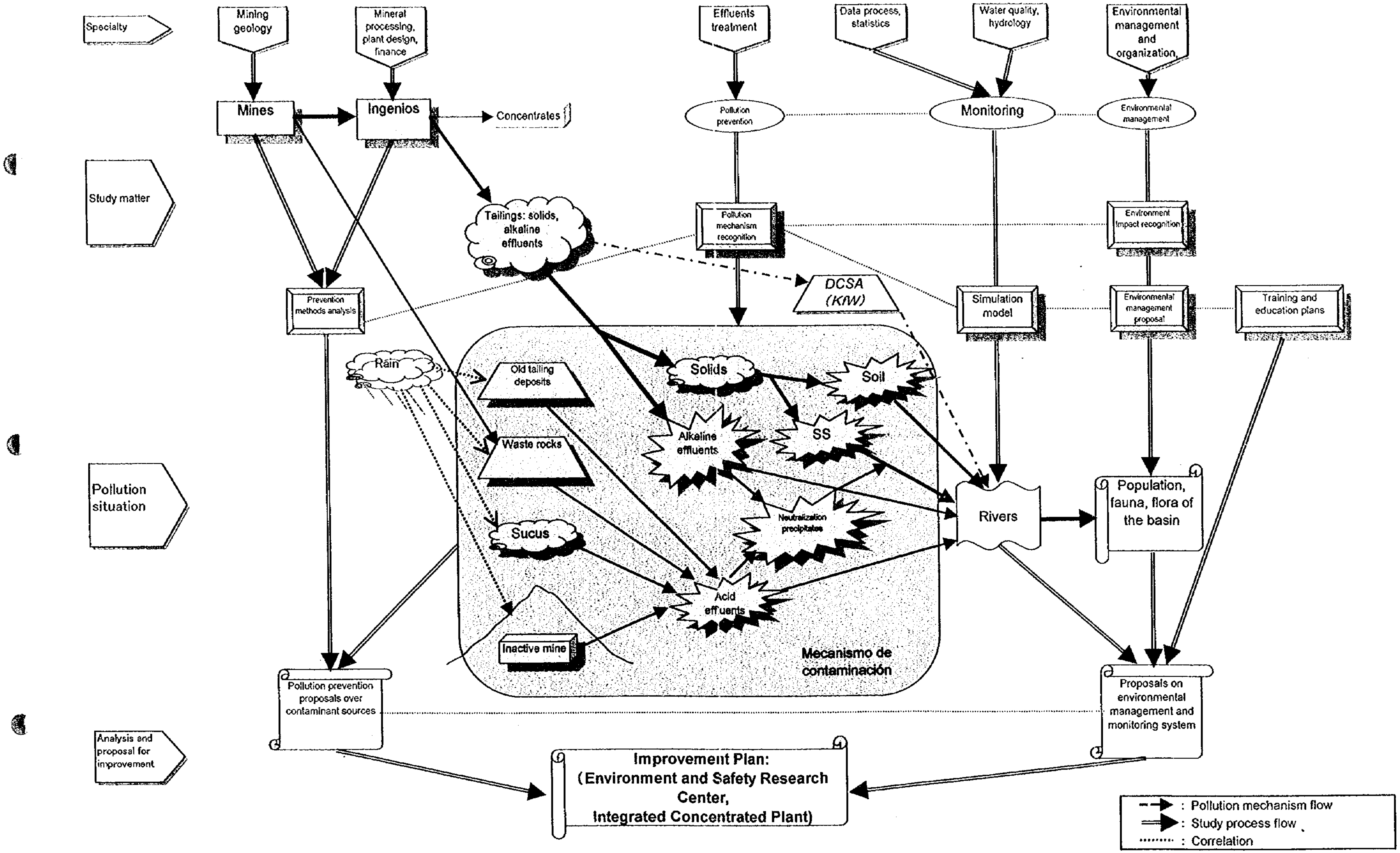


Figure 2. Study Context

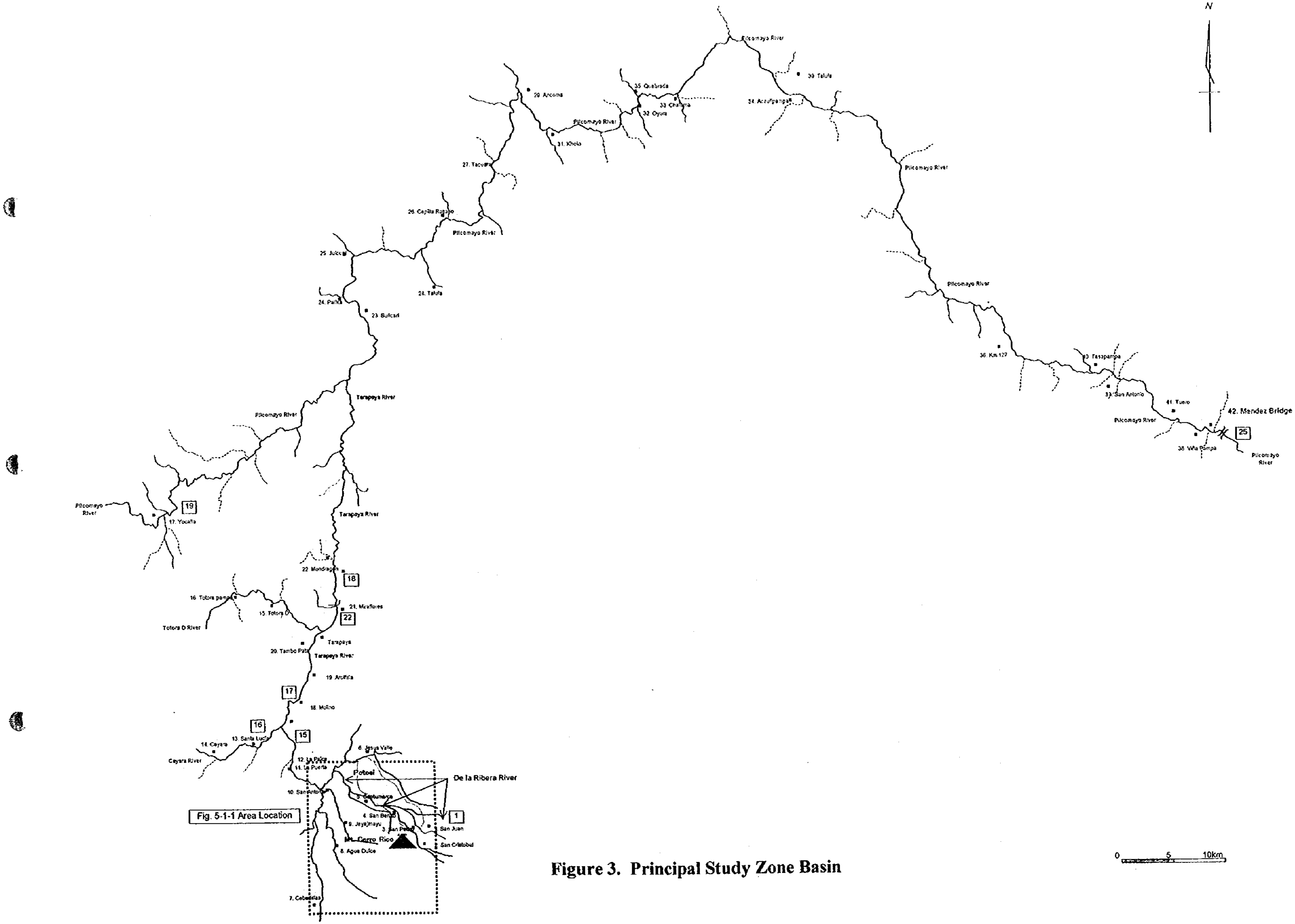


Figure 3. Principal Study Zone Basin

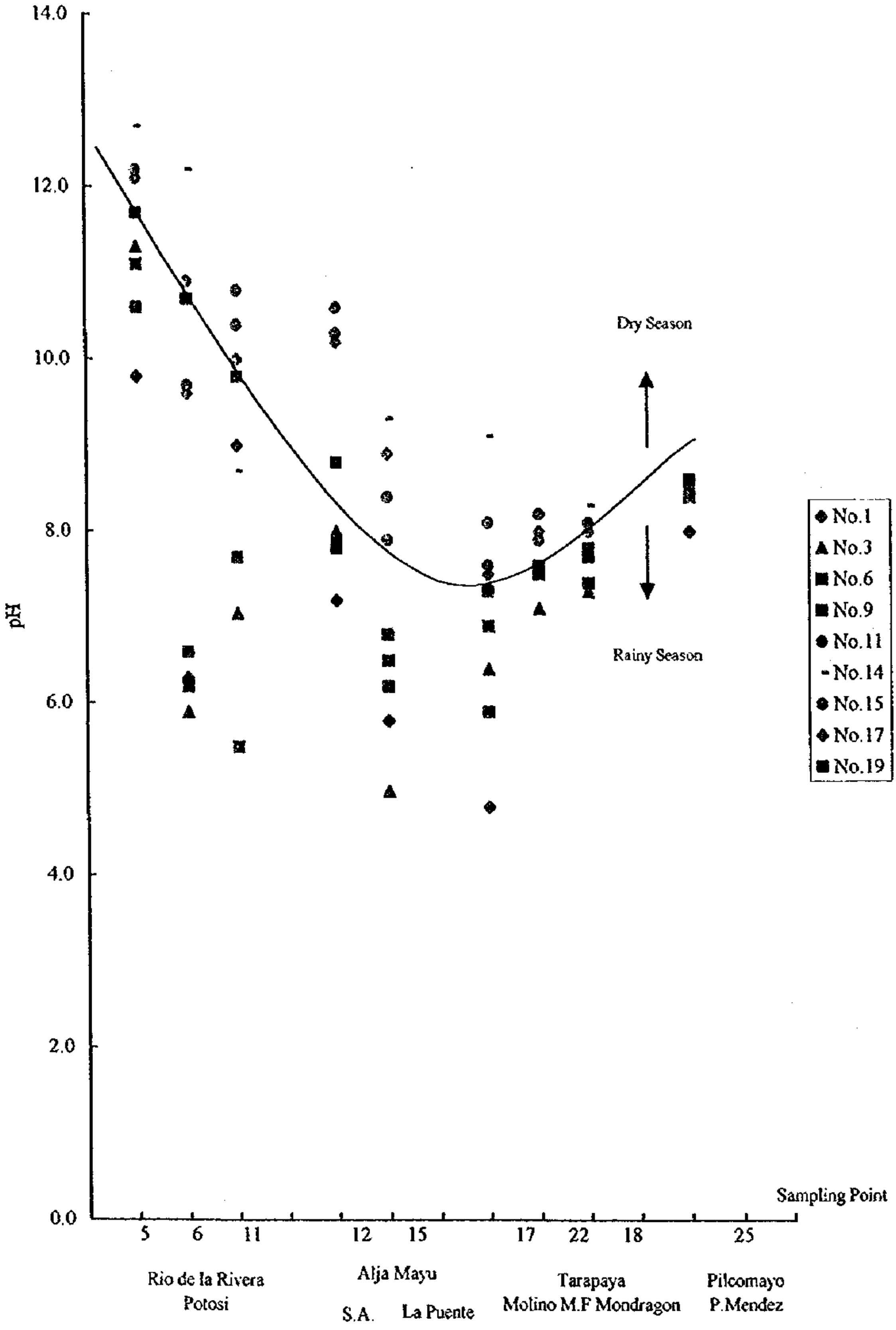


Figure 4. Trend of pH in Rivers

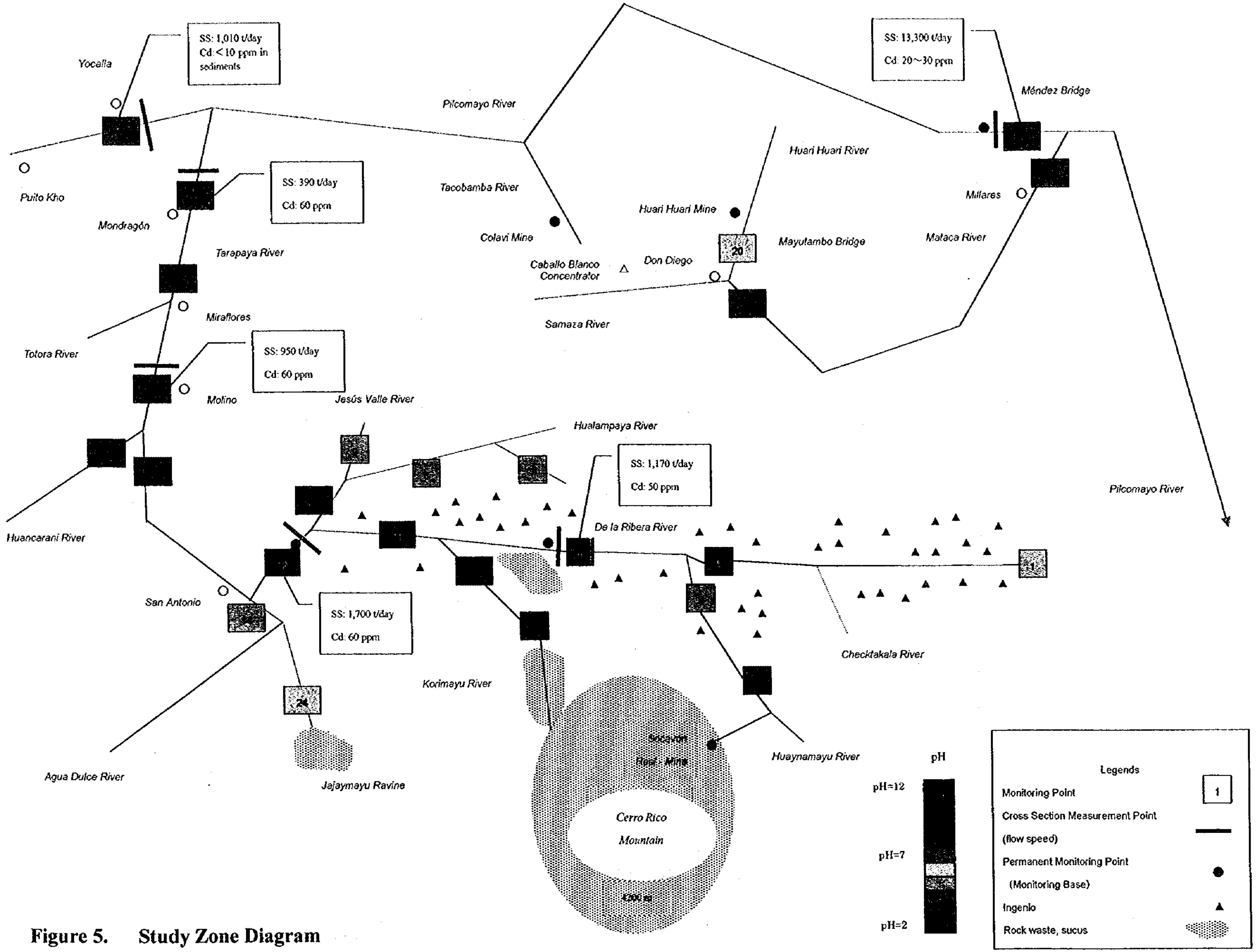


Figure 5. Study Zone Diagram

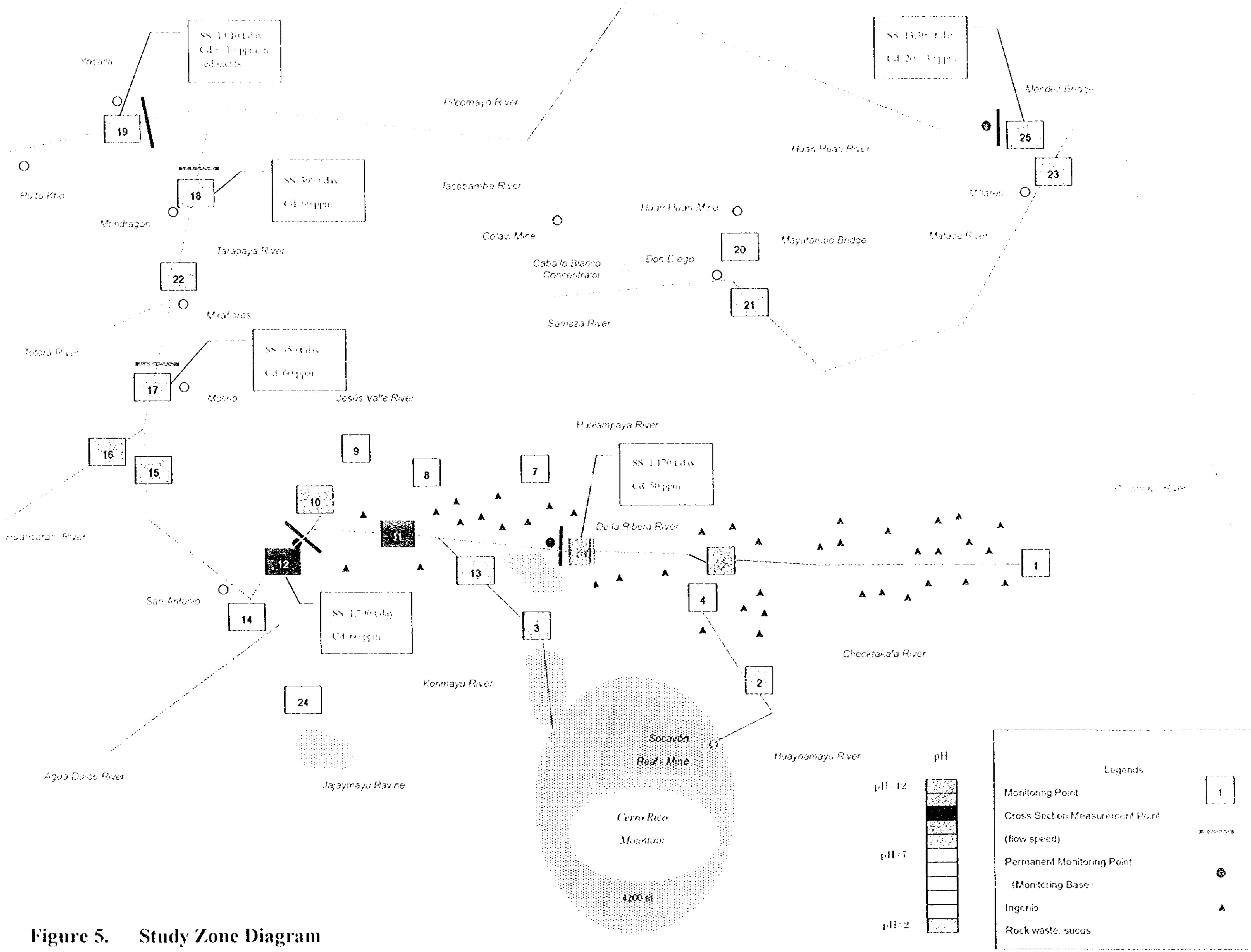


Figure 5. Study Zone Diagram

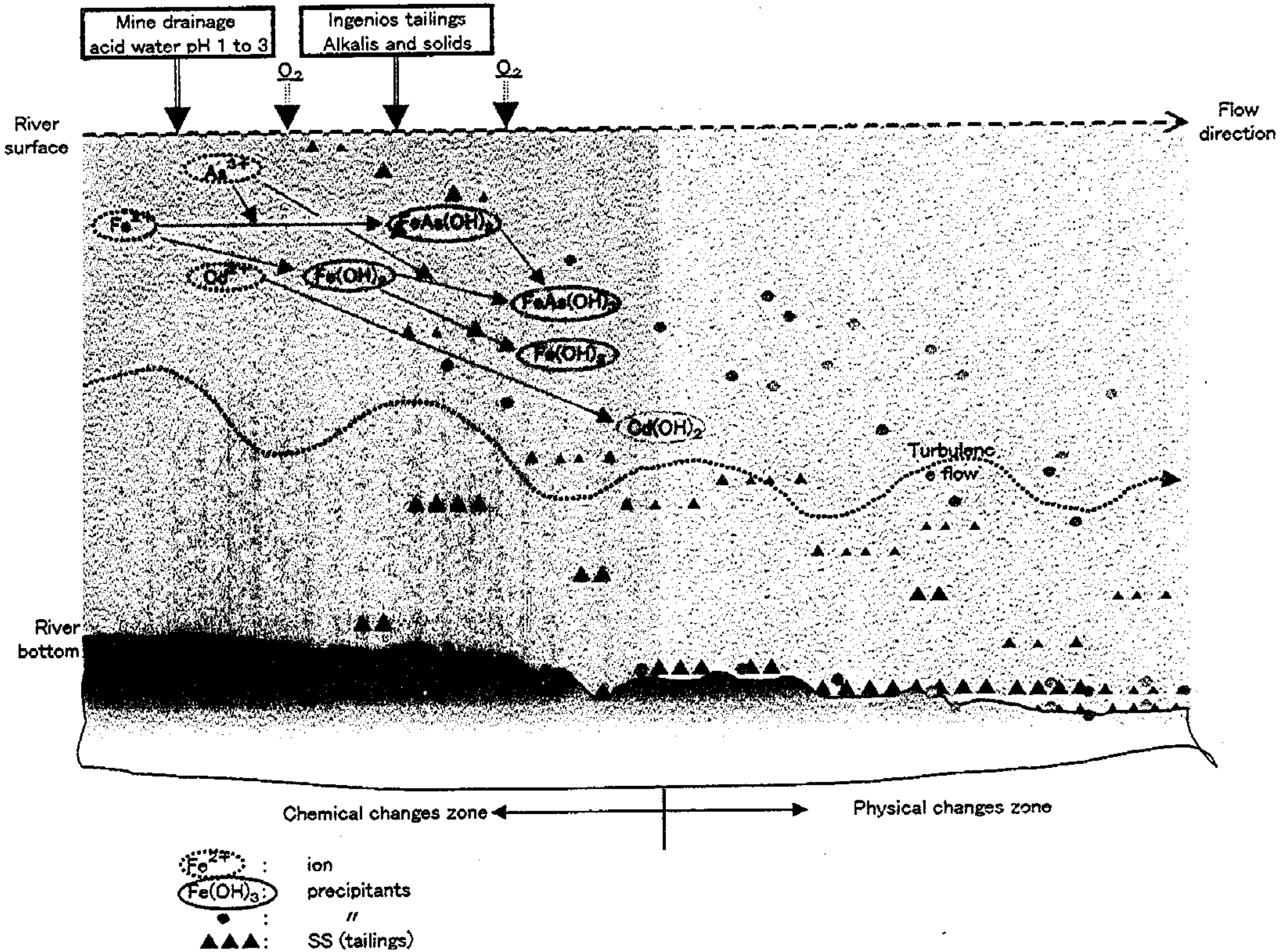


Figure 6. River Pollution Mechanism

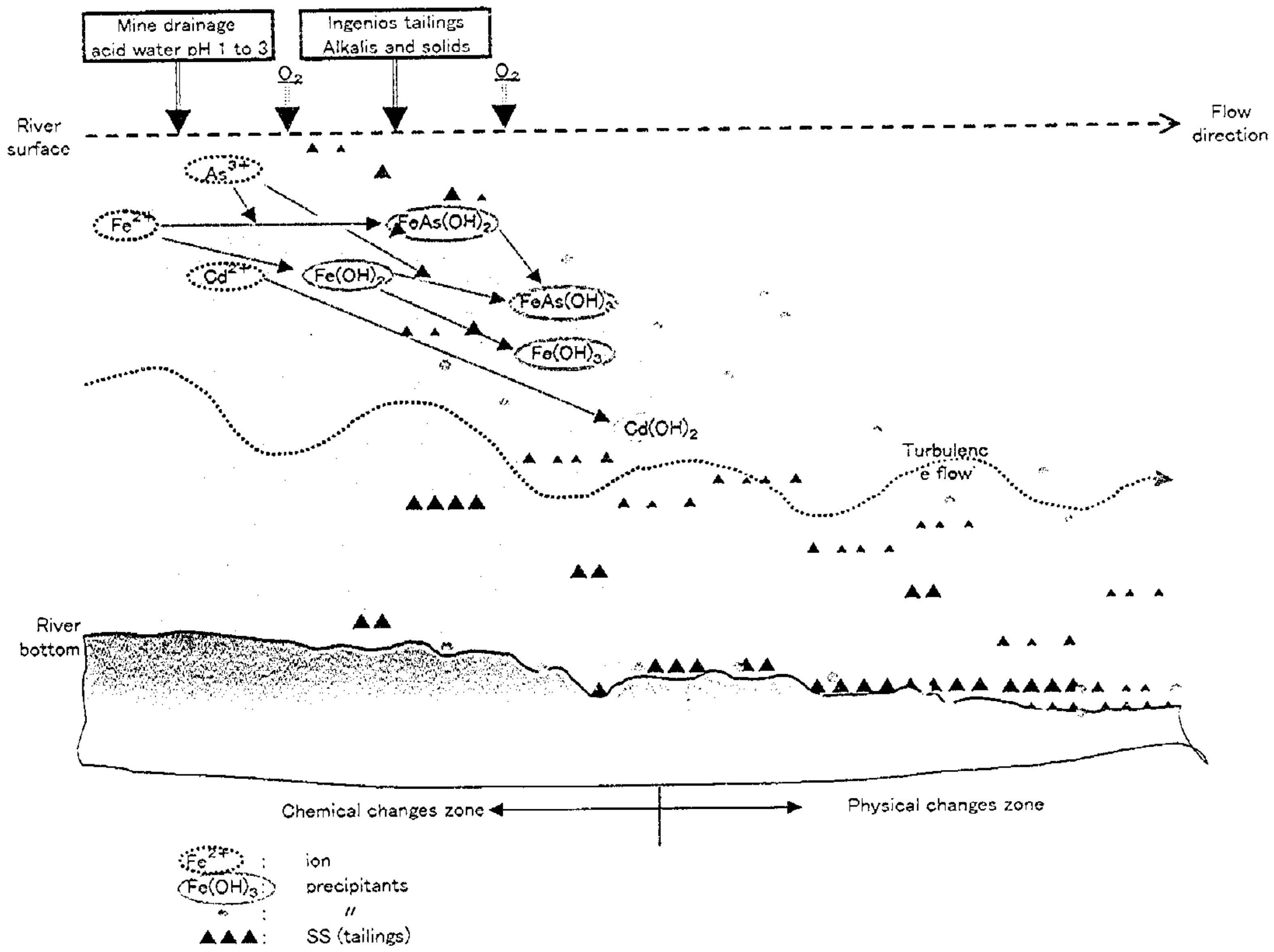


Figure 6. River Pollution Mechanism

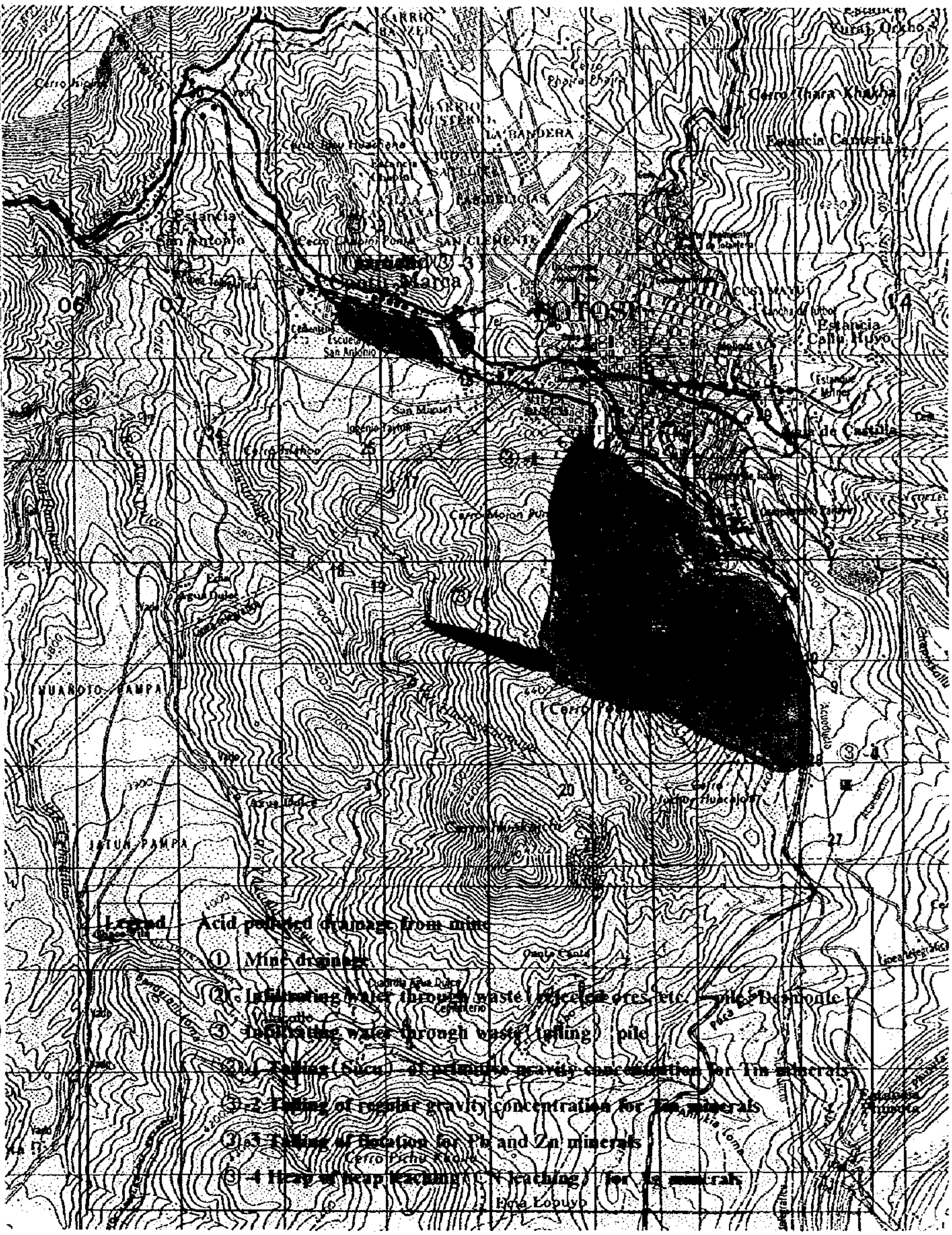


Figure 7. Sampling Points for Mining Pollution Divisior

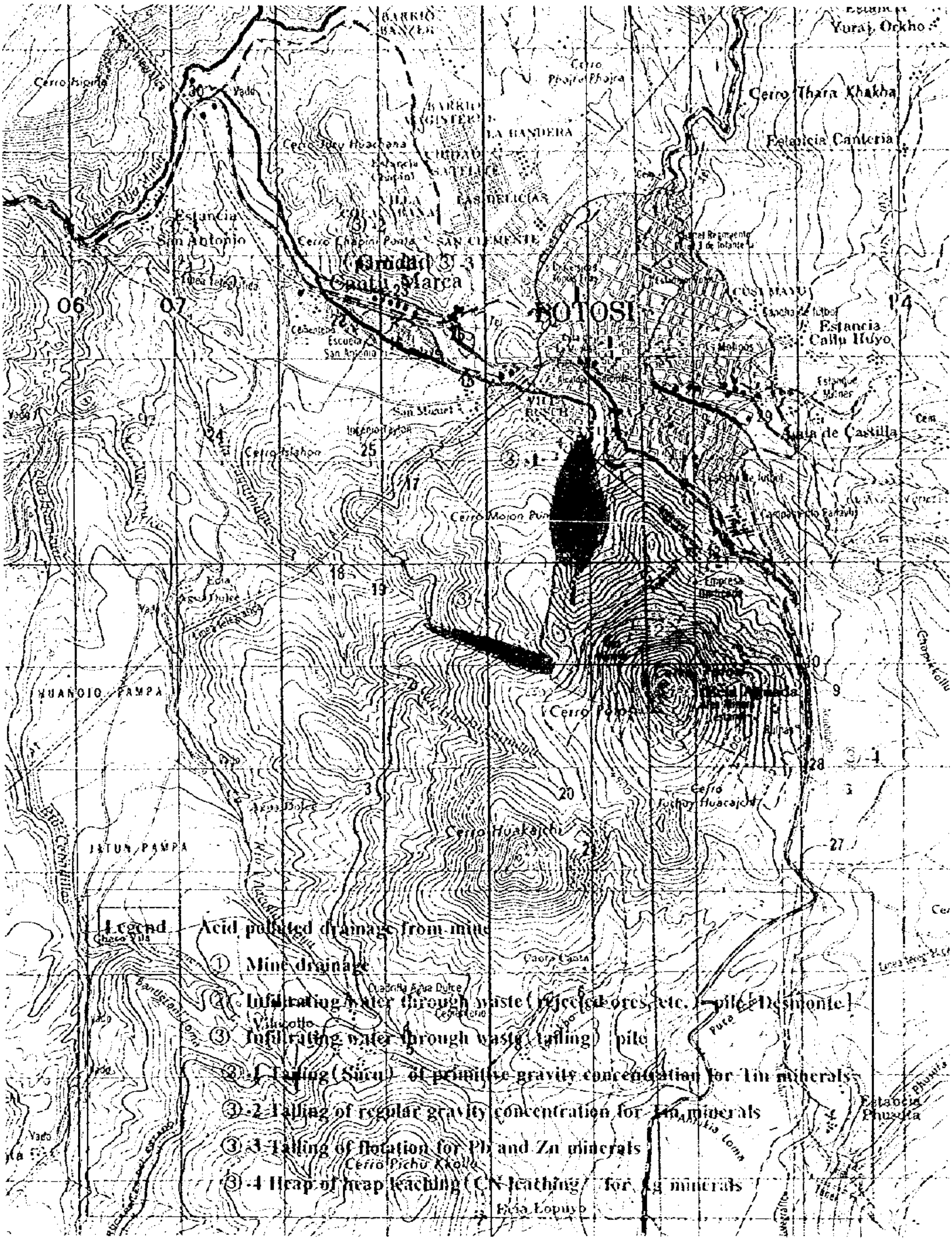
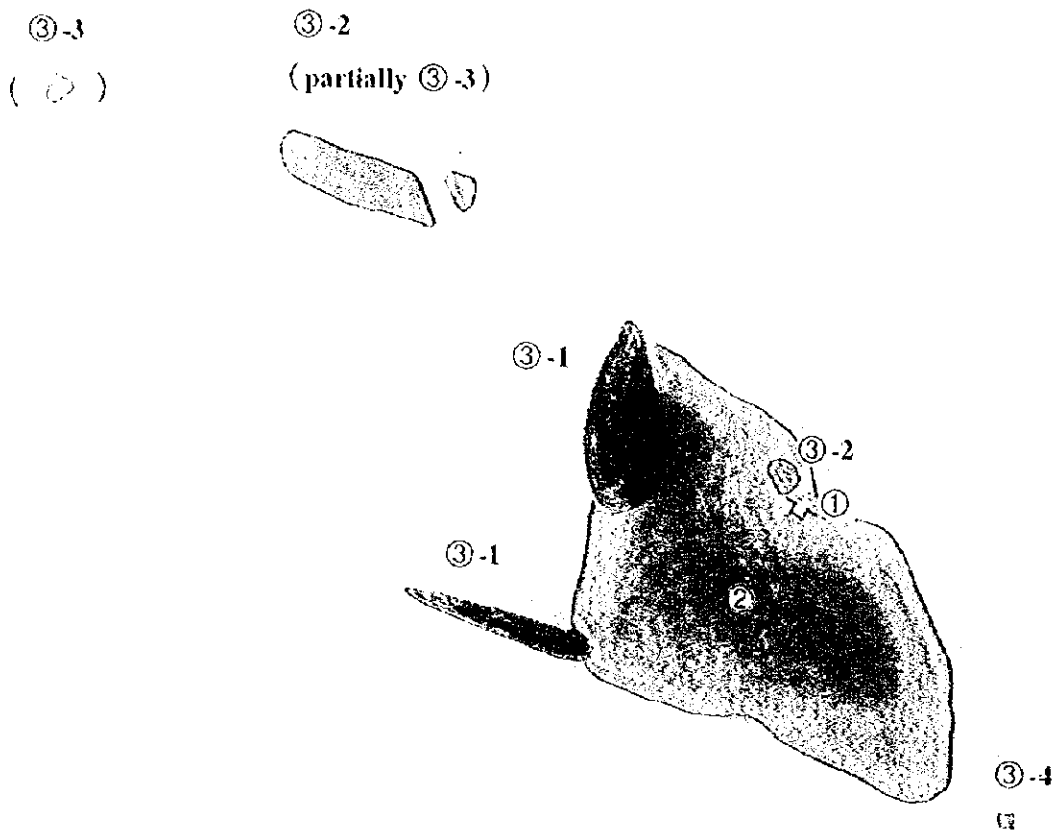


Figure 7. Sampling Points for Mining Pollution Divisior



Legend Acid polluted drainage from mine

① Mine drainage

② Infiltrating water through waste (rejected ores, etc.) pile [Desmonte]

③ Infiltrating water through waste (tailing) pile

③-1 Tailing (Sucu) of primitive gravity concentration for Tin minerals

③-2 Tailing of regular gravity concentration for Tin minerals

③-3 Tailing of flotation for Pb and Zn minerals

③-4 Heap of heap leaching (CN leaching) for Ag minerals

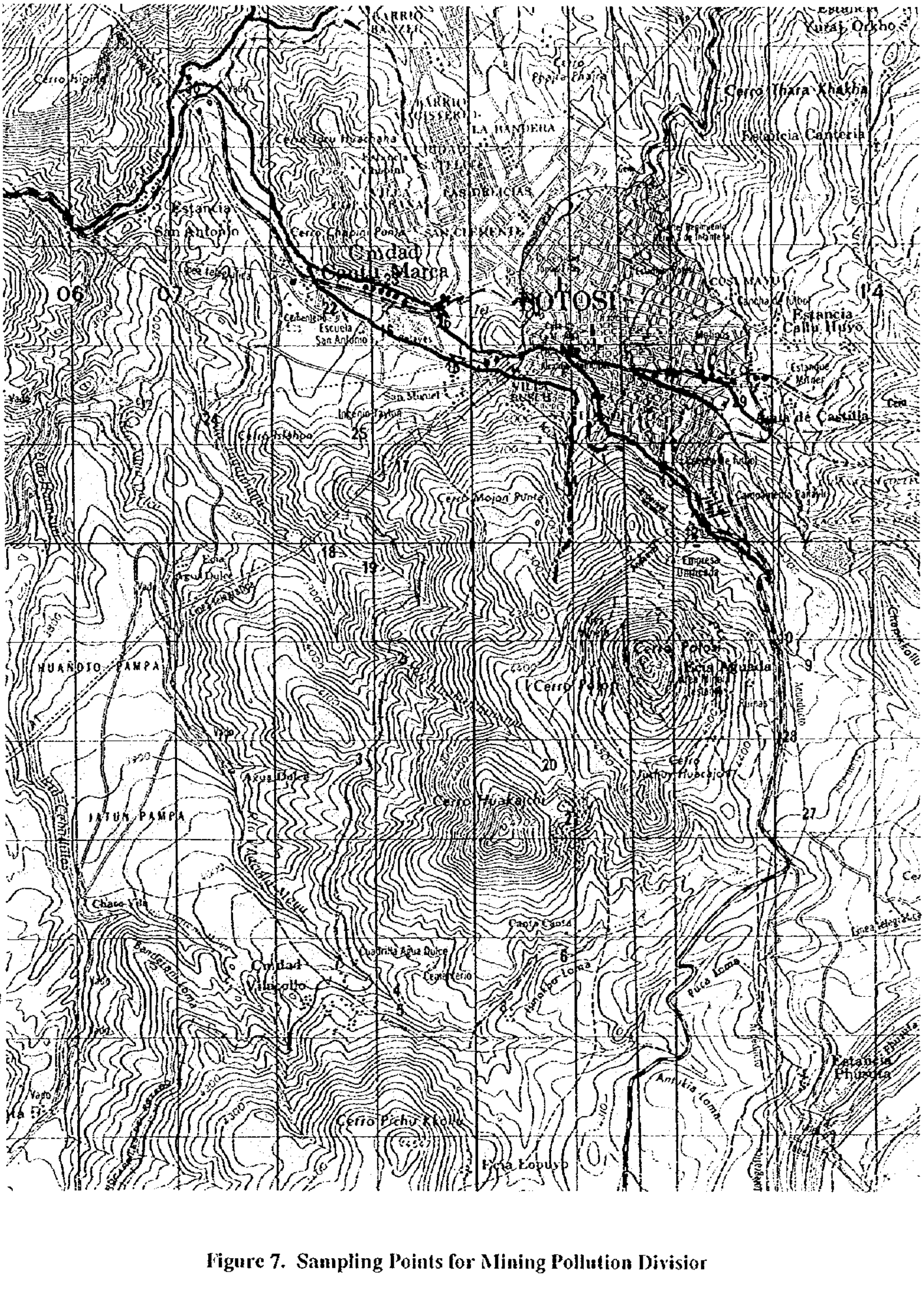


Figure 7. Sampling Points for Mining Pollution Divisior

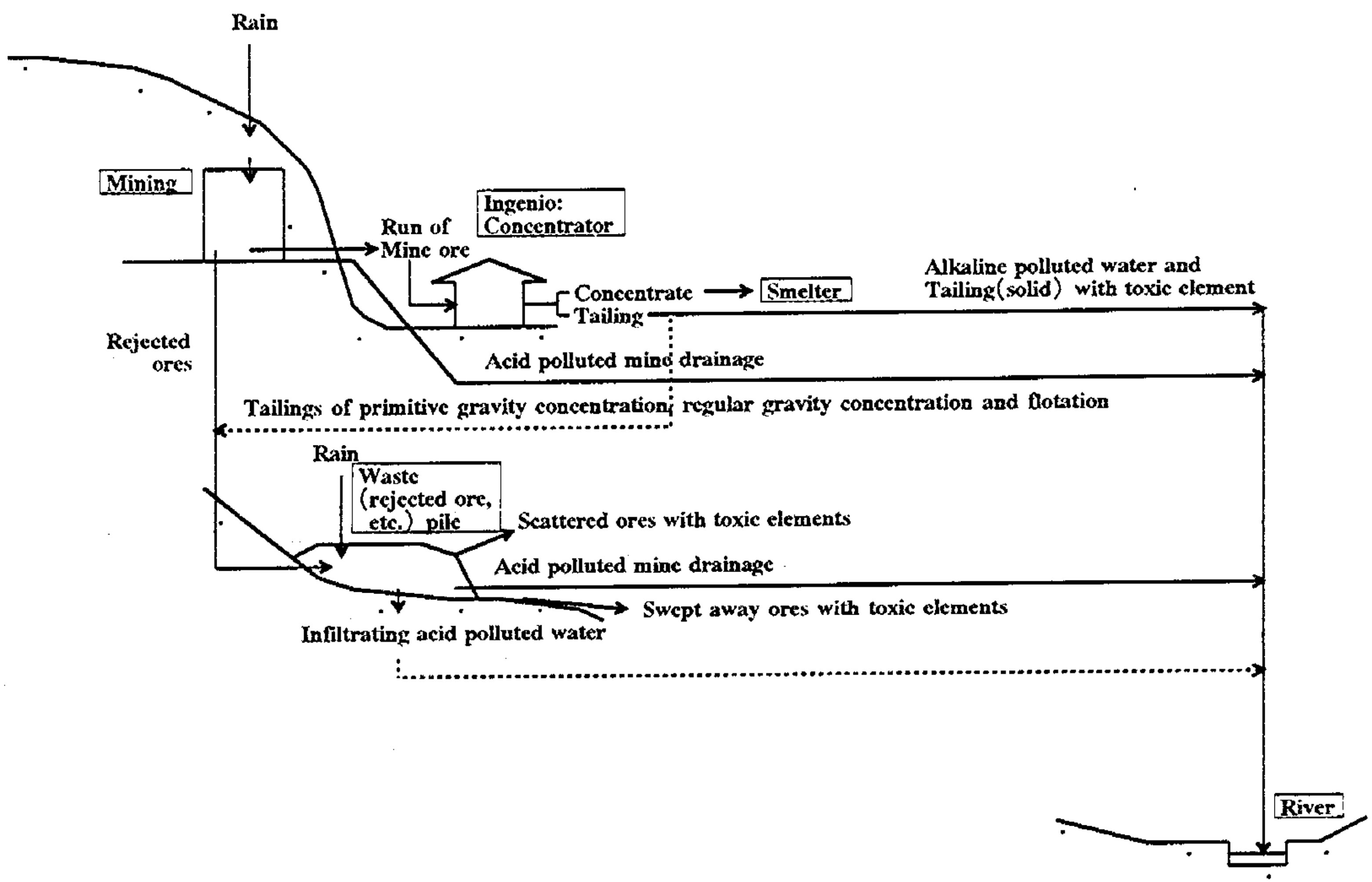


Figure 8. Pollution Mechanism Map in Potosi Area (Concept) [Present]
: Concept of pollution for river, etc. caused by mine and Ingenio with toxic elements

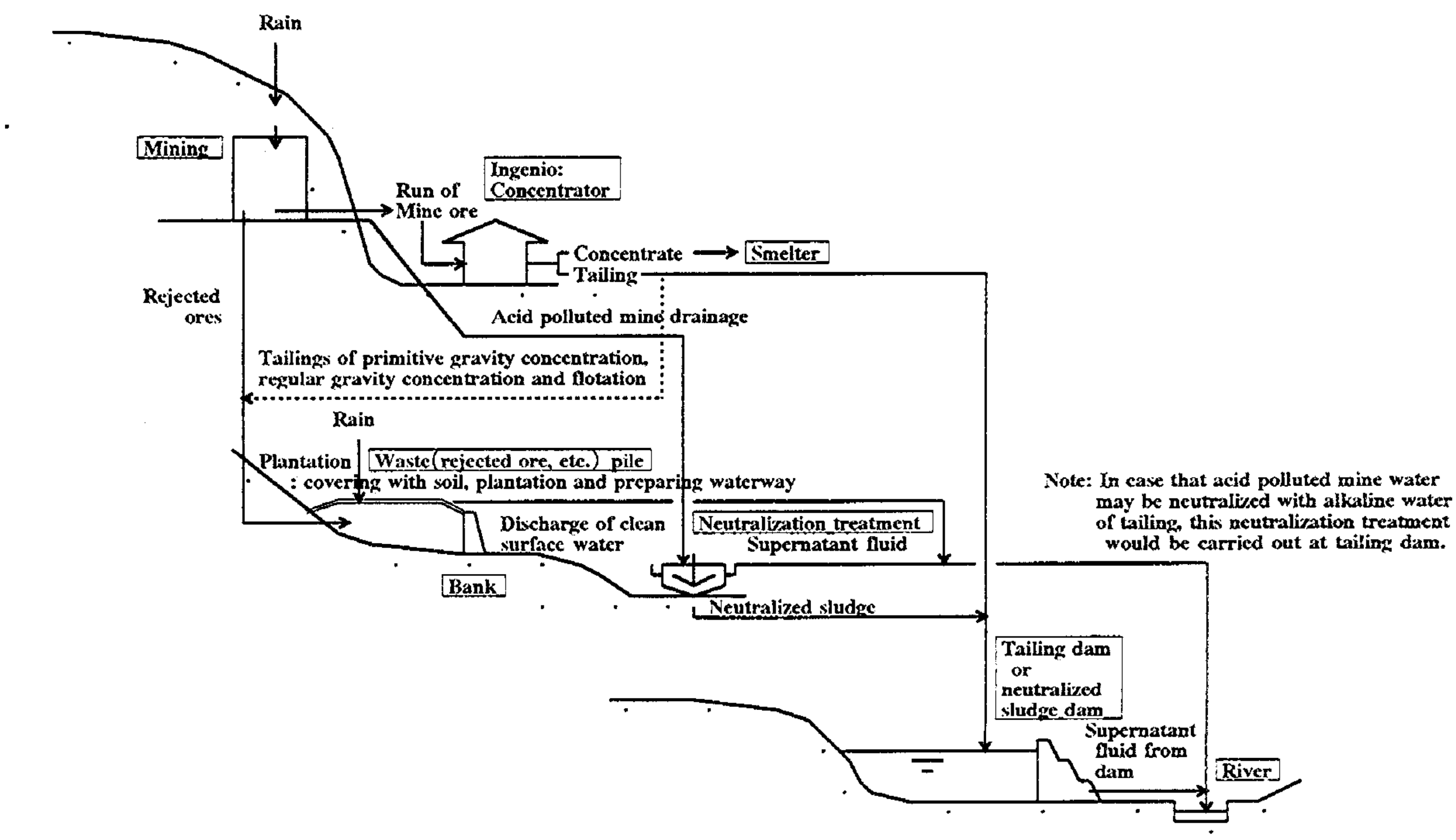
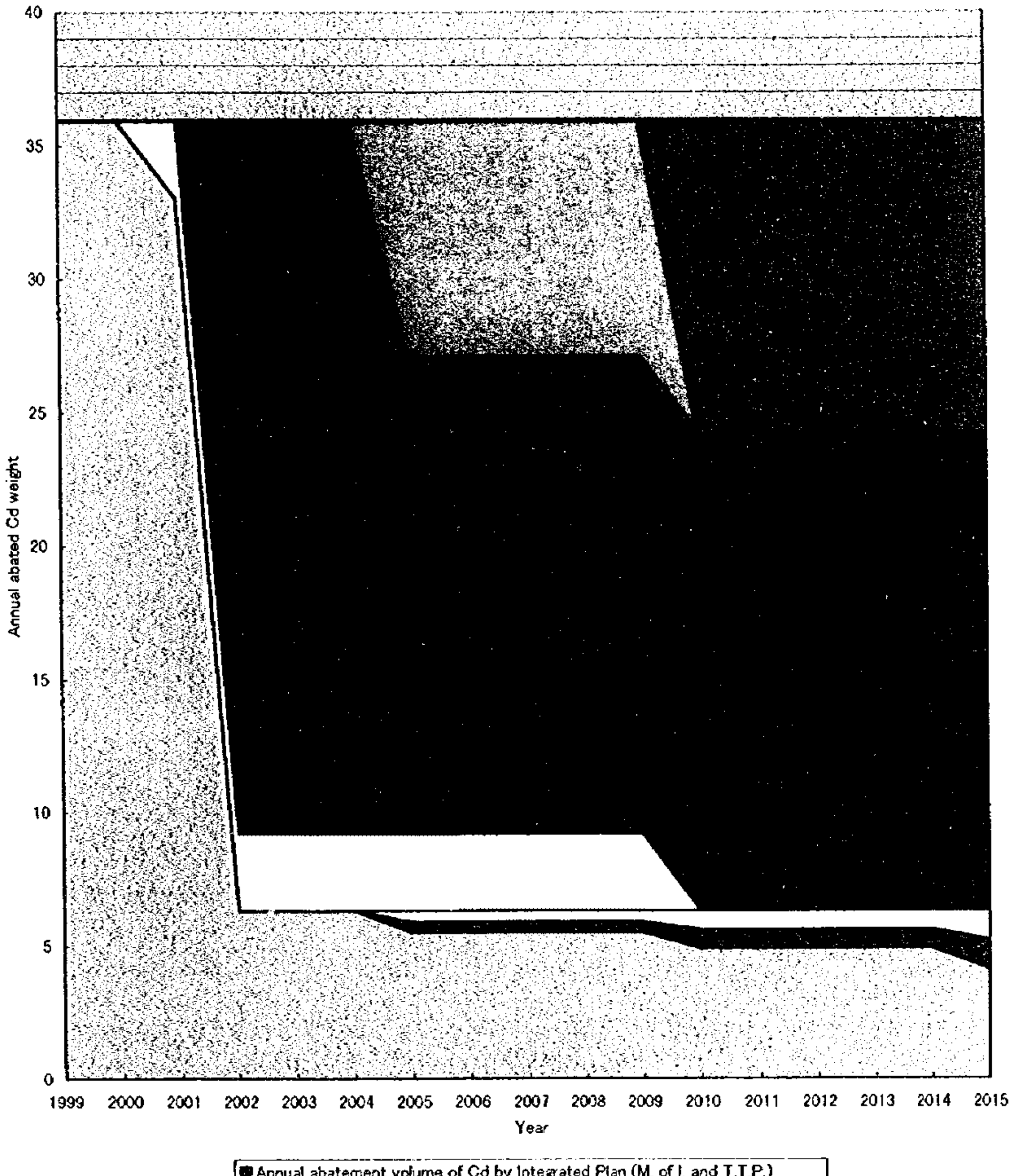


Figure 9. Mine Pollution Control/Prevention Technology to be applied in Potosi Area(Concept)
Note: Neutralization treatment for acid polluted mine drainage from waste(rejected ore, etc.) pile would be necessary, because acid polluted mine drainage still generated at waste(rejected ore, etc.) pile until plantation may be completed.

Figure 10. Abatement Effect of Cd contamination



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