THE STUDY ON ENVIRONMENTAL IMPACT OF MINING ACTIVITIES AND COUNTERMEASURES IN THE UNITED MEXICAN STATES

FINAL REPORT SUMMARY

MARCH, 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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1. INTRODUCTION

In July, 1990, The Government of the United Mexican States requested the Government of Japan to conduct an extensive study on "Environmental Impact of Mining Activities and Countermesures in the United Mexican States" as a part of national policy in its mining industry. Based on this request, an agreement was made in August, 1990, as the Scope of Works (S/W) between the Government of Mexico and Japan International Cooperation Agency (JICA), the official agency for the Government of Japan, to realize this technical cooperation program.

The main objective of the Study is, as indicated in the above S/W and the instruction given by JICA in December, 1990, to formulate appropriate environmental protection measures at the mining sites through the following investigations of present environmental condition.

(1) Investigation on environmental influence of tailing dams by collapse of embankment and outflow of waste materials.
(2) Investigation on contamination of surface and ground water by effluent from tailing dams.
(3) Investigation on scattering dust particles carried away by the wind from tailing dams.

Technology transfer to the Mexican counterparts assinged in this studies also included throughout the program.

This Final Report describes present environmental situation obtained from the field investigation performed over dry and rainy seasons and practical, appropriate countermeasures for improvement.

2. OUTLINE OF THE FIELD INVESTIGATION

Field investigation was planned in two stages, in dry and rainy season. The first part was carried out in dry season from Jan. 21st till March 27th for 66 days and the second was in rainy season from July 15th till Sept. 18th for another 66 days. The survey areas were the following three mining sites as designated in the S/W shown in Fig.2-1.

(1) El Bote tailing dam, State of Zacatecas (hereafter referred to El Bote)
(2) Parral tailing dam, State of Chihuahua (Parral)
(3) El Coco new tailing dam (proposed) site, State of Sinaloa (New El Coco)

Principal objects of the survey were as follows.

(a) Collection of data regarding topography, geology, meteorology, mineral processing plant and tailing dam
(b) Geological reconnaissance in and around the survey areas
(c) Study on geology and ground water movement through electric exploration
(d) Study on geology and ground water movement through boring works
(e) Measurement of flow rate and velocity of surface and ground water
(f) Analysis of chemical components contained in the surface and ground water
(g) Physical properties of soil constituting tailing dam
(h) Physical properties of soil around New El Coco dam construction site
(i) Analysis of chemical components like heavy metal ions, contained in the soil
(j) Scattering of dust fall from the existing tailing dam

Based on these technical data obtained through the survey, following matters were analysed and investigated collectively.

1.Local hydrographic system including surface and ground water (a ~ f)
2.Influence of dam effluent and penetration on the ajacent area (a ~ f,h)
3.Evaluation for physical stability of the existing dams (g)
4.Constructive estimation for the proposed dam site (h)
5.Environmental influence of dust fall from the existing dams(j)

The above-mentioned investigation matters are almost common to the three areas, however, actual survey plans were finally decided after considering local situation in each area and adopting CFM's request as far as possible through successive discussions. Also some modification was made in each area due to limit of the working days.

Electric exploration and boring works were actually performed by local contractors after written agreements were signed respectively. Location of exploration lines and boring holes were previously designed by the Preliminary Study Team but finally decided by this Study Team with minor changes due to local topographic conditions. Physical properties mesurement for soil investigation was also commissioned to a local contractor. Chemical analysis of soil, water, dust was undertaken by Tecamachalco Research Laboratory of CFM.

Actual survey works were advanced as illustrated in Fig.2-2 and 2-3. Table 2-1 shows total amount of the electric exploration and boring works in each survey area. Detailed results obtained in each survey area are described in the following Chapters.

3. SURVEY RESULTS AND COUNTERMEASURES IN THE AREA OF EL BOTE

3-1 General Situation

El Bote mine is located 2km northwest of Zacatecas City. El Bote is about 2,400m above the sea level. The climate is "Step type". Average temperature throughout a year is 10～15°C but goes down to 7°C in the winter season. The rainy season usually runs for five successive months starting in May till September, the rest of which is almost dry. Annual rainfall averages 660mm. Throughout the dry season the south-west wind blows so hard.

El Bote mine was started by a private person in the late 19th century as a gold-silver-lead mine. Since 1972, the entire operation has been unified by CFM as an organization,"Unidad Minero Metalurgica El Bote", and operated until now.

Total output from the underground mine reached 166,000 tons in 1989. According to recent records, metal contents in the crude ore are 0.8 g/t Au, 110 g/t Ag, 0.5% Pb and 1% Zn. Its mineral processing plant has a capacity of 650 tons a day, which is the highest among the whole plants owned by CFM. Up to 1987, lead and zinc concentrates had been recovered separately by differential flotation method, however, due to decrease in metal in the crude ore, it has been converted into bulk flotation for the recent four years to recover single sulfide bulk concentrate. In these days, when the metal contents are comparatively high, differential flotation is operated temporarily. In this case about 600kg of sodium cyanide per month is added into flotation pulp to separate lead and zinc and this could bring water pollution problem of mine effluent. When bulk flotation is employed this harmful reagent is not used at all. Metal contents in the bulk concentrate are 20 g/t Au, 3,000 g/t Ag, 6% Pb and 12% Zn. Water consumption in the plant is about 1,400m^3 a day, of which 1,000m^3 is supplied as fresh water from the underground mine and the rest is recirculated from the tailing dam effluent. Waste water is discharged into nearby rivers without any treatment.

3-2 Geology

This area is formed on Pimienta Metasediments of Triassic age (Fig.3-2-1). This layer generally inclines toward NE～E～SE. Thus, as going westwards the lower layers are more widely distributed. In the south-eastern part of the area, the andesite of Eocene of Tertiary distribute covering the basement layer unconformably. The dip of NE-SE and the strike of NE direction seem to be dominant. The rhyolite dyke of post Eocene and the ore veins like La Cantera develop,mainly extending WNW to ESE and crossing the northern part of the tailing dam. The Quarternary fan deposits form a flat plane in the north-western and central part of this area. Recent Terrace deposits develop along the river by erosion of the old fan deposits.

Structurally, an anticline axis with NNE ~ SSW is possible. And there exist two faults, one lies along the La Candera vein and the other is parallel to the dip of basement layer cutting the La Candera.

3-3 Electrical Prospecting

The Schulumberger's Electrode Arrey was used in this survey. The survey was carried out with 49 stations arranged on 20 lines. The analysed resistivity is classified into following four groups (Fig.3-3-1).

S Zone: tens of to thousands of Ω · m

L Zone: Less than 100 Ω · m

M Zone: 100 ~ 200 Ω · m

H Zone: more than 200 Ω · m

L zone shows low resistivity, M zone shows medium resistivity, H zone shows high resistivity and S zone shows complex zone of low and high resistivity.

S zone forms the surface in thickness of 5m ~ 45m, the average thickness is 20m. S zone is composed of the terrace deposits of recent (Holocene of Quarternary), old fan deposits and weathered overburden of phillites, slates and limestones of Triassic System.

M zone and H zone form in the eastern part of 9-39-27 line and the lower part of S zone. There are less L zones in the eastern part of this line But, M zone (medium resistivity) or H zone (High resistivity zone)is formed in the lower part than 150m of S zone.

M zone and H zone are composed of phillite and limestone of Triassic System. Almost all the part of H zone corresponds to the part lying between Triassic System. M zone and H zone correspond to the part of the axis of anticline and the eastern wing of the anticline from the geological structure.

Ground water movement was observed in S zone and L zone in boring test. From this fact, it is considered that S zone and L zone are aquifer. M zone is aquitard and H zone is aquiclude or aquifuge, respectively.

3-4 Hydrology

The collection of flow data and various analysis of water were carried out at the points shown in Fig.3-4-1 both in the dry season and in the rainy season.

3-4-1 The Surface Water

(1) Streamflow of Surface Water

The measurement of current velocity was carried out at No.0 ~ No.6 in Fig.3-4-1. The results are shown in Table 3-4-1 and Fig.3-4-2.

The variation of the amount of the streamflow is generally small in survey site. The amount of streamflow in the dry season and that in the rainy season are approximately same at points No.4 and No.6 and others.

Compared with the data of the dry season and that of the rainy season in upper reaches, the amount of streamflow at point No.1 is approximately twice of that in the rainy season in appearance. Each fact seems to be contradictory from the seasonal characteristics. But, the waste water from the mine flows into between No.1 and No.2, the variation of the amount of streamflow in this section is much affected by the variation of the amount of waste water from the mine. And the relation between the measurement time and discharge time from the mine affects the variation more than the seasonal change. The streamflow at No.2 and No.3 are affected by the difference of the amount of evaporation. The amount of stream flow in the dry season and in the rainy season are same. The seasonal change can not be seen in this section.

(2) Water Quality of Surface Water

The sampling of water was carried out at the 9 points of B-D1, B-W1 and B-R1 ~ B-R7 in order to analyse pH and pollutants. The analysis data of the samples of surface water are shown in Table 3-4-3. Background and water supply ceiling of pollutants are shown in Table 3-4-2.

The number of origins of the pollution of the survey site is considered to be three mineralization zone near B-R2, the settling pond of CMF dressing plant and the outlet of waste water of Prisima Mine. However, the mine water of Prisima includes Zn 1.7 % less than that of surface water of this site(B-R1 ~ B-R7). The water from the mine hardly affects the pollution of the area of the lower reaches. Therefore, the biggest origin of the pollution is the mineralization area near B-R2. The slime and waste water from the mine in the upper reaches of the area gives some influence to the pollution . There is some possibilities penetrating water from the settling pond gives some influence to the pollution.

PH of waste water from the dressing plant and river water except the sample at B-R2 is in the range of 7.50 ~ 8.20, which is weakly alkalinic. However, the sample of B-R2 shows acidity of pH 2.55. From the facts, B-R2 area is obviously recognized to be markedly polluted.

3-4-2 Groundwater

(1) Streamflow of Groundwater

The survey of the rate of streamflow and the position of aquiferous layer were carried out in three observation holes along El Bote River, just the lower reaches of the tailing dam.

The results are shown in Table3-4-4 ,Fig.3-4-3 and Fig.3-4-4. The current speed of groundwater generally increases in rainy season. The groundwater level also rises approximately 0.6m in B-1 and B-2, and approximately 0.8m in B-3 in the rainy season compared with in the dry season. By the fact, the groundwater in shallow place along the El Bote River occur to change of the rate of streamflow reflecting seasonal change.

(2) Water Quality of Groundwater

The water samples are collected at 6 holes of B-B1 ~ B-B3 and B-M1 ~ B-M3 in order to analyse water quality including measurement of pH. The result is shown in Table 3-4-5.

The contents of Pb, Fe and Cd of the mine water of B-M1 ~ B-M3 exceed the upper limit of the Environmental Standard. On the other hand, the content of Cd in B-B1 ~ B-B3 decreases and the contents of Pb and Fe exceed the upper limit of the Environment Standard. The contents of Cu, Pb and Total Cr in B-B1 ~ B-B3 along the river increase in the dry season,and Zn, Cd and Hg were detected in rainy season. It is considered to be caused of the fluctuation of groundwater table and the rate of streamflow or the vertical and horizontal change of the route of stream, and permeable layer is presumed to slightly differ from in the dry season and in the rainy season.

Therefore, the groundwater in shallow place along the river fluctuate not only in the rate of streamflow but also in water quality affected by seasonal change. The content of almost all the pollutants in the sample at B-M2 which is the mine water of San Bartolo Mine is higher than that of other groundwater samples. Particularly, the content of Zn shows abnormally high value of 140 ppm. Moreover, pH is lowest different from other samples, it shows almost neutrality.

Almost all the waste water from CFM dressing plant flows into the settling pond located just below the plant. The contents of Pb, Zn, Fe, Cd and total Cr of the sample at B-D1 in settling pond exceed the upper limit of the Environmental Standard. However, the contents of Pb and Fe in the lower reaches of the plant only exceed the upper limit of the Environmental Standard. Therefore, it cannot be considered that the penetrating water from the plant is the major origin of the pollution of groundwater which exists in the lower reaches.

3-4-3 Groundwater Flow System Simulation

Optimum simulation blocks of physical and hydraulic properties are modelled around El Bote Mine. A Groundwater flow system is simulated by these properties which are obtained by integrating the results of meteorological,geological,hydrological surveys and soil test.

By this simulation, clarified are water table, flow direction and flow speed. Simulation results are contributed to calculate effective goundwater harness, waste water recycle and mining pollutant dispersion.

(1) Simulation Method

A numerical simulation for groundwater flow is conducted by the use of three dimension simulator "GWS3D2P" originally developed by Dr. Hiroyuki Tosaka of Tokyo University. In this simulator, Darcy's law and mass balance equations are analysed by Finite Difference Method.

(2) Simulation Model

① Block Model

Simulation area is rectangular, 15km wide in the NW direction and 12km wide in the NE direction (Fig.3-4-5). El Bote Mine is located in the southeastern side of the area. The veins and fissures generally strike northwest around El Bote ore deposits. The water supply pump of Zacatecas municipality is located on the northwestern side of the area. The simulation is conducted to predict the pollutant dispersion from El Bote mine to the municipality water supply pump. Consequently, the direction of the simulation area is in accordance with the vein strike, and the area is decided to cover the mine and the pump site. The simulation depth is decided to 1,800m above sea level ,because of the pumping 200m below the surface at the municipality water supply site and the pumping 150m below the surface at El Bote mine site.

The simulation area is divided into 30 blocks in the northwest direction, 31 blocks in the northeast direction. The block size is 200m × 200m wide around El Bote mine, 1.2km × 1.2km wide around the marginal area. X and Y axes are in the directions of NW-SE and NE-SW, respectively in the figure.

Vertically, the area is divided into 9 underground layers and 1 atmosphere layer, total 10 layers. The uppermost atmoshere layer is the first layer Z1. Surface layers are 10 to 20m thick, deep site layers are 200m thick. The height of each block is represented by the elevation of the center of the block as Fig.3-4-6 shows.

② Permeability and Porosity Model

Permeability and porosity of each simulation block are determined by integrating the geological, geophysical and hydraulic properties.

Geologically, the mountain side, in which El Bote mine is situated, is underlain by compact Triassic and Tertiary rocks which are not permeable. On the other hand, the hill side is underlain by thick alluvial deposits which are permeable. Triassic rocks of hill side is assumed to be situated 1,900m above sea level, which rocks is situated in deeper site than the rocks of mountain side.

The fissures and veins around El Bote Mine generally strike in the NW and NE directions. Therefore, The rocks which accompany fissures or veins are permeable in this direction. The mountain side is upheaved in the N-S direction and the permeable fissures parallel to this direction are also recognized in the boundary between mountain side and hill side.

As the results of the electrical prospecting and boring observation, low resistivity zone and low-high complex resistivity zone correspond to aquifer. Intermediate resistivity zone corresponds to aquitard. High resistivity zone corresponds to aquiclude and aquifuge.

As compared with geology and geological structure, the aquifer zone is equivalent to alluvial deposit and the Traissic-terrace deposit boundary and fault zone. The aquitard is equivalent to weathered overburden and fault periphery. The aquiclude is equivalent to surface soil and clayey terrace deposit. The aquifuge is equivalent to the Triassic of mountain side.

As the results of grain size distribution, the aquifer permeability coefficient of alluvial sandy deposits is 10^{-2}cm/sec (sample No.BR-1,2). The aquiclude permeability coefficient of clayey terrace deposit is $10^{-5} \sim 10^{-6}$cm/sec (BR-3,4,5). Consequently, the aquifer permeability coefficient of alluvial sandy to clayey deposits is set to 5×10^{-4}cm/sec. The aquiclude's is 10^{-6}cm/sec. The aquitard's is 10^{-4}cm/sec. The aquifuge's is 10^{-7}cm/sec.

At El Bote mine, several big veins are embedded. The veins have been mined 3 km long along the strikes, 400m wide and 200m deep below the surface. So, the permeability coefficient of the vein zone is presumed to be 10^{-3}cm/sec, because the vein zone corresponds to big fault zone.

Porosity is presumed to be 30% to vein and aquifer, 20% to aquitard, 15% to aquiclude, 5% to aquifuge, respectively.

Table 3-4-6 shows permeability and porosity model. On the basis of this table, Fig.3-4-6 shows rock classification. In this plane map (X-Y CROSS SECTIONAL VIEW), the coordinates of left-bottom and right-top ends are (X1,Y1) and (X30,Y31), respectively. In the cross section (Y-Z CROSS SECTIONAL VIEW), left and right ends are Y31 and Y1, respectively. The legend No. of Table 3-4-6 corresponds to it of Fig.3-4-6.

③ Hydraulic Model

El Bote river flow down northwestward near El Bote mine. As Fig.3-4-1 shows, No.4 river flow measuring point is situated downstream from El Bote mine. At this No.4 point, flow rate is constant through dry and rainy season. On the other hand, upstream from this point, the river is divided into tributary streams which are not constant flow rate. Therefore, the flow rate 1,200 m^3/day is set at No.4 point for simulation.

Each Water level of the observation wells is set for simulation as to be situated at the top of the third layer counted from atmosphere layer. However, the water level at El Bote mine is set at the top of of the seventh layer because of pumping water from the mine tunnel which is 200m below the surface.

④ Meteorological Model

Annual precipitation is 400mm on the average. 95 percent of it precipitate during rainy season from May to September. Therefore, during 5 months, the precipitation is 380mm from May to September. During other 7 months the precipitation is 20mm.

Evaporation data are referred from New El Coco observation. Evaporation of it ranges 0.35 to 0.84mm/day.

Recharge rate is set as 0mm/day during dry season, 2mm/day during rainy season, by precipitation minus evaporation.

⑤ Recharge Discharge Model

Groundwater of El Bote mine is pumped 200m below the surface at the rate of 1,200m^3/day. The municipality well pumps 200m below the surface at the rate of 1,000m^3/day. The mineral dressing plant of El Bote mine discharges waste water at the rate of 1,000m^3/day.

These coordinates are (X1,Y29), (X26,Y12), (X24,Y11), respectively.

(3) Simulation Results

Fig.3-4-7 shows groundwater saturation maps. Rainy season map is of the 150th day, counted from the first day of rainy season. Dry season map is of the 360th day, which is end of dry season, counted from the first day of rainy season. In this maps, blue color zone is saturated with free water. In accordance with the changing blue to yellow, the saturation level decreases.

The alluvial deposits area (A site) shows high saturation degrees of the surface layers in rainy season compared with dry season. The mountain side (B site) show same saturation degrees in both rainy and dry seasons. This means not remarkable change of groundwater level ,but change of saturation degrees above the groundwater level. This difference of saturation is attributed to the small water level variation in both seasons.

Therefore, there is a strong suspicion that pollutants are stored in the surface layer, because the groundwater including eventwater moves in the top thin layer in the aquifer, under the variable depth of water table.

100% saturated zone is widely distributed in the surface layers on the C and D side ,compared with A side . El Bote Mine is located at weakly saturated zone of Site E, from which groundwater is pumped.

Influence of the El Bote river flow is clearly recognized down to the G site , below to the second and third layers ,and weakly to the fourth layer. The influence range is 7km west from the El Bote Mine, 2.5km wide, 80m deep.

The waste water the El Bote mine is discharged at the rate of 1,000m^3/day. Flow rate of the El Bote river is 1,200m3/day. Most of the flow is attributed to the waste water discharge. From the results of chemical water analysis, Water pollution is attributed to mineralization zone or the discharge from the other mines rather than El Bote Mine.

In either case, the contaminated water infiltrates down to the alluvial area (hill side). To prevent this infiltration, pollutants extraction and waste water recycle should be conducted not so as to discharge the waste water into El Bote river.

Fig.3-4-8 shows groundwater velocity plane and cross sectional maps. Rainy season map is of the 150th day, counted from the first day of rainy season. Dry season map is of the 360th day, which is end of dry season, counted from the first day of rainy season. The velocity is presented by X, Y, and Z components, that is NW-SE, NE-SW, and vertical directions, respectively. The length of segments is proportioned to the velocity.

The seventh layer maps of rainy season (the 150th day) indicates clear flow direction to the El Bote mine tunnel(E site). In the alluvial area (A), the velocity of Y component is remarkably larger than of X component. This indicates that the groundwater flows south-westward, because this flow direction is caused by the potential inclination from north-eastern mountain side to south-western alluvial hill side. The velocity of the dry season is weakly slower ,but has the same direction as the rainy season.

The municipal water well is situated at the site F on the map. Not observed the flow direction from El Bote mine to this site, because above-mentioned potential inclination prevents the flow direction from the El Bote mine to this well. Judging from this simulation, the direct influence of the waste water of El Bote mine is not considerable.

It is easy to estimate that polluted groundwater flows to the well faster than present rate of groundwater flow from mountain side to hill side, if pumping up too much groundwater to keep the balance of the groundwater potential distributions of present, for example, people needs much amounts of water for drinking and for industries in the Zacatecas city.

We certainly propose, therefore, to make a observation system of groundwater to know the behavior of polluted groundwater from the mining area. The cross section maps of the groundwater velocity show the down-flow in the surface layers, the up-flow in the deep layers, and lateral flow in apart from the mine. This lateral flow is rapid in the surface layers.

3-5 Soil

As the results of soil assay in this area, high levels of contamination by heavy metals were detected. Especially around the tailing dam, concentration of Cu, Pb and Zn is remarkable. These contamination was supposedly brought by multiple pollution sources like natural mineralization, dust particles carried away from the dam and effluents of mining activity in this region.

In the region west of the dam, contamination levels of the metals are lower than the others.

3-6 Tailing Dam

The purposes of the survey are to study about present situation of the deposition and drainage system,and to evaluate the stability against collapse of the dam in order to take measures against unstable conditions.

The examination was carried out based on the results of drilling test, laboratory soil test and field survey of the dam. As the results, following facts were clarified.

(1) The deposition and drainage system

The slime deposition in this dam has already been finished, and no surface water usually exists in the dam. However, rainwater is stagnant on the slime in rainy weather, the rainwater flows out scouring the slope of the dam. Moreover, slime deposits were also recognized to flow out with outflow of the water.

(2) Nature of the deposits

The deposits of the dam is considered to be classified into dam material (coarse grained) and inside deposits of the dam(fine grained). No marked difference was not recognized by laboratory soil test, it was clarified that the grain size of the dam material is bigger than the inside deposits and water content of the dam material is lower than that of the deposits.

Both the materials are classified as "silty sand", and are comparatively compact.

(3) Evaluation of the stability of the dam

As the result of stability calculation based on the survey data, minimum safety factor(Fs) at ordinary times is 0.664 and Fs during earthquake is 0.0498, respectively. By the safety factor, the situation of the dam is markedly unstable. The following two reasons of the unstable conditions are pointed out.

① As regards prevention power of the dam, the section of the dam is too small to prevent.

② The gradient of the slope of the lower reaches is steep.

Judging from the facts, it is necessary to take measures against the dam collapse.

(4) Judgement of the dangerousness by liquefaction

The examination was carried out based on the survey data. As the result, dangerousness by liquefaction is judged to be "Nothing".

3-7 Dust Problem

It is possible that the dust particles scattered by the wind from El Bote tailing dam have harmful effects on living conditions in and around the mining site. To analyse actual circumstances, various investigations were carried out with use of meteorological observation apparatus, dust collecting jars, low volume air samplers (LVS) and digital type dust monitors.

Especially in the dry season, violent sand storm blows almost continuously toward the north-eastern valley due to the heavy wind from south or south-west. There exists a highly concentrated zone of dust, 100m in width and 3 km in length in in this direction. Because of nearly constant wind direction, neither the city of Zacatecas nor the farmland west of the dam suffer from this dust problem at present. In the rainy season dust particles are hardly blown up. However, as some heavy metal elements are contained in the dust particles, it is required to carry out longer term measurement and study their influence on human body.

3-8 Summary of the Investigation

This area is formed on the Pimienta of Metasediments of Triassic Period. The River El Bote, main stream of the area, passes south of the El Bote mineral processing plant and tailing dam running toward northwest by west. As a result of the survey, ground water is likely to run underground along this river. In the rainy season ground water level rises by 0.6 ~ 0.8m with increased current movement.

Heavy metals are highly concentrated in surface water and soils almost all over the area because of natural mineralization. In soil samples, heavy metals like Cu, Pb, Zn, Fe, Cd, As and Hg are remarkably concentrated. In the samples of surface water Pb, Fe and Cd exceed the criterion limit of water supply standard set by EPA(USA) in many points. Especilly, sample B-R2 show very lower pH value of 2 with extraordinarily high content of metal ions. Since this sample was taken from a branch river, upper stream from the tailing dam, it is more likely affected by natural mineralization than the dam effluent. Furthermore, it may be suffered from other mining activity situated upstream from CFM.

Ground water is less contaminated than the surface, however, Pb and Fe exceed the criterion limit at several points. Cd is also near the limit. Cyanide has not been detected from surface and ground water during the survey period.

A part of the tailing dam embankment has already collapsed due to landslide. Thus, an urgent counterplan is required on entire embankment. Study from the soil property tests also led to a conclusion that the dam stability was in so dangerous condition. Furthermore, in the rainy season, water could run on the dam surface flowing over the embankment. It is inevitable to install suitable drainage system.

Influence of dust particles carried away by the wind from the tailing dam is another problem. In the dry season, violent sand storm blows almost continuously toward the northeastern valley due to heavy wind from south or south-west. This greatly affects living conditions in the vicinity. Because of nearly constant wind direction, neither the city of zacatecas nor the farmland west of the dam suffer from this dust problem at present. However, as the dust particles contain some metal elements like Pb and Zn, it is required to carry out longer term measurement and study the influence on human body. Without reference to further study some countermeasures against dust scattering should be done urgently.

3-9 Measures against Mine Pollution

3-9-1 Measures against the dam collapse

The following two measures are necessary to increase the stability of the dam.

① Make the dam slope gentle.

② Make the dam section larger to increase prevention power.

As the result, counter weight fill work is most suitable as the measure against collapse of this dam. Rock fragments are used as the banking material. The section of the counter weight fill work is shown in Fig.3-9-1. The minimum safety factor(Fs) in this section at ordinary times is 1.873 and Fs during earthquake is 1.278, respectively. The sta-bility by this counter weight fill work is judged to be "No Problem".

3-9-2 Measures against Drainage of the Dam

As the slime deposition in this dam has already finished, no slime is dischaged. Therefore, the object of the drainage of this dam is only collection and discharge of rainwater. In case of El Bote tailing dam, inflow of rainwater from the outside of the dam is negligible.

Therefore, only the drainage of rainwater fallen in the dam is examined.

The covering with soil 30 ~ 50 cm in thickness on the surface of the dam in order to avoid to the direct contact of rainwater with polluted soil.

After the covering, drainage channels are installed. The drainage channels in the 1st dam and 2nd dam are installed individually. U type corrugated flume is used as the drainage channel inside of the dam.The discharged water outside of the dam is led to the outlet through the poly-ethylene pipe. The plan and the section of the drainage are shown in Fig.3-9-2 and Fig.3-9-3, respectively.

3-9-3 Measure against Dust Scattering

Powder dust due to drying of the dam surface scatters in the dry season. The following three works for prevention from the powder dust scattering are considered.

(1) Sprinkling work: to sprikle water with sprinkler.

(2) Surface hardening work: to harden the surface by sprinkling of chemical liquid.

(3) Planting treatment: to plant vegetation with spraying of seeds or turfing lawns

(4) Soil covering work: to cover the dam surface with soil.

The permanent measures against pollution are necessary, because the use of this tailing dam has already been finished. And, taking measures against the dam collapse and drainage problem are also necessary together with the measures against dust scattering at the same time. As the results of examination with consideration to the issues mentioned above, soil covering work is considered to be the most suitable mesure against powder dust scattering.

As regards soil covering work, counter weight fill work on the surface of the dam slope and soil covering work on the upper surface of the dam are performed, according to the chapters "3-9-1 Measures againstthe Dam Collapse "and "3-9-2 Measures against Drainage of the Dam".

3-9-4 Measures against Groundwater Pollution

By the hydraulic observation, El Bote river water percolates underground in the downstream area from El Bote tailing dam. Chemical contents of river water and groundwater is higher than the usual background due to influence of veins and mineralization zone. But, Infiltration of waste water from tailing dam and mineral dresssing plant does not affect to the groundwater pollution.

However, it is considered that the polluted groundwater flows down to the pumping up well of the Zacatecas city easily, with the condition of ① small amounts of rainfall in long terms and
② increasing of population and industries in the Zacatecas city
after the consideration of
① formerly said groundwater flow characteristics, that is, event water runs on the surface of aquifer easily, and
② the present distribution of groundwater potential is formed by small taking of groundwater from the pumping up well. We have make a observation of groundwater behavior between the El Bote mine and this well, and monitor the quality of the pumping up groundwater.

The waste water of the mine does not control the groundwater property at the present time, but the following measures should be done to prevent the pollution in the future.

The first measure is to cover tailing dam by soil covering and planting to decrease dissolution of dam material by infiltration of rainwater. The second is to flatten the deposit plane for rapid evaporation of waste water. The third is waste water recycle to prevent the infiltration of pollutant to the downstream.

3-9-5 Work Program and Construction Cost

Work program and construction cost for completion of each countermeasure plan are roughly estimated as follows.

(1) Work program

Work program is illustrated in the figure shown below.

Type of Work	Amount	5month 10month 15month 20month
Counter Weight Fill Work	580,000 m^3	22 month
Soil Covering Work	20,000 m^3	2.2month
Drainage Inside The Dam	290 m	0.8month
Drainage Outside The Dam	450 m	0.2month

(2) Construction Cost

According to the construction basis in Mexico, total costs are estimated as follows.

Type of Work	Amount	Unit Cost (US$)	Total Cost (US$)
Countermeasures against			
Dam Collapse and Dust Problem			
· Counter Weight Fill Work	580,000 m^3	6.3	3,654,000
Soil Covering Work	20,000 m^3	4.0	80,000
(Sub Total)			(3,734,000)
Drainage			
Inside the Dam	290 m	120.0	35,000
Outside the Dam	450 m	113.3	51,000
(Sub Total)			(86,000)
TOTAL			3,820,000

4. SURVEY RESULTS AND COUNTERMEASURES IN THE AREA OF PARRAL

4-1 General Situation

Parral mineral processing plant is located 5km west of Hidalgo del Parral. It is about 1,800m above the sea level. Average temperature throughout a year is 14～15°C but goes down to 5°C in the winter season. The rainy season starts in May and runs till September for five months. The rest is almost dry. Annual rainfall averages 600mm. Throughout the dry season the west wind blows hard.

Parral plant was started in 1967 by an union type organization and then has been operated by CFM since 1983. State of Chihuahua ranks the top position in production of Ag,Pb and Zn, and the second in Cu in the United Mexican States. In Parral area are located about 30 medium and small size metal mines producing Au, Ag, Pb and Zn. The Parral plant purchases these crude ores to process them by the following two different circuits. Thus, Pb and Zn concentrates are recovered by flotation from the sulfide ores and Au-Ag precipitate through cyanidation from the oxide ores. Capacity of the flotation and cyanidation plants are 400 and 240 tons a day respectively.

In the flotation plant bulk or differential flotation method is employed depending upon metal contents in the crude ore, just like El Bote plant. In case of differential flotation about 200kg of sodium cyanide is added per month into the flotation pulp. Cyanidation is operated intermittently, also depending on metal values and other conditions. when in operation considerable amount of NaCN, 1,500～2,000kg per month is added into the circuit. This could seriously affect on environmental water pollution.

In the tailing dam a large volume of slime(waste) material containing cyanide have been dumped for long. It is urgent to take some countermeasures to prevent these waste materials and effluent from flowing into nearby rivers.

Water consumption in the plant is about 600m^3 a day, of which 400m^3 is supplied as fresh water from the underground mine and the rest is recycled from the flotation tailing by recovering as thickener overflow.

4-2 Geology

The basement of the survey area is Parral Formation of early Cretaceous (Fig.4-2-1). The strike and the dip of the formation are NW-SE and 40° ~ 60° NE, respectively. The formation is mainly composed of compact and bedded shale layers which partly intercalates with sandstone seams. The Pliocene andesite lava flows cover the formation with unconformity. Acidic rocks such as dacites and rhyolites intrude into the former two layers, and form low belt-type elongated hill area from south to north.

After Neogene, hard intrusive rocks are exposed by weathering and erosion, and form unique topography characterized by residual hills resulted from selective erosion caused by the differences of rock components.

There are terrace deposits along Parral River with over 5m in thickness. Clayey soil is mined in the northern side of the river, north of the Parral tailing dam,to manufacture bricks. The existence of several faults is structurally presumed in the southern site to cut the Parral Formation and acidic rocks,with the direction of ENE-WSW. The nature of the faults is not well known, but, judging from the topography,it is considered that the north-western side is comparatively subsided.

4-3 Electrical Prospecting

The Schulumberger's Electrode Arrey was used in the this survey which is the same method in El Bote Area. The analysed resistivity is classified into four groups as El Bote Area (Fig.4-3-1).

L zone shows low resistivity, M zone shows medium resistivity, H zone shows high resistivity and S zone shows complex zone of low and high resistivity.

S zone forms the surface in thickness of 5m ~ 25m, the average thickness is 10m. Thick part of S zone is located around Parral dressing plant and the area along Parral River. S zone is composed of the terrace deposits of recent and soil layer of weathered Cretaceous System and Tertiary System.

L zone forms the lower part of S zone around 1-12-28 line. Parral dressing plant and tailing dam is located along the line, and pumping up ground water from the underground of 400m of station 19. In the east and west side of the line, resistivity zone gradually changes to M zone or H zone. L zone is composed of shale of Cretaceous System. The L zone is formed in the lower part of S zone more than 150m thickness. L zone is composed of shale of Cretaceous.

M zone is formed around L zone and along Parral River. M zone is composed of shale of Cretaceous System, andesite lavas and dacite intrusive rocks of Tertiary System.

H zone is formed in the area of shale and dacite intrusive area of Tertiary System in the eastern side of the dressing plant, and is formed in the area of andesite lavas of Tertiary System in the north-eastern part of Parral dressing plant.

The movement of groundwater was observed in a part of M zone, but was not observed in H zone. Therefore, it is presumed that M zone is aquitard, H zone is aquiclude or aquifuge.

L zone (low resistivity zone) distributes in the western area bordered andesite intrusives which lays north to the south, and M zone (medium resistivity zone) and H zone (high resistivity zone) distributes in the eastern area in geological structure. Parral River develops cutting the structure extending north to south, L zone is also formed along the river. It is considered that the L zone is controlled by main structure extending from east to west.

4-4 Hydrology

Parral river gathers two branches which locate in the east and the west side of the tailing dam to the north, and flow down meandering from west to the east. The purpose of this survey is studying the effect of tailing dam of CFM processing plant on the surface and groundwater. The survey of streamflow and water quality analysis were carried out at the points shown in Fig.4-4-1.

4-4-1 The Surface Water

(1) Streamflow of Surface Water

The measurement of current velocity was carried out at No.1 ~ No.5 in Fig.4-4-1. The results are shown in Table 4-4-1 and Fig.4-4-2.

Most of the rivers in the survey area except the main stream of Parral River dries up both in dry and rainy season. The flow rate of main stream of Parral River decreases in dry season, and the river is shallow enough to cross to on foot. However,the flow rate of the main stream of Parral River increases and the river changes to violent stream by rapid increasing of precipitation in the upper stream area. According to the rising up of water level,the feature of flowing also remarkably changes. The waste water from the plant of private mine flows into the river near P-R1 point and the waste water from the underground mine is discharged into Parral River at the northern bank of the river.

The main stream of Parral River dries up in the dry season. On the other hand, it changes to turbid current in the rainy season. Seasonal differences of the flow rate is remarkable in the main stream of Parral River as above mentioned. The order of the flow rate in the dry season is 10^3 m^3/day. On the other hand, in the rainy season, it increases to 10^6 m^3/day. However,the flow rate near the tailing dam has no seasonal change. The reason is considered that precipitation amount of rainy season and dry season remarkably varies in the upper stream area of Parral River in spite of small amount of precipitation in this area.

(2) Water Quality of Surface water

The analysis data of the samples of surface water are shown in Table 4-4-3. Background and water supply ceiling of pollutants are shown in Table 4-4-2.

Point P-R3 is located in the upper reaches of CMF plant. The water in this area is comparatively clear which does not include pollutants except Fe in the dry season. The surface water flowing in the river is transparent. The surface water changes to muddy and it includes almost all the pollutants except Cr^{+6} and CN in the rainy season. Particularly, Pb, Fe and Hg contents exceed the upper limit of the Environmental Standard of Pollutants Content in the rainy season.

P-R4 point locates in the junction of Parral River and the southern branch which the waste water from CMF plant and private plant are discharged. Various pollutants are detected having no connection with the season. It means that the pollutants are continuously supplied from the southern branch. By the data of the rainy season, the inclination is not obvious due to the supply of the same pollutants from the upper reaches of Parral River. By the data in the rainy season, pollutants such as Cu, Pb, Zn, Fe, Cd, Total Cr, Cr^{+6} and CN are obviously supplied from this branch. Particularly, CN does not naturally exist but is used in C.M.F.dressing plant. By the fact, the pollution up to P-R4 point is obviously affected by the waste water from CMF plant. As CN is not supplied from the upper reaches of Parral River, CN is considered not to be detected due to dilution by the river water which markedly increases in the rainy season.

P-W1 is from the CMF plant. All the waste water of the plant is discharged to the tailing dam. The chemical components of the waste water and the surface water at P-D1 show almost the same nature.

For mine water pumped up from P-M3 point is used as milling water in this plant, the surface water is obviously affected by the mine water. The chemical components of the samples of P-W1 and P-D1 were affected mostly by chemical components of milling ore and amounts of regents for milling.

4-4-2 Groundwater

(1) Streamflow of Groundwater

4 observation holes, 3 of the holes of B-1 ~ B-3 locate along the Parral River from the lower reaches to the upper reaches, and B-4 hole near the curving point, were drilled. The results are shown in Table4-4-4, Fig.4-4-3 and Fig4-4-4.

A Low resistivity zone is cut by the area of intrusive rocks and the zone only continues in EL.1,720 m. In EL.1,710 m and EL.1,730 m.
The aquiferous layer is the same layer as of low resistivity zone of 150 Ω · m. Judging from the topography, groundwater is considered to flow to NE direction.

The seasonal change of the groundwater appears in the change of average current speed. The groundwater level markedly differs in the dry season and in the rainy season. The groundwater level in the rainy season rose by approximately 0.2 m from that of the dry season in B-1 hole. There is no water in B-2 hole in the dry season, but, the groundwater existed in approximately 5.3 ~ 5.8m from the bottom in the rainy season. In B-3 hole, the difference of the groundwater table became more marked, and the difference reaches approximately 19.3 ~ 19.6 m. Therefore,as the marked falling of the groundwater table is considered to occur in the dry season around the CMF plant in the survey area, the flow rate naturally decreases and the effect is estimated to appear in the area where the ground water flows down. The major reason of the decrease in the flow is due to pumping up the large amount of mine water at P-M1

~ P-M3. For eliminating this effect of pumping up, it is necessary to keep the groundwater level around B-3 hole over EL.1,730m (GL.-19.15m).

(2) Water Quality of Groundwater

Groundwater is sampled at P-B1 ~ P-B4 and P-M1 ~ P-M3 in order to analyse the contents of ten kinds of heavy metals including measurement of pH. Table 4-4-5 shows the results of chemical analysis.

The contents of pollutants at P-B1(B-1 hole) are generally higher than the contents of surface water at P-R5 in spite of neighboring P-R5.Pb and Fe contents in the dry season exceed the upper limit of the Environmental Pollutants Content.

In the groundwater at P-B3(B-3 hole), Pb and Fe content exceed the upper limit of the Environmental Pollutants Content in the dry season.

Comparing with the component of the groundwater at P-M3 which locates in the south-west of P-B3, Zn and Cd contents are markedly higher than that of the other samples. There is same nature that Pb, Zn, Fe and Cd contents exceed the upper limit of the Environmental Pollutants Content. This means the groundwater of the same nature, which pumping up near P-M3 exists in shallow part at P-B3.

P-M1 and P-M2 locate in the western side of Parral River. The chemical components and their contents are resemble closely. It is considered that the samples are collected in the same layer.

The groundwater at P-M3 contains Pb, Zn, Fe, Cd and Hg exceeding the upper limit of the Environmental Standard. The Surface water is affected by the groundwater at P-B3 as already mentioned. Because the ground water is used as the milling water, the surface water in the tailing dams also affected.

4-4-3 Groundwater Flow System Simulation

Optimum simulation blocks of physical and hydraulic properties are modelled around the Parral Mine. A Groundwater flow system is simulated under the condition of these properties which are obtained by integrating the results of meteorological, geological, hydrologial surveys and soil test.

By this simulation, clarified are water table, flow direction and flow speed. Simulation results are contributed to calculate effective goundwater harness, waste water recycle and mining pollutant dispersion.

(1) Simulation Method

A numerical simulation for groundwater flow is conducted by the use of three dimension simulator "GWS3D2P" originally developed by Dr. Hiroyuki Tosaka of Tokyo University.

(2) Simulation Model

① Block Model

Simulation area takes the form of rectangular, 3.0km wide in the north-south direction and 2.0km wide in the east-west direction (Fig.4-4-5). The Parral mine is located in the southern side of the area. From this mine tunnel the groundwater is pumped up for mine plants, slime and the sewerage system of Parral municipality. This pumping brings drawdown of grounwater level.

The veins and fissures mainly strike north-south and subordinately strike east-west around the Parral ore deposits. These veins and fissures control groundwater flow direction. The simulation area is framed to predict the drawdown and waste water dispersion. Consequently, the direction of the simulation area is in accordance with the vein strike. and the area is decided to cover the mine and the pump site. The simulation depth is decided to 1,500m above sea level, because of the pumping 150m below the surface at the municipality water supply site (P-M3 site in Fig.4-4-6) in the mine tunnel.

The simulation area is divided into 30 blocks in the north-south direction, 20 blocks in the east-west direction. The block size is evenly 100m × 100m wide . X and Y axes of this area are in the directions of east-west and north-south, respectively. The coordinates of the south-west end and north-east end are (X1,Y1), (X20,Y30), respectively.

Vertically, the area is divided into 9 underground layers and 1 atmoshere layer, total 10 layers. The uppermost atmosphere layer is the first layer named Z1. Surface layers are 10 to 20m thick, deep site layers are 50m thick. The height of each block is represented by the elevation of the center of the block.

② Permeability and Porosity Model

Permeability and porosity of each simulation block are determined by integrating the geological,geophysical and hydraulic properties.

Geologically, the southern part of the simulation area is underlain by Cretaceous mudstones. The northern part is underlain by Tertiary andesite lavas and its pyroclastic rocks. The parral river is running across the boundary of both parts. Dacite intrudes these Cretaceous and Tertiary rocks in the north-south direction. These rocks are usually compact and not permeable except around the veins and fissures along the Parral river.

As the results of the electrical prospecting and boring observation, low resistivity zone and low-high complex resistivity zone correspond to aquifer. Intermediate resistivity zone corresponds to aquitard. High resistivity zone corresponds to aquiclude and aquifuge.

As compared with geology and geological structure, The aquifer zone is equivalent to vein, boundary of the intrusive rock, sandy terrace deposit ,and fault zone. The aquitard is equivalent to weathered overburden and fault periphery. The aquiclude is equivalent to surface soil and calyey terrace deposit. The aquifuge is equivalent to the compact Cretaceous, Tertiary or intrusive rocks.

As the results of grain size distribution, the aquiclude permeability coefficient of clayey terrace deposit ranges 10^{-5} to 10^{-7}cm/sec (BR-1 to BR-7). 10^{-5}cm/sec is dominant. Consequently, the aquiclude permeability coefficient is set to 10^{-5}cm/sec.

Around the Parral mine, several veins and faults are developed in the Cretaceous and Tertiary rocks. Permeability coefficient of these fractures is different from its peripheral rocks. this permeability coefficient of these fractures is named fracture permeability coefficient (pkf). To the contrary, the permeability coefficient of the peripheral rocks is named matrix permeability coefficient (pkm). From this basis, The average permeability coefficient (K) of the simulation block is calculated as follows.

$$K=(hef/\triangle X)\times pkf+(1-hef/\triangle X)\times pkm$$

$\triangle X$:width of fracture

hef:width of block

The porosity is also distinguished fracture porosity (porf) from matrix porosity (porm) and is given the value corresponds to the hydraulic observation.

Table 4-4-6 shows the permeability coefficient and porosity model, and

Fig.4-4-6 shows the rock classification maps on the basis of this concept. At the Parral mine, several big veins are embedded. The veins have been mined 1 km long along the strikes, 200m wide and 200m deep below the surface. So, the permeability coefficient of the vein zone is presumed to be 10^{-3}cm/sec, because the vein zone corresponds to big fault zone.

Fig.4-4-6 shows rock classification. In this plane map (X-Y CROSS SECTIONAL VIEW), the coordinates of left-bottom and right-top ends are (X1,Y1) and (X20,Y30), respectively. In the cross section (Y-Z CROSS SECTIONAL VIEW), left and right ends are Y30 and Y1, respectively. The legend No. of Table 4-4-6 corresponds to it of Fig.4-4-6.

③ Hydraulic Model

The Parral river flow down from west to east near the Parral mine. As Fig.4-4-1 shows, No.4 river flow measuring point is situated upstream of the Parral river. At this No.4 point, flow rate is 1,453m^3/day in the dry season and $1.967 \times 10^5 m^3$/day in the rainy season. The flow rate is various ,because its large drainage basin area collect large quantities of the river water. Therefore, The flow rate $1.967 \times 10^5 m^3$/day is set in the rainy season during June to October, 1,453m^3/day in the dry season during November to May at No.4 point for simulation.

The tributary stream running eastern side of the Parral mine has no riverwater through the year. At this stream the initial flow rate is not set for simulation.

Each Water level of the observation wells is set for simulation as to be situated at the top of the third layer counted from atmosphere layer. However, at the several undergrounds of the Parral mine, groundwater is pumped up as Fig.4-4-5 shows. Therefore, the water level of the P-M1 and P-M2 pumping sites are set at the top of the sixth layer, which water levels are 82m and 65m below the surface, respectively The P-M3 site's is set at the top of the seventh layers, which water level is 150m below the surface.

As the result of chemical analysis of groundwater, P-M3 water shows strongly acid of pH 4.8 and high chemical components in contrast with the riverwater, P-M1 and P-M2 sites groundwater which show weakly alkaline. From this fact, the P-M4 water, near the P-M3 site, is inferred to be deep seated origin similar to mineral spring and to flow upwards through the vein at the rate of 2,000m^3/day, 200m below the surface, 1,550m above sea level. The P-M4 site is set at the top of the ninth layers,

④ Meteorological Model

Annual precipitation is 500mm on the average during 1977 to 1990. 95 percent of it precipitate during rainy season from June to October. Therefore, during these 5 months, the precipitation is 475mm from June to October. During other 7 months the precipitation is 25mm.

Evaporation data are referred from New El Coco observation. Evaporation of it ranges 0.35 to 0.84mm/day.

Recharge rate is set as 0mm/day during dry season, 2mm/day during rainy season, by precipitaion minus evaporation.

⑤ Recharge Discharge Model

Groundwater of the Parral mine is pumped up at three sites. P-M1 site is at the rate of 450m^3/day, from the sixth simulation layer, and 82m below the surface. P-M2 site is 450m^3/day, the sixth layer, and 65m below the surface. P-M3 site is 7,800m^3/day, the seventh layer, and 150m below the surface. The mineral dressing plant of the Parall mine discharges waste water at the rate of 400 m^3/day from P-W1 site, which is the second simulation layer.

(3)Simulation Results

Fig.4-4-7 shows groundwater saturation map. Rainy season map is of the 150th day, counted from the first day of rainy season. Dry season map is the 360th day, counted from the first day of rainy season. In this maps, blue color is 100% saturated with free water. In accordance with the changing blue to brown, the saturation level decreases.

The Parral mine area (Site A on the map) shows higher saturation degrees of the surface layers of the second and the third layers in the rainy season, compared with the dry season. It means the higher water level in the rainy season than dry season in the Parral mine area. But,in the dry season, pumping the groundwater from the mine causes drawdown of the water level. The influence extends to the opposite northern side over the Parral river and eastern side of the mine. This influence decreases in the rainy season.

On the other hand, the downward area along the Parral river (site B)shows the same saturation level during both the dry and rainy seasons as shown in the third layer.

Fig.4-4-8 shows groundwater velocity plane and cross sectional map. The rainy season map is of the 150th day, and the dry season map is of the 360th day, counted from the first day from the rainy season, respectively

The velocity is presented by X, Y, and Z components, i.e. E-W, N-S, and vertical direction, respectively.

The fourth layers map of the rainy season indicates clear flow directions which concentrates to the Parral mine tunnel. On the northern and southern side of the mine, flow velocity is remarkable. From the composite of X and Y components, The flow directions are south-eastward and north-eastward and westward on the northern, southern, and eastern side of the mine, respectively. At the boring B-3 site, the flow direction shows east because of pumping up from the mine tunnel and this flow is opposite direction to the down-flow the Parral river.

The boring B-1,2,4 sites don't show remarkable groundwater flow. This results correspond with the field observation of micro flow measurement in the boring holes.

The influence of the pumping from the mine ranges within a radius of 1km from the mine tunnel judging from this simulation and micro flow measurements data. The eastern area apart from the mine shows weak flow from the high to the low place which flow is controlled by the topography. The fourth layers map of the dry season indicates the same flow directions as the rainy season ,but the velocity and influence area is small. The eastern area apart from the mine shows no flow in the dry season.

The cross sectional maps shows down-flow in the surface layers and up-flows in the deep layers around the mine tunnel, apart from the tunnel,lateral flow is recognized. This lateral flow is rapid in the surface layers.

The mineral dressing waste water and the tailing dam waste water are discharged at the sites of PW and PD on the map, respectively These sites underground is not so saturated by the groundwater that infiltrate easily these waste water.

No anomaly from the waste water infiltration is recognized from this time chemical tests because of owing the large portion of shallow groundwater flow to the small infiltration flow of waste water.

Even though not critical observation, The suspicion of actual influence would arise in the case of the drawdown of the water level in the dry season and increasing of the waste water discharge to the river or underground, judging from this simulation.

Consequently, The extraction of pollutants from the waste water and the recycle of waste water should be conducted to prevent the discharged of pollutants to the river and infiltration underground.

4-5 Soil

From the assay results of the soil samples and the extracted solution, it is obvious that the soils in this area are highly contaminated with harmful metals as well as cyanide. It is also remarkable that cyanides are not decomposed in the soil but remain in stable condition after aging.

4-6 Tailing Dam

The purpose of the survey are to study about present situation of the deposition and drainage system, and to evaluate the stability against collapse of the dam in order to take measures against unstable conditions.

The examination was carried out based on the results of drilling test, laboratory soil test and field survey of the dam,

As the results, following facts were clarified.

(1) The deposition and drainage system

The height of this dam are about 25 m in the eastern side and about 2 m in the western side, respectively. The use of the eastern part of the dam has already finished. The slime deposition continues in the western part. The slime is discharged to deposit toward the western part of the dam through the sludge pipe installed in the central part of the dam. Therefore, the stagnant water generally exists. The water sometimes overflows the dam to the outside by the water level rising due to rainfall. No slime is discharged in the eastern part. However, surface water is stagnant in the rainy season, the water often overflows the dam to the outside.

(2) Nature of the deposits

The dam material and deposits are classified into "silty sand". No marked difference was not recognized by laboratory soil test. The inside deposits includes slightly much silty component than the dam material. The water content of inside deposits is higher than that of the dam material. Both of them are compact, but, both the grain size distributions are poor and easily take on liquefaction.

(3) Evaluation of the stability of the dam

As the result of stability calculation based on the survey data, minimum safety factor(Fs) at ordinary times is 0.859 and Fs during earthquake is 0.701, respectively. By the safety factor, the situation of the dam is markedly unstable. The following two reasons of the unstable conditions are considered.

① As regards prevention power of the dam. the section of the dam is too small to prevent.

② The gradient of the slope of the lower reaches is steep.

Judging from the facts,it is necessary to take measures against the dam collapse.

(4) Judgement of the dangerousness by liquefaction

The examination was carried out based on the survey data. As the result, dangerousness by liquefaction is judged to be "Nothing".

4-7 Dust Problem

In this area measurement of dust was carried out in the rainy season. However, neither characteristic features of dust distribution nor dust scattering was observed in this season. This is because the soil surface was so wet as to depress dust scattering from the dam and the wind velocity hardly exceeds 5 m/sec. On the other hand, in the dry season sand storm was visibly seen when the wind blows hard. It is possible that some particles reach the city falling down to the residential area.

4-8 Summary of the Investigation

This area is formed on the Parral Formation of early Cretaceous Period and is mainly composed of shale layers partly accompanied with thin sandstone seams. The River Parral, the main stream of the area, runs zigzagging from west to east merging some branch rivers close to the tailing dams. The River Parral shows a big variation in water volume throughout a year, almost draught in the dry season, while muddy and rushing in the rainy. Ground water also rises in the rainy season with increased current movement. The ground water stream is likely to flow from the aquifer below the dam site toward north-east direction.

Into the Parral River flows the waste water from CFM mineral processing plant and other effluent of near-by privately owned plants as well. Among the surface water samples, P-R3, taken from the upper-most stream,was clear and metal ion free in the dry season. On the other hand, in the rainy season, all the heavy metal ions analysed were found in the sample. This results, by rain-fall, from washout of soils and bank deposits into the river. In the samples of P-R2, taken from the branch river to the south and P-R4 from its merging point into the main Parral River, higher levels of metal ions and cyanide are detected. These result from the effluence of CFM plant and dam as well as other private plants. Samples P-D1 and P-W1 represent filtrate solutions of CFM plant tailing and dam deposits respectively. Since Cu, Zn and Cr are highly contained in both of them, these pollutants are assigned to CFM mining operation. On the other hand, Fe and As may result from other sources than CFM. In the sample of P-R5, taken from the downstream of the river,contents of heavy metals are considerably lowered because of dilution.

Ground water samples also contain all heavy metals but Cr^{6+} and these could be derived from mineralization zone widely distributed in this area. Cyanide has not been detected in the ground water samples. This suggests that penetrated water from the dam is unlikely affect the groundwater.

In the soil samples heavy metals are highly concentrated. Especially, Cu, Pb, Zn and As are contained at remarkably high levels at some points.

Some countermeasures are urgently required to prevent collapse of the tailing dam embankment, because its stability was found so dangerously as in El Bote. Furthermore, in the rainy season, dam water level might increase and overflow the embankment. Suitable drainage system is required.

Influence of dust particles carried away by the wind from the dam was not recognized during the rainy season. In the previous dry season measurement of dust concentration was practically impossible due to time shortage, however, sand storm was visually observed so often.
Consequently, some countermeasures are inevitable as in El Bote tailing dam.

4-9 Measures against Mine Pollution

The following two measures are necessary to the stability of the dam.

① Make the dam slope gentle.

② Make the dam section larger to increase prevention power.

4-9-1 Measures against the dam collapse

This dam is comparatively low in height and the dam material is well compact in comparison with those of El Bote tailing dam. There is no stagnant water both in the dry season and the rainy season. Therefore, earth removal work together with counter weight fill work is most suitable as measure of the dam collapse. The section of the work as countermeasure is shown in Fig.4-9-1. Rock fragments are used as the material of counter weight fill work. The minimum safety factor in this section at ordinary times is 1.909 and during earthquake is 1.293. The stability against collapse is judged to be "No Problem".

4-9-2 Measures against Drainage of the Dam

The deposition in the eastern side of this dam has already finished, but, the slime has been discharging in the western part. Therefore, the drainage of the eastern part and that of the western part are installed individually as the inside drainages of the dam. In addition to the inside drainages, drainage of outside of the dam is installed in order to avoid the inflow of the rainwater from the southern slope of the hill.

(1) The eastern drainage inside of the dam

The drainage is installed after the covering with soil on the dam surface as the same in El Bote tailing dam, because the slime deposition in the eastern side of this dam has already been finished. U type corrugated flume is used as the drainage channel.

(2) The western drainage inside of the dam

The water on the deposits and rainwater are dischaged by inclined sluice way because the slime has been depositing in the western part. The discharged water is led to the outlet through polyethylene pipe. The water cannot be directly discharged into the river, because it is polluted.

(3) The drainage outside of the dam

The canal is constructed on the southern slope of the hill by excavation. The water through the canal joins that through the discharged water from the eastern part of the dam, and finally flows into the river.

The plan and the section of the drainage are shown in Fig.4-9-2 and 4-9-3, respectively.

4-9-3 Measures against dust scattering

Powder dust scatters due to drying of the dam surface in the dry season. The same consideration in case of El Bote tailing dam is necessary, because the slime deposition in the central to the eastern part of Parral tailing dam has already been finished. Therefore, soil covering work on the dam slope and the upper surface of the dam is the most suitable as the countermeasure.

As regards soil covering work, it is already explained in the chapters"4-9-1 Measures against the Dam Collapse" and "4-9-2 Measures against Drainage of the Dam".

Soil covering work is the most suitable as the measures against powder dust scattering for the central to the western part of the dam where slime deposition continues at present and will continue in future. Covering with soil on the surface of the dam slope is performed every 1 ~ 2 m in height at any time. After the time when the height of the dam reaches the upper limit and deposition is finished, the upper surface of the dam is covered with soil. The depositing surface is considered to be wet by discharged water with slime. For the dry part where powder dust comes out , water is sprinkled with sprinkler.

4-9-4 Final Treatment of Waste Water

The waste water that includes cyanide ion cannot be discharged into the river without decomposing of cyanide by some methods. Although there are many treatment methods, the most popular method is the decomposing and oxidation of cyanide by sodium hypochloride(NaClO) dosing in waste water in alkaline environment. There are reactions of the following two stages.

$$NaCN + NaClO = NaCNO + NaCl$$

$$2NaCNO + 3NaClO + H_2O = 2NaHCO_3 + 3NaCl + N_2$$

Two reaction tanks are usually used. The solution is agitated during 10～15 minutes in each tank. The treated water can be discharged into the river.

4-9-5 Measures against Groundwater Pollution

According to the hydraulic observation, the Parral river is losing river in the dry season, but change to gaining river in the rainy season. This losing means that infiltration rate exceeds recharge rate. The gaining means that recharge rate exceed infiltration rate. Eventually, in the dry season surface water easily infiltrate underground. In the rainy season it does not infiltrate so much ,but flows in to the river and pollutants would be transported to the long distance down to the Parral city.

Consequently, to prevent of the underground pollution, the next measures should be conducted. The first measure is to cover tailing dam by soil covering method and planting in the same way as El Bote mine. The second is to set up drainage system and a simple deposition pond. The third is to take waste water recycle system, so that the waste water from the tailing dam can not flow into the Parral river.

We suggest that to make a deposition (settling) pond between the tailing dam and Parral river and connect it to the drainages from the dam,

① to expand the evaporating area in the dry season, and

② to prevailing the discharge of tailings with an unexpected big storm rainfall in the rainy season.

This plan play a significant role in the prevailing sub-system as "prevailing the *transportation of pollutants by the Parral river*".

Groundwater from the tunnel of the Parral mine indicates strongly acid. This water is pumped up and used for the mine plant and sewerage system of Parral municipality. This water is no adequate to drink. Chemical composition of this water is anomalous compared to surface water or shallow groundwater. It is thought that this groundwater is deep-seated origin.

The Parral river runs in the upside of this area. It is considered that there exists no deep polluted groundwater in the shallow aquifer, because the unconfined groundwater consists by water that originate in rainwater, from the view points of topography and river morphology.

To improve this water quality , new shallow aquifer along the Parral river should be utilized by boring work, because more clean groundwater can be got.

4-9-6 Work Program and Construction Cost

Work program and construction cost for completion of each countermeasure plan on the tailing dam are roughly estimated as follows.

(1) Work program

Work program is illustrated in the following figure.

Type of Work	Amount	5 month	10 month
Earth Removal Work	14,000 m^3	2.5 month	
Counter Weight Fill Work	66,000 m^3	4 month	
Soil Covering Work	6,000 m^3	0.6 month	
Drainage Inside The Dam	300 m	0.9 month	
Drainage Outside The Dam	780 m	1 month	
Temporary Passage	100 m	0.2 month	

(2) Construction Cost

According to the construction basis in Mexico, total costs are estimated as follows.

Type of Work	Amount	Unit Cost (US$)	Total Cost (US$)
Countermeasures against			
Dam Collapse and Dust Problem			
Earth Removal Work	14,000 m^3	1.7	24,000
Counter Weight Fill Work	66,000 m^3	6.3	416,000
Soil Covering Work	6,000 m^3	4.0	24,000
(Sub Total)			(464,000)
Drainage			
Inside the Dam	300 m	120.0	36,000
Outside the Dam	780 m	113.3	88,000
(Sub Total)			(124,000)
TOTAL			588,000

Then, for chemical treatment of the waste water, main equipment and their purchase prices are described below. If the Alkali Chlorination method is adopted to treat approximately 200m^3 per day of waste water, they are roughly estimated as follows. The operation costs are not included.

Main Equipment and Prices for the Alkali Chlorination Method

Equipment	Specification	Unit	Unit Price (US$)	Total(US$)
Reaction Tank	1,800×1,800mm, SS made with agitator	2	15,000	30,000
Reagent Feeding Tank	1,000×1,000mm, SS made with agitator	2	6,000	12,000
Reagent Feeding Tank	1,000×1,000mm, SS made FRP lining, with agitator	1	7,000	7,000
Reagent Feeding Pump	Plunger Type	3	8,000	24,000
Process Control System	pH Regulators and others	1 set		70,000
Piping and Others		1 set		7,000
Total				150,000

It will take about eight months before completion, i.e. approximately seven months of delivery and one month of setting up respectively.

5. SURVEY RESULTS AND COUNTERMEASURES IN THE AREA OF NEW EL COCO

5-1 *General Situation*

The present El Coco mineral processing plant is located about 80km east-north-east of Mazatlan city. New Plant and tailing dam are projected in the area closer to Mazatlan by 20km and about 200m above the sea level. This region is within Sabanna zone. Average temperature throughout a year is 24.5° C and in the summer season exceeds 40° C at times. The rainy season starts in June running for five months till October. The rest of the year is almost dry. Annual rainfall averages about 800mm. This region is abundant in vegetation like broad-leaved trees.

The present plant was built in 1979 with capacity of 150 tons a day. Since it is located on the middle slope of a narrow valley, the plant has encountered much difficulties such as ore and concentrate transportation, limited tailing dam capacity and others. To overcome these difficulties CFM decided to move the whole operation by constructing a new processing plant and a tailing dam in different area. The proposed site is a basin beside the Magistral River, 20km west from the existing area. Capacity of the new plant is designed to receive 200 tons of crude ore, larger by 33% than the existing one.

The plant construction site is a plateau with an area of about 0.15km^2 surrounded by steep hills. The tailing dam is designed on a middle-slope of a hill, which stands to the south and 347m high. One of the water supply sources in this area is located about 3km downstream from the site. For this reason site selection should be made carefully after studying surface and ground water movement from the dam to avoid water contamination in the vicinity.

5-2 Geology

The basement of the area is metasediments of Pre-Tertiary age which is covered by Tertiary pyroclastic rocks and seen at window area of the over layer (Fig.5-2-1). The metasediments mainly consist of slates. They were often changed into phyllites by low-grade metamorphism. In Tertiary age, volcanism was activated. Porphyrites and dacites intruded into the basement, and Toba pyroclastic rocks covered on the surface of this area, later. Hydrothermal process followed the volcanic activity and alteration zone was formed in the survey area with the direction of NNW to SSE, and pyrite was deposited with a small amount of silver and copper in the contact area of intrusive body and basement slates. During Pleistocene age in Quaternary era erosion by rivers was activated and resulted three steps of terrace. At present, alluvial terrace was formed along the Magistral River, and coarse-grained sediments deposited in the river.

5-3 Electrical Prospecting

The Schulumberger's Electrode Arrey was used in this survey which is the same method in El Bote Area. The analysed resistivity is classified into as same groups as El Bote Area (Fig.5-3-1).

L zone shows low resistivity, M zone shows medium resistivity, H zone shows high resistivity and S zone shows complex zone of low and high resistivity.

S zone forms the surface in thickness of 3m～15m, the average thickness is 7m. S zone is composed of the river deposits of recent (Holocene of Quaternary time), terrace deposits of Pliocene of Quaternary age and soil layer of weathered Tertiary System and Pre-Tertiary System.

L zone is widely formed in the lower part of S zone along the Magistral River of 1-2-3 and 4-5-8 lines. Large shear zone is confirmed approximately parallel to the lines, low resistivity zone(L zone) is considered to be formed by the effect of this shear zone. L zone is composed of dacites and pyroclastic rocks of Tertiary System.

Judging from the survey on 9-11, 12-14 and 15-17 lines, L zone in the lower reaches of Magistral River is not systematically formed. At the 17 stations on 15-17 line, L zone is formed up to the depth more than 200m. But, at other stations, the width of L zone is narrow and the depth is also shallow. The L zone is composed of dacite and pyroclastic rock of Tertiary System.

M zone is formed around L zone in each line. The scale is small. M zones formed comparatively massive in lower part of S zone near planned site of tailing dam under S zone at the stations of 9, 13, 14 and 16. M zone is formed up to 120m in depth except at station No. 16. M zone is composed of pyroclastic rocks and andesite lavas.

H zone is formed in comparatively massive form in 18-20, 21-23, 24-26 and 9-11 lines in the planned site of tailing dam in the lower reaches of Magistral River. The scale of H zone observed in other lines is small. H Zone is composed of porphyrites which are intrusive of Tertiary System and shales of Pre-Tertiary System.

The movement of groundwater was observed in L zone and M zone by boring test. Judging from the result of survey, L zone is aquifer,M zone is aquitared and H zone is aquiclude or aquifuge.

5-4 Hydrology

Magistral River flows curving to the south into Panuco River. One big branch flows into in the north side of planned tailing dam from the east, another big branch flows into Magistral River from the west in the central part of the survey site, respectively. The purpose of this survey is studying the movement of surface water and groundwater in order to collect the fundamental data necessary to design new dressing plant. The survey of the flow and water quality was carried out at the points shown in Fig.5-4-1.

5-4-1 The Surface Water

(1) Streamflow of Surface Water

The measurement of cross sections of the rivers was carried out at 6 points, No.1 to No.6, in this survey shown in Fig.5-4-1. The results are shown in Table 5-4-1 and Fig.5-4-2.

The seasonal change of the rate of streamflow is obvious. The rate of streamflow near No.1 was 0 m^3/day, but, the rate of flow in the rainy season increases. For example, compared with the rate of streamflow near No.1, the amount of the rate of streamflow is approximately $4.2x10^2$ m^3/day in dry season, and the amount of that at ordinary time in the rainy season was approximately $4.1x10^2$ m^3/day or amount at the water rising time was 8.6 $x10^4$ m^3/day. There is obvious difference between not only in dry and rainy season but also at ordinary time and the water rising time in the rainy season.

(2) Water Quality of Surface water

The analysis data of the samples of surface water are shown in Table 5-4-3. Background and water supply ceiling of pollutants are shown in Table 5-4-2.

The sampling of water was carried out at 6 points of C-R1 ~ C-R3 along the main stream of Magistral River and C-R4 ~ C-R6 along the branch in order to analyse pH and contents of 9 heavy metals. The result of the analysis is shown in Table 5-4-2.

Cd, Hg and Cr^{+6} were not detected in the river water in the survey site, but, Cu, Zn, Fe, Total Cr and As were included all over the survey site. Particularly, Fe is always included, which has no relation with season. It is not doubtful that these heavy metals exist in this area due to the wide mineralization.

No samples exceed the upper limit of the Environmental Pollutants Content in C-R1 ~ C-R3 which locate along the Magistral River in the dry season. Only the Fe content in C-R3 exceed the upper limit of the Environmental Standard of Pollutants Content in the rainy season. Therefore, pollutants of the surface water supplied from the upper reaches of Magistral River is comparatively small.

Only Fe content exceeds the upper limit of the Environmental Pollutants Content in C-R4. Andesite is distributed around this point. The reason of high Fe content is considered that Fe is supplied from altered andesite contaminates in the surface water.

Only As content at C-R5 located near the fault exceeds the upper limit of the Environmental Standard. About As, it is explained in the chapter of groundwater including the sample at C-B1 and C-B7, later, the reason is not obvious, but As is presumed to concentrate along the fault.

Pb and Fe contents exceed the Environmental Standard at C-R6. The general nature of the surface water in this area is the same of the groundwater in this area where groundwater emanates from middle terrace deposit of the planned tailing plant.

pH changes from neutral to weak alkalinity from the upper to the lower reaches. The change of pH is considered to have some relationship with pyroclastic flow, andesite and slate of basement layer distributed in the upper reaches and in the lower reaches, respectively.

5-4-2 Groundwater

(1) Streamflow of Groundwater

The 13 observation holes were drilled in order to measure the position of aquiferous layer and current speed with micro-flow meter. 3 holes(B-1 ~ B-3) locate along Magistral River, 9 holes(B-4 ~ B-12) locate near the planned tailing plant and 1 hole(B-13) locate east of the planned dressing plant. The result is shown in Fig.5-4-3 Fig.5-4-4 and Table 5-4-4.

Aquiferous layers in survey site exist within Pre-Tertiary System (basement layer), Toba pyroclastic rocks, Middle Terrace deposits and recent Terrace deposits, respectively. As the movement of groundwater within basement rocks cannot be easily observed, eqivalent-resistivity plan was made in the range of EL.110 ~ 210 m sliced every 10 m. Current direction of groundwater is presumed to be approximately the same as the current direction of Magistral River. The low resistivity zone of 100 Ω · m exists in comparatively deep part around the planned dressing plant. It is considered to be strongly affected by fault.

Groundwater within Middle Terrace deposits in the planned plant area is stagnant in the basin, because the surface of basement rocks is comparatively flat and shows basin like topography. Only the weak current of groundwater to B-10 was observed. The reason of the existing of temporary current in B-6 and B-8 is presumed that the water level rises due to precipitation and difference of water levels in the upper reaches and the lower reaches occurs. By the difference of the water level, movement of groundwater is presumed to occur. The movement of groundwater once commences, it does not stop if the water level recovers to the stable position in the normal condition, and the water level goes down. Concluding this idea, the fluctuation of the groundwater level and current of the water shows contradiction in appearance. It can be explained by this idea, the movement of groundwater happens in B-8 hole when water level is the highest, and, the movement of groundwater occurs in B-6 hole when water level is the lowest. The case is the same in B-3 hole located in the lower reaches of the Parral River. The difference of the rate of streamflow (also current speed)has wide variation in B-4 hole. The steep valley locates behind B-4. The current in B-4 hole is presumed to occur due to quick response to precipitation. The fluctuation of water level in the dry season is considered not to occur due to small amount of precipitation. The current of groundwater has no relationship with seasonal change around B-5 hole. Environs of B-5 hole is presumed to be an outlet stagnant water within Middle Terrace deposits near the planned plant dischages here.

There was another aquiferous layer where the current speed could be measured except two layers in B-2 hole in the dry season mentioned above, but, it cannot be recognized in the rainy season. This is considered to happen to a temporary phenomena by drilling. It is considered that the pore water pressure arises and the movement occurs in developed cracks due to gush out of confined water in deeper part. Moreover, movement of ground water is presumed to stop due to saturation by pore water filled the cracks and the movement ceased before the survey in the rainy season.

(2) Water Quality of Groundwater

Groundwater was sampled at 13 holes in order to analyse the contents of 9 heavy metals including measurement of pH. C-B1 ~ C-B3 holes locate along the main stream of the Magistral River and C-B4 ~ C-B13 holes locate around the planned plant. The result is shown in Table 5-4-5.

Considering the result shown in Table 5-4-6, Cr^{+6} could not be detected in groundwater in the survey site. Very little Hg was included. Zn and Fe are generally included in groundwater. Particularly, Fe contents in all the samples exceed the upper limit of the Environmental Standard. Cu, Pb, Total Cr and As were detected in all the samples, however, sometimes they were not detected due to the seasonal change of ground water.

The fault with NNW-SSE direction was presumed to exist by the existing data and aerial photographs, The existence was confirmed by drilling test in this survey. The contents of Fe and As in the sample from C-B1 exceed the upper limit of the Environmental Pollutants Content.

The sample from C-B7 located on the extensive line of the fault has the same nature of that from C-B1. As regard to the As content, the samples which exceed the Environmental Standard are C-R5 except C-B1 and C-B7. The existence of fault with NNW-SSE direction is presumed in C-R5 area. Therefore, As is possible to distribute along the fault (particularly the fault with NNW-SSE direction). Pb content in the dry season exceed the upper limit of the Environmental Standard.

The fault with ENE-WSW direction was recognized in the area of C-B2 hole by interpretation of aerial photographs, geological survey and drilling. Fe content of the sample from C-B2 only exceed the upper limit of the Environmental Standard. Groundwater in C-B2 area is planned to use as the milling water. Water quality of the groundwater for the milling water is permitted except high Fe content. Compared with the milling water in Parral, the water quality has no problem for plant use.

5-4-3 Groundwater Flow System Simulation

Optimum simulation blocks of physical and hydraulic properties are modelled around the New El Coco planned Tailing dam site. A Groundwater flow system is simulated under the condition of these properties which are obtained by integrating the results of meteorological, geological, hydrothermal surveys , boring, pumping test and soil test.

At the first step simulation, clarified are water table, flow direction and flow speed under the condition of no existing of a tailing dam and its periphery constructions to get the present groundwater flow system.

At the next step simulation, a tailing dam, two bore hole for pumping, one surface discharge site, and one deposition pond are set up to clarify the groundwater condition after the construction.

Simulation results are contributed to calculate effective goundwater harness, waste water recycle and mining pollutant dispersion in both safety and economy.

The tailing dam construction guide line of Japan is referred to design this new El Coco tailing dam in article 5-8-1 and 5-8-2, in which a engineering method for drainage system is described to prevent tailing-rainwater contamination and waste water infiltration. On the other hand, a hydraulic method, described here, is recommended as a counterplan to reduce construction cost. The fundamentals of this hydraulic method are proposed from Dr.Atunao Marui of Geological Survey of Japan. The simulation starts from this basis and proceeds to fit to the field observation.

(1) Simulation Method

A numerical simulation for groundwater flow is conducted by the use of three dimension simulator "GWS3D2P" originally developed by Dr. Hiroyuki Tosaka of Tokyo University.

(2) Simulation Model

① Block Model

Simulation area takes the form of rectangular, 1.7km wide in the north-west direction and 1.8km wide in the north-east direction (Fig.5-4-5). The Magistral river is situated in the western part of the simulation area, which river has the south-west flow direction after the south-east. The new El Coco Planned tailing dam is located in the southern side of the area. This site is on the river terrace deposits which were formed by the Magistral river. At the present time, The Magistral river curves apart in the western side of the new tailing dam site.

The fissures mainly strike north-west, north-east, east-north-east, and subordinately strike north-south in the simulation area. These fissures control the Magistral river direction and groundwater flow direction. Andesite intrudes in the north-west direction in the southern side apart from this area, which direction is controlled by the main fissure.

The simulation area is framed to predict the drawdown and waste water dispersion from the new planned tailing dam. Consequently, the direction of the simulation area is in accordance with the main fissure strike. The area covers the planned dam and is surrounded with water divide.

The simulation depth is decided to 25m above sea level ,because of the influence prediction of pumping for planned tailing dam.

The simulation area is divided into 25 blocks in the north-west direction, 29 blocks in the north-east direction. The block size is 50m × 50m wide around the planned dam, 50m × 50m wide around the marginal area. X and Y axes are in the directions of north-west and north-east, respectively in the figure. the coordinate of north-west and north-east ends are (X1,Y1), (X25,Y29), respectively.

Vertically, the area is divided into 8 underground layers and 1 atmoshere layer, total 9 layers. The uppermost atmoshere layer is the first layer named Z1. Surface layers are 2 to 20m thick, deep site layers are 100m thick (Fig.5-4-10). At the model after construction of the tailing dam, a tailing dam layer is added between the atmosphere layer and the underground layer, totaled 10 layers as

Fig.5-4-9. The height of each block is represented by the elevation of the center of the block.

② Permeability and Porosity Model

Permeability and porosity of each simulation block are determined by integrating the geological,geophysical and hydraulic properties.

Geologically, the simulation area is underlain by Pre-Tertiary shales, Tertiary volcanic to intrusive rocks, and Quaternary terrace deposits. Pre-Tertiary and Tertiary rocks are usually compact and not permeable except around fissures along the Magistral river and terrace deposits.

As the results of the electrical prospecting and boring observation, low resistivity zone and low-high complex resistivity zone correspond to aquifer. Intermediate resistivity zone corresponds to aquitard. High resistivity zone corresponds to aquiclude and aquifuge.

As compared with geology and geological structure, The aquifer zone is equivalent to the boundary between sandy terrace deposit and lower formations, fault zone, intrusive rocks periphery. The aquitard is equivalent to weathered overburden and fault periphery. The aquiclude is equivalent to surface soil and calyey terrace deposit. The aquifuge is equivalent to the compact Pre-tertiary, Tertiary and intrusive rocks on the mountain to hill sides.

As the results of grain size distribution, the aquiclude permeability coefficient of Recent terrace deposits ranges 10^{-5} to 10^{-7}cm/sec. That of Pleistocene terrace deposits ranges 10^{-5} to 10^{-7}cm/sec. The soil test for new tailing dam indicates $10^{-4} \sim 10^{-5}$cm/sec as to aquiclude clayey terrace deposits, and 10^{-3}cm/sec as to aquifer sandy terrace deposits. Consequently, the aquifer and aquiclude permeability coefficients are set to 10^{-3}cm/sec and 10^{-5}cm/sec on the average, respectively. The other permeability coefficient values are given in the same way as the Parral area.

Along the Magistral river, several faults are developed in the pre-Tertiary and Tertiary rocks. Permeability coefficient of these fractures is different from its peripheral rocks. this permeability coefficient of these fractures is named fracture permeability coefficient (pkf). To the contrary, the permeability coefficient of the peripheral rocks is named matrix permeability coefficient (pkm). From this basis, The average permeability coefficient (K) of the simulation block is calculated as follows.

$$K=(hef/\triangle X) \times pkf+(1-hef/\triangle X) \times pkm$$

$\triangle X$:width of fracture

hef:width of block

The porosity is also distinguished fracture porosity (porf) from matrix porosity (porm) and is given the value corresponds to the hydraulic observation.

Table 5-4-6 shows the permeability coefficient and porosity model, and Fig.5-4-6 shows the rock classification maps on the basis of this concept.

In this Fig.5-4-6 plane map (X-Y CROSS SECTIONAL VIEW), the coordinates of left-bottom and right-top ends are (X1,Y1) and (X25,Y29), respectively. In the cross section (Y-Z CROSS SECTIONAL VIEW), left and right ends are Y29 and Y1, respectively. The legend No. of Table 5-4-6 corresponds to it of Fig.5-4-6.

③ Hydraulic Model

As Fig.5-4-1 shows, No.1 river flow measuring point is situated upstream of the Magistral river. In the dry season, at this point, flow rate is 415 m^3/day. At No.2 point dwonstream of the magistral river, flow rate is 0 m^3/sec because of infiltration. In tributary of this river, the water flow is not observed. On the other hand, in the rainy season, the continuous waterflow is recognized in the Magistral river. No.1 point flow rate is 4,000 to 86,000m^3/day, No.2 point flow rate is 7,000 to 28,000m^3/day as Fig.5-4-2 shows.

In both seasons, at No.2 point, the river flow reduces because of infiltration between No.1 and No.2 point. The large faults are observed along these points, and control the infiltration of riverwater, so that initial river flows are set as 415m^3/day in dry season during November to May and 4,000m^3/day in the rainy season at No.1 point, respectively The tributary streams don not have initial river flow, because of non flow observation in both seasons.

Each water level of the observation wells is set for simulation as to be situated at the top of the third layer counted from atmosphere layer. Though the boring B-2 is flowing well at the rate of 120 m^3/day, the water level is set at the top of the third layer which is uppermost of Tertiary rock, because the water level was set at this depth before boring.

④ Meteorological Model

Annual precipitation is 800mm on the average during 1985 to 1990. 90 percent of it precipitate during rainy season from June to October. Therefore, during these 5 months, the precipitation is 720mm from June to October. During other 7 months the precipitation is 80mm.

Evaporation data are referred from New El Coco observation. Evaporation of it ranges 0.35 to 0.84mm/day.

Recharge rate is set as 0mm/day during the dry season, 4mm/day during the rainy season, by precipitation minus evaporation.

⑤ Tailing Dam Model

A new tailing dam is planned to set up on the terrace deposits along the old path of Magistral river as Fig.5-4-5 shows.

To estimate the influence to the surroundings by the construction of a new tailing dam, Another simulation is carried out under the condition of including the dam data which are consist of scale, permeability, porosity, recharge, and discharge models.

As described in the Paragraph 5-6, the planned dam is 300m long, 100 wide, 10m thick, and $3 \times 10^5 m^3$ volume. In this simulation after constructing a tailing dam, the simulation blocks of the dam is set in this site. The permeability of the tailings is adapted it from El Bote and Parral tailings, that is 10^{-3}cm/sec. The block model is shown in Fig.5-4-9, and the dam site is situated at the D site on the map.

⑥ Recharge and Discharge Model

Waste water discharged is set as 200m^3/day, as tailings discharge is estimated as 200/day. 50m^3/day out of 200m^3/day waste water is recycled by being stored in the deposition pond, which is used to prevent the surface runoff of the waste water. 150m^3/day groundwater is pumped up from two boring holes, which is 25m short with full strainer. The boring sites are shown in Fig.5-4-5. The main pumping depth is set in the fifth layer for simulation.

The water for living supply is planned to be used from boring well B-2, from which groundwater discharged at the rate of 120m^3/day. This water is set to be directly discharged to the river near the pond. this site is situated at the top of the third layer.

(3) Simulation Results (before Constructing a Tailing Dam)

Fig.5-4-7 shows groundwater saturation map before constructing a tailing dam. Rainy season map is of the 150th day, counted from the first day of rainy season. Dry season map is the 360th day, counted from the first day of rainy season. In this maps, blue color is 100% saturated with free water. in accordance with the changing blue to yellow, the saturation level decreases.

The groundwater is recognized below than the second layer at the bore hole B-2 and upstream. But, the water level is drawn down downstream.
This appearance corresponds to the reduction between No.1 and No.2 site in Fig.5-4-1,2, that is, infiltration of riverwater.

The water table is continued to it of the Maigstral river below the fourth layer. Saturation level is lower in the surface layer in the dry season than that in the rainy season. In the dry season, Unsaturated area widens around saturated area ,and this unsaturation leads to the drawdown. But, this drawdown is not remarkable among in the dry and rainy seasons ,and corresponds to the field observation of bore hole water level.

Fig.5-4-8 shows groundwater velocity plane and cross sectional map. The rainy season map is of the 150th day, and the dry season map is of the 360th day, counted from the first day from the rainy season, respectively

The velocity is presented by X, Y, and Z components, i.e. NW-SE, NE-SW, and vertical direction, respectively. The length of arrow is in proportion to the groundwater flow velocity.

The fourth layers plane map of the rainy season indicates clear northwestern flow directions ,which runs to the Magistral river, around the dam site (site A on the map) ,and northern terrace deposits area (site B). This flow changes in the southwest direction around the Magistral river. This tendency is not different in the dry season, but the velocity is slightly low.

The cross sectional velocity maps show down-flow in the surface layers around the dam site (site A) and northern terrace deposits site (site B). In the deep layers, The lateral flow from site B to site A is obvious. this direction is not changeable during the rainy and dry seasons , but velocity is lower in the dry season in the surface layers.

(4) Simulation Results (after Constructing a Tailing Dam)
Groundwater existence below the new planned tailing dam site is clear, and this groundwater flows to the Magistral river. The hydraulic properties, obtained from this simulation, should be applied to model the dam construction.

The shape and volume of the Tailing dam is described in Paragraph 4-6. The model of two pumping bore holes, one deposition pond, and other facilities is described in Article ⑤ Tailing Dam Model.

Fig.5-4-10 shows groundwater saturation map after constructing a tailing dam. In the rainy season, the saturation level is slightly higher in the fourth layer around two boring sites (P1, P2 on the map), because of gathering of the water from the surrounding layers. In the dry season, more saturated zone is clarified above the fourth layer around boring site because of collecting of the groundwater.

The cross sectional velocity maps Fig.5-4-11, after constructing a tailing dam, show down-flow in the surface layers down to the sixth layer around the dam site (site D on the map). This section runs Y7 blocks and is parallel to X axis of the northwest direction. This down-flow changes to the lateral flow in the seventh and eighth layer. This lateral flow changes to up-flow around the boring site P-1 in the surface layers. The influence of pumping is not recognized in the ninth and tenth deep layers.

Even though the down-flow velocity is larger in the rainy season because of rainfall, compared with in the dry season, the boring holes recycle the waste water efficiently.

It could be thought that the polluted groundwater infiltrates to deep zone by construction of network of pipe and water paths caused by the downwards flow of groundwater under the tailing dam.

We should have a counterplan that installing some wells in the tailing dam (strainer underlie the original surface) and some deep zone wells at the neighborhood of the pumping up well.

5-5 Soil

Concentration levels of the heavy metals in this area are lower than the other survey areas, El Bote or Parral, and close to the normal contents in standard soil (Background value). These concentration has been brought by natural mineralization in and this area. One characteristic is Sb concentration, which is remarkably higher than background value.

5-6 Tailing Dam Model

The purposes of the survey are to make proper evaluation of the planned site for construction of new tailing dam and to design the model of new tailing dam. Field survey, drilling test, laboratory soil test of foundation ground and measurement were carried out in the survey site. As the result, following facts are clarified.

(1) Proper evaluation of the planned site for construction of new tailing dam

There is no problem about the preservation in the planned site for construction of new tailing dam. The bigger pondage cannot be expected, because of flat topography. However, as the hillside in the site has gentle slope, the site is suitable to locate the tailing dam. The foundation ground of the dam is well compacted and has necessary bearing capacity, and there is no emanation. The foundation ground has no problem as the dam foundation of the dam by the reasons mentioned above.

(2) The model of new tailing dam

The section shown in Fig.5-6-1 was obtained.

The outline of design of new tailing dam is described below.

① Inclination of slope

- starting dam upstream side i=50%
  downstream side i=43.5%
- slope with spreaded soil i=40.0%

② Spreading soil on the slope (for prevention of dust scattering and scouring of surface)

- covered by soil and vegetation

③ Drainage

- drainage for outside of the dam ; channel along mountain slope
- drainage for inside of the dam ; inclined pipe

· drainage for penetrated ground water; collecting channel

④ Dam height

· the mean height H=25m

· the height of initial embankment H=11m

⑤ Pondage approximately 300,000m^3

5-7 Summary of the Investigation

This area is formed on Metasediments of Pre-tertiary Systems. The Magistral River passes through the area zigzagging from north to south. As a result of geological survey, it is likely that ground water also runs underground along this river. Thus, one observation hole, B-2, reached the high pressured water layer at a depth of around 105 m. This water can be supplied satisfactorily to a new mineral processing plant to be built in this area.

Since there exists no mining activity at present in and around this area, concentration levels of heavy metals in surface and ground water or soil samples are not as high as those of other survey areas, El Bote and Parral. Cyanide has never been detected in this El Coco area.

In the samples of surface water, Cd, Hg and Cr^{6+} are not detected. Among the other metals, Pb and As exceed the criterion limit of water supply standard by EPA in the samples of C-R6 and C-R5 respectively. These are regarded as natural mineralization in this area.

In the samples of ground water heavy metal ions, except Cr^{6+}, were detected at higher levels than surface water. Among them Pb exceeds the criterion limit in almost all samples, especially high in C-B3. Arsenic exceeds the limit in the two samples, C-B1 and C-B7 situated near the faults found by the geological survey. It is possible that As is concentrated along the geological faults. More studies are yet to be done.

Arsenic is also concentrated at considerably high level in the soil samples taken in this area. This suggests the land is unlikely to fit for agricultural use.

These high levels of metal concentration are derived from natural mineralization in and around the survey area. Thus, it may be impossible to take some counterplans at present against the contamination. When a tailing dam is constructed inside the area, it is essential to prevent further contamination, which might be caused by effluent from the dam. To know the change in the environmental situation, another investigations shall be performed after mining activity starts.

As the results of soil property tests, the ground foundation of the proposed dam site was found suitable for construction. Based on these results a model tailing dam, which causes no pollution problems, was designed technically and economically for final recommendation.

5-8 Measures against Mine Pollution

5-8-1 Measures against Collapse of New Tailing Dam

The target safety factor of new tailing dam is over 1.2. The minimum safety factor in the model at ordinary times is 1.783 and during earthquake is 1.202. The stability against collapse of new dam is judged to be "No Problem".

5-8-2 Measures against Drainage of the New Tailing Dam

The drainage outside of the dam (canal on the hillside), the drainage inside of the dam (inclined sluice way) and the drainage for seepage water (blind drainage conduit) are installed. The water outside of the dam is directly discharged into river or used as recycled water, because the water is not polluted. The water inside of the dam and seepage water is discharged into the river after the treatment, because the water is polluted.

The plan of the drainage is shown in Fig.5-8-1, and the standard map of the drainage is shown in Fig.5-8-2.

5-8-3 Measure against Power Dust Scattering

The origin of dust is particles if sand and silt which were dried up in the dry season in El Bote and Parral tailing dam. The covering the slope with soil and making vegetation on it prevents from dust scattering. The measure is also effective to prevent surface from scouring due to rainfall in the rainy season.

5-8-4 Measures against Groundwater Pollution

According to hydraulic observation, groundwater is abundantly stored along fault zones and in permeable terrace deposits. The fault zones and the terrace deposits are well developed along the Magistral river and ex-river of planned tailing dam area.

The tailing dam construction guide line of Japan is referred to design this new El Coco tailing dam in article 5-8-1 and 5-8-2, in which a engineering method for drainage system is described to prevent tailing-rainwater contamination and waste water infiltration. On the other hand, a hydraulic method, described in article 5-4-3 in which groundwater flow systems are simulated, is recommended as a counterplan to reduce construction cost. The hydraulic method is the second countermeasure to prevent groundwater pollution. This method utilizes flow system between waste water and groundwater, in which system waste water infiltrates underground and mixed with groundwater. The groundwater is pumped up from the bore hole near the new tailing dam to use for slime transport. This waste water recycle system is adequate to prevent groundwater pollution and to use groundwater efficiently below the planned new tailing dam.

The water for living supply is should be used from boring well B-2, from which groundwater discharged at the rate of 120m^3/day.

It is not necessary for the hydraulic counterplan to set up the drainage system described in article 5-8-2, but to set up water recycle system economically. This system is composed of two bore holes for pumping ,trench around the tailing dam and a deposition pond to collect surface runoff water as Fig.5-4-5 shows. The groundwater for drink is used from bore hole B-2 of the Magistral river side.

We suggest that to take much volume of groundwater which is not polluted by waste water of tailings by making pumping up well along the Magistral river in the future, that will be constructed by the same manner of construction and best-site finding survey of our project team done.

5-8-5 Work Program and Construction Cost of the Model Tailing Dam

The model tailing dam is based on upstream depositing system, which has traditionally been adopted in Mexico. Consequently, routine costs for slime depositing is excluded from the following estimation.

(1) Work Program

Work program is illustrated in the figure shown below.

Type of Work	Amount	5month 10month 15month 20month
Basic Groundwork	20,000 m^3	2month
Starting Dam Piling Work	65,000 m^3	4 month
Rubble Filter Work	3,000 m^3	0.6 month
Drainage Inside The Dam	900 m	5 month
Drainage Outside The Dam	510 m	3 month
Underdrainage Work	730 m	0.6 month

(2) Construction Cost

According to the construction basis in Japan, total costs are estimated as follows.

Type of Work	Amount	Unit Cost (US$)	Total Cost (US$)
Countermeasures against			
Dam Collapse and Dust Problem			
Basic Groundwork	20,000 m^3	2.6	52,000
Starting Dam Piling Work	65,000 m^3	5.6	364,000
(Sub Total)			(416,000)
Drainage			
Inside the Dam	900 m	140.0	126,000
Outside the Dam	510 m	186.7	95,000
Underdrainage	730 m	100.0	73,000
(Sub Total)			(294,000)
TOTAL			710,000

6. SUMMARY

This survey works were composed of the following three steps as described in the indication made in Dec., 1990.

First Step : Collection and review of all existing data and information related to the Survey

Second Step : Field reconnaissance and measurement to obtain necessary data in the dry and rainy seasons

Third Step : Design of counterplans for appropriate environmental protection measures

As the first step, existing data on topography, geology, mining, metallurgy and tailing dam were collected at the head quarter of CFM as well as the mine offices in each survey area. Furthermore, meteorological data were obtained at a local station of each area.

Field reconnaissance and measurement were carried out in the three designated areas, El Bote, Parral, and New El Coco, on geology, meteorological, soil property, dust concentration etc.,in and around the tailing dams or its proposed site (New El Coco).

The collected data and the survey results were collectively analysed in Japan for understanding the present environmental situation at the mining sites and making any counterplans against the pollution problems.

Throughout the survey period, technology transfer was made to the Mexican Counterparts on the key elements of environmental study, measurement method, apparatus and others.

The results obtained in each area are summarized as below.

El Bote Area In this area, first of all, a part of the dam embankment has already collapsed by landslide and any counterplan is urgently required on entire embankment. Study from the soil property tests also led to a conclusion that the dam was in a dangerous condition. As a counterplan "Counter Weight Fill Work" method was proposed in Sec.3-9.

Dust problem brought by the wind from the dam is another serious problem.

It is concluded at present that dust particles never reach the urban area, however, they should have a great influence on living conditions at and around the mine site. Against this problem "Soil Covering" and Planting on the dam surface are recommended.

Copper and other heavy metal ions were detected in the samples of surface and ground water as well as soils in this area. All possible sources of these metals are listed below.

(1) Effluent from CFM El Bote plant and tailing dam
(2) Effluent from other mines than CFM
(3) Natural phenomena derived from local mineralization

Environmental pollution in this area is possibly related to all three sources above-mentioned. It is so difficult or practically impossible to know how much effect were brought by each pollution source. However, it can be concluded that CFM mining operation is not the only one source because a highly contaminated point (B-R2) is found at upper stream from CFM plant and tailing dam. This point is always short of water flow, almost stagnant during the dry season. This suggests that metals were dissolved and concentrated there from natural mineralization zone in the area.

The samples taken directly from the El Bote flotation plant tailing (B-W1) and tailing dam (B-D1) contain less metal ions than those of Parral operation. No cyanide was detected in either sample. Consequently, it is not absolutely necessary to install water treatment facility. The following measures are recommended tentatively.

(1) To reuse as much waste water as possible by recycling to the mineral processing plant
(2) To install a drainage system inside the dam to prevent rain water from contacting with the dam deposits
(3) to widen the waste water evaporation area by flattening the deposition plane

Details of the drainage system was described in Sec. 3-9.

Parral Area The stability of the tailing dam is a serious problem as in El Bote. In case of the Parral dam "Earth Removal Work" method,which reduces overload of soil mass, is recommended together with "Counter Weight Fill Work" proposed in El Bote.

On the dust problem the "Soil covering" and Planting are recommended as in the El Bote dam.

On the water contamination, it is obvious that the effluents from the Parral plant and dam have an influence on the nearby rivers because high levels of metals are detected in these effluents. Especially, detection of cyanide ions in the river water is noticeable and any countermeasures are required. As one example "Alkali-Chlorine Method" is described in the Sec.4-9.

Soils around the mine site are also highly contaminated by heavy metals and cyanide as well.

The drainage system inside the tailing dam is also recommended as in the El Bote dam.

It is suggested to make a deposition pond between the tailing dam and Parral river and connect it to the drainages from the dam to expand the evaporating area in the dry season, and to prevailing the discharge of tailings with an unexpected big storm rainfall in the rainy season.

Groundwater from the tunnel of the Parral mine indicates strongly acid. This water is no adequate to drink. It is thought that this groundwater is deep-seated origin.

The Parral river runs in the upside of this area. It is considered that there exists no deep polluted groundwater in the shallow aquifer, because the unconfined groundwater consists by water that originate in rainwater, from the view points of topography and river morphology.

To improve this water quality , new shallow aquifer along the Parral river should be utilized by boring work, because more clean groundwater can be got.

New El Coco Area Contamination by heavy metals is also detected in the nearby water system and soil of this area. However, concentration levels are not as high as those of other survey areas, El Bote and Parral. Since there exists no mining activity at present, these contamination should have been derived from natural and local mineralization. It is recommended that another investigations shall be performed to compare the environmental situation after some mining activities get started.

As the results of soil property tests, the ground foundation of the proposed dam site was found suitable for construction. Based on these results a model tailing dam of pollution free was designed technically and economically for final recommendation.

The tailing dam construction guide line of Japan is referred to design this new El Coco tailing dam in article 5-8-1 and 5-8-2, in which a engineering method for drainage system is described to prevent tailing-rainwater contamination and waste water infiltration. On the other hand, a hydraulic method, described in article 5-4-3 in which groundwater flow systems are simulated, is recommended as a counterplan to reduce construction cost. The hydraulic method is the second countermeasure to prevent groundwater pollution. This method utilizes flow system between waste water and groundwater, in which system waste water infiltrates underground and mixed with groundwater. The groundwater is pumped up from the bore hole near the new tailing dam to use for slime transport. This waste water recycle system is adequate to prevent groundwater pollution and to use groundwater efficiently below the planned new tailing dam.

Since the above-mentioned countermeasures against the regional pollution are all practicable without difficulty, it is desirable to realize them urgently. Furthermore, this type of investigation shall be continued in a long range plan for recognition and protection of environment.

Global attention and concern have been focussed increasingly on pollution of life-environment. Mining activities are indispensable to the growth of modern life, however, they sometimes bring serious environmental contamination on the surrounding area. Therefore, special attention should be paid to the protection against the pollution and destruction of the nature, which may be accompanied with mine development.

Japan International Cooperation Agency (JICA) hereby proposes to enact official Guidelines that ensure the compatibility of mine development and the environment throughout the United Mexican States. If any laws or regulations are already existing, they should be observed strictly.

The principal concerns are as follows.

Air pollution by dust
Water pollution by mine effluent
Soil contamination by waste materials, dust and mine effluent
Regulation on construction of tailing dam
Subsidence of mining site
Noise and vibration
Destruction of forests

For reference the principal Guidelines established in Japan are listed below.

The Basic Law on Countermeasures against Pollution
(Kogai-Kihon-Ho), Aug., 1967
The Act for Prevention of Air Contamination
(Taiki-Osen-Boshi-Ho), Jun., 1968
The Act for Prevention of Water Contamination
(Suishitsu-Odaku- Boshi-Ho), Dec., 1968
The Construction Standard of Rubble/Slime Deposition Mound and its Explanation
(Suteishi-Kosai-Taisekijo-Kensetsu-Kijun-Oyobi-Kaisetsu),
Nov., 1954 by the Ministry of International Trade and Industry
OECF Environmental Guidelines, Oct., 1989 by The Overseas Economic Cooperation Fund
Environmental Control Regulation in Japan July, 1990, Industrial Pollution Control Association of Japan , Tokyo, Japan