

2. RESULTS OF THE FIELD SURVEY

2.1 Findings of the Fixed Points Observation

All data obtained at the Fixed Points observation are described in the Appendix "E" Data of the Fixed Points Observation.

Only noteworthy items are indicated here.

Fixed Point A

At the Binga Dam, there was an overflow from the spillway during the period from the end of August to the early part of September and at the end of October. During the remaining period, water only used in the power plant was discharged. The observation on water quality and sampling was conducted on the surface water in the reservoir.

Monthly average values of the data obtained at the Fixed Point A are tabulated below.

Month	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (μS/cm)	DO (mg/l)	Turb. (ppm)	SS (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Ca (mg/l)	Mg (mg/l)	CN (mg/l)	SO ₄ (mg/l)
Dec.	21.58	24.8	8.8	220	6.6	14.5	4	0.003	0.005	0.0031	25	5.6	-	22
Feb.	10.86	27.3	8.5	240	6.5	4.9	7	0.003	0.010	0.0026	37	6.0	<0.01	26
Mar.	20.13	29.5	9.0	220	6.7	8.0	3	0.003	0.010	0.0023	23	5.7	<0.01	28
Apr.	33.86	31.7	9.0	210	6.8	2.6	3	0.004	0.010	0.0033	26	5.7	<0.01	29
May	18.13	31.0	8.8	230	7.0	4.1	12	0.003	0.005	0.0031	30	5.9	<0.01	30
June	46.53	30.7	8.7	230	7.3	4.6	6	0.003	0.003	0.0032	27	6.0	<0.01	30
July	43.75	30.1	8.8	230	7.1	3.2	3	0.003	0.003	0.0033	29	6.0	<0.01	30
Aug.	67.14	27.8	8.8	220	8.9	4.3	3	0.003	0.004	0.0021	28	5.6	<0.01	22
Sept.	71.59	29.4	8.4	170	6.7	67.6	41	0.003	0.004	0.0010	22	4.8	<0.01	14
Oct.	45.75	26.9	9.0	170	7.2	8.0	9	0.003	0.006	0.0008	25	4.7	<0.01	19
Nov.	50.01	27.0	9.2	180	7.3	3.7	23	0.003	0.002	0.0015	21	5.1	<0.01	20
Average	39.03	28.7	8.8	200	7.0	15.7	10	0.003	0.006	0.0024	26	5.4	<0.01	23

- : No data
- * : Average of Cu is calculated on the ground that the Cu concentrations below the detection limit are regarded one half of the limit value:
 $0.005 \times 1/2 = 0.0025$

Although turbid water covering the whole strata, a result of a big flood caused by a Typhoon Maring, which occurred at the end of August and lasted until the early part of September, when turbidity of the surface water was over 100 ppm, the surface water in the reservoir was generally clear as it is obvious from the record of turbidity. The reservoir water is of good quality with very little noxious dissolved matter as it is apparent from the record of EC and from the results of the chemical analysis.

It is one of the remarkable features of natural water in this area that a pH value shows 8 to 9 of a weak alkaline nature.

The yearly average values shown above are used as representative values of the natural water in the San Roque watershed on an estimation of the water quality, because of little seasonal fluctuation of data.

Fixed Point B

Monthly average values of the data obtained at the Fixed Point B are tabulated below.

Month	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (µS/cm)	DO (mg/l)	Turb. (mg/l)	SS (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Ca (mg/l)	Mg (mg/l)	CN (mg/l)	SO ₄ (mg/l)
Dec.	2.80	24.9	8.3	1400	6.9	270	210	0.075	0.005	0.0344	258	13.8	-	541
Feb.	1.62	26.8	7.9	1600	7.1	870	650	0.545	0.010	0.0323	280	24.3	1.11	749
Mar.	1.41	28.1	8.2	1600	7.6	490	420	0.220	0.010	0.0380	191	24.4	0.13	841
Apr.	1.22	30.2	8.3	1600	7.4	690	630	0.200	0.010	0.0531	338	26.7	0.22	834
May	1.81	29.5	8.2	1400	6.8	470	700	0.467	0.008	0.0239	239	17.6	0.18	675
June	2.31	29.1	8.1	1100	7.1	690	880	0.181	0.009	0.0179	199	17.9	0.23	522
July	4.99	27.9	8.1	940	7.5	210	280	0.168	0.006	0.0151	156	20.5	0.20	444
Aug.	7.47	26.7	8.2	840	7.4	630	830	0.213	0.009	0.0159	147	18.0	0.51	390
Sept.	19.19	29.2	7.8	730	7.2	860	1400	0.135	0.010	0.0047	118	20.4	0.25	274
Oct.	6.05	26.5	8.0	960	7.2	300	420	0.188	0.039	0.0106	179	19.0	0.32	458
Nov.	7.37	25.7	8.2	880	7.5	230	320	0.132	0.008	0.0140	143	17.7	0.26	831
Average	5.11	27.7	8.1	940	7.3	570	820	0.179	0.012	0.0143	161	19.4	0.31	474

- : No data

The flow rate is higher in July to November which corresponds to the rainy season.

At point B, EC is high especially during the dry season; and As, Ca, Mg and SO₄ concentrations are high in the dry season and relatively low during the rainy season. This shows that the dilution grade tends to increase in the rainy season. On the contrary, Cu and CN concentrations are not decreased in the rainy season; therefore the dissolved load (flow rate × concentration) is shown to become larger in the rainy season. This phenomenon is remarkable as a behavior of pollutant together with their high values.

Zn concentration is generally low and has no tendency to fluctuate.

Fixed Points C and D

Monthly average values of the data obtained at the Fixed Points C and D are shown in the following tables.

At both of the points, the flow rate is high in July to November the same as of the Point B, which corresponds to the conditions of the rainy season.

At both of the points, turbidity is very high exceeding in many cases a reading limit of the turbidity meter (2,000 ppm). EC and Ca, Mg, SO₄ concentrations are decreased in contrast to the increasing of the flow rate, which shows an increasing dilution grade in the rainy season. Concentrations of noxious dissolved matter such as Cu, Zn, As and CN are very low and are mostly under the detection limits of chemical analysis.

Fixed Point C

Month	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (µS/cm)	DO (mg/l)	Turb. (ppm)	SS (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Ca (mg/l)	Mg (mg/l)	CN (mg/l)	SO ₄ (mg/l)
Dec.	1.20	21.7	8.5	860	8.0	500+	3700	0.010	0.005	0.0010	187	6.3	-	383
Feb.	0.76	25.7	8.5	1200	7.4	2000+	10000	0.008	0.010	0.0096	258	8.0	0.01	702
Mar.	0.43	28.8	8.6	1700	6.8	1900+	18000	0.020	0.010	0.0010	317	8.6	0.01	781
Apr.	0.41	28.6	8.3	1200	7.7	2000+	22000	0.010	0.008	0.0006	357	10.5	0.00	809
May	0.76	27.7	8.2	1200	7.5	2000+	13000	0.006	0.010	0.0003	257	9.2	0.01	640
June	2.12	26.8	7.9	760	7.7	2000+	10000	0.008	0.009	0.0004	143	9.1	0.01	355
July	4.03	25.0	7.7	590	7.8	1800+	6600	0.003	0.003	0.0004	100	6.4	0.00	238
Aug.	4.99	23.4	8.1	620	7.7	2000+	9000	0.003	0.004	0.0003	95	7.3	0.01	226
Sept.	7.73	26.5	7.3	510	7.4	1200+	3900	0.006	0.008	0.0003	79	12.2	0.00	203
Oct.	3.17	25.0	8.4	600	7.5	2000+	11000	0.003	0.004	0.0008	126	6.1	0.01	287
Nov.	4.12	21.6	8.5	510	8.0	2000+	4500	0.005	0.003	0.0005	86	4.7	0.01	193
Average	2.70	25.5	8.2	640	7.7	1700+	10000	0.005	0.006	0.0004	116	8.2	0.01	278

- : No data

Fixed Point D

Month	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (µS/cm)	DO (mg/l)	Turb. (ppm)	SS (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Ca (mg/l)	Mg (mg/l)	CN (mg/l)	SO ₄ (mg/l)
Dec.	0.81	23.7	8.1	900	8.1	500+	1200	0.014	0.005	0.0017	207	7.2	-	433
Feb.	0.55	24.6	8.4	1100	7.3	1270	5800	0.005	0.010	0.0011	236	8.0	0.01	655
Mar.	0.41	26.2	8.3	960	7.7	820	630	0.008	0.010	0.0018	196	7.0	0.01	521
Apr.	0.45	28.2	8.1	1400	7.3	190	390	0.004	0.008	0.0013	314	8.4	0.01	747
May	0.72	27.9	8.1	1200	7.4	1600+	9200	0.004	0.013	0.0011	258	9.3	0.01	632
June	1.60	26.5	7.9	740	7.8	1900+	13000	0.003	0.006	0.0004	143	6.4	0.01	338
July	2.08	26.1	7.8	630	7.5	1400+	3800	0.003	0.003	0.0007	108	5.5	0.01	265
Aug.	2.76	21.8	8.0	470	7.6	880	1700	0.003	0.003	0.0004	80	3.6	0.01	173
Sept.	3.21	27.6	7.5	430	7.4	110	150	0.006	0.006	0.0006	68	6.3	0.01	160
Oct.	1.37	25.6	8.1	880	7.2	460	580	0.003	0.005	0.0004	195	6.4	0.01	439
Nov.	2.12	23.4	8.2	710	7.6	1100	2300	0.003	0.004	0.0005	118	3.5	0.00	276
Average	1.46	25.6	8.0	690	7.5	890+	3200	0.004	0.005	0.0007	131	5.7	0.01	310

- : No data

Fixed Point E

Monthly average values of the data obtained at the Fixed Point E are tabulated below.

Month	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (µS/cm)	DO (mg/l)	Turb. (ppm)	SS (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Ca (mg/l)	Mg (mg/l)	CN (mg/l)	SO ₄ (mg/l)
1983 Dec.	22.13	25.4	8.3	430	7.1	-	1200	0.010	0.005	0.0041	71	6.7	-	98
1984 Feb.	14.63	26.4	8.0	470	7.0	900	990	0.011	0.014	0.0045	81	7.3	0.01*	124
Mar.	32.27	28.9	8.2	440	7.1	610	920	0.011	0.010	0.0049	62	7.6	0.01	115
Apr.	32.37	31.1	8.3	430	7.0	290	510	0.018	0.006	0.0043	52	6.9	0.01	96
May	46.41	30.1	8.3	420	7.1	770	1300	0.012	0.005	0.0041	53	7.0	0.01	104
June	61.48	27.6	8.2	410	7.2	850	1400	0.018	0.003	0.0032	49	6.3	0.02	89
July	80.24	25.4	8.2	370	7.2	880	1600	0.036	0.003	0.0031	47	6.6	0.04	88
Aug.	265.25	26.1	8.1	240	7.2	1500	2900	0.014	0.003	0.0023	31	5.1	0.02	47
Sept.	198.90	26.6	8.1	250	7.2	360	410	0.011	0.004	0.0019	33	5.7	0.02	48
Oct.	114.53	26.5	8.2	330	7.3	590	2300	0.015	0.006	0.0018	47	5.7	0.01	88
Nov.	104.82	26.3	8.2	330	7.4	310	690	0.012	0.003	0.0021	41	5.9	0.01	77
Average	88.46	27.3	8.2	310	7.2	700	1600	0.015	0.004	0.0026	41	5.9	0.02	70

* : Concentrations below the detection limit are regarded one half of the limit value, so that CN content is 0.01 mg/l even if many of the daily data are below the limit.
 - : No data

The flow rates increase rapidly in June and reach a peak at the early part of September then tend to decrease. Although the obtained flow rate is higher in March, April, May, August, November and lower in January, February, June, July, September, October, December, in comparison with estimated average value determined by hydrologic analysis, differences between two values are not very remarkable. It can be said that this year is an average one in respect to the flow rate.

A significant positive relation is observed among EC, As, Ca, Mg and SO₄ concentrations and a significant negative relation between these 5 elements and flow rate. These relations show that a dilution grade tends to increase in the rainy season. However, it is noticed that Cu and CN concentrations increase in July according to an increasing flow rate. This phenomenon is similar to the one at the Fixed Point B, and is discussed below as a noteworthy behavior of the pollutant.

Note 1:

pH of natural water

As shown in the results of the Fixed Points observation, all of pH values measured at each Fixed Points are weakly alkaline.

A part of the heavy metals is presumed to behave in hydroxide compounds and its solubility is sensitively effected by pH value. Therefore, pH values were measured at many rivers and creeks in order to check pH variations.

As shown in Table IV-1, it is confirmed that natural river water is regionally weakly alkaline.

The pH value of water at the Fixed Point E undergoes within the range from 8.0 to 8.3, though it tends to decrease to 7.5 during a flood combined with much rain water (mean value of 9 measurements of rain water pH is 6.9)

Accordingly, 8 as an average pH value of inflow and 7.5 as a minimum pH value are adopted when estimating the water quality.

Table IV-1 REGIONAL SURVEY FOR pH AND EC IN THE BENGUET PROVINCE

No.	Sampling Place		June 4-5			August 12-13		
			pH	WT (°C)	EC (μ S/cm)	pH	WT (°C)	EC (μ S/cm)
1	Kennon Road (Baguio to Urdaneta)	241.0 Km	7.6	23	380	7.9	24	380
2	"	239.1	-	-	-	8.6	24	390
3	"	238.1	8.2	24	430	8.5	24	410
4	"	237.0	-	-	-	8.1	24	750
5	"	235.3	8.4	26	390	7.6	25	360
6	"	234.3	8.3	27	270	8.3	24	280
7	"	232.1	9.6	26	480	8.1	25	260
8	" (Attaki Bridge)	230.2	8.4	27	230	8.4	26	230
9	" (Ampasite Bridge)	228.9	8.4	27	290	8.3	25	230
10	" (Twinpeaks)	223.2	8.3	27	160	8.2	25	160
11	" (Colorado Bridge)	222.6	8.4	27	120	8.2	24	130
12	" (Peak Bridge)	222.0	-	-	-	8.4	24	200
13	" (Bridal Veil)	217.0	8.5	27	230	8.5	24	250
14	" (Hot Spring Klondykes)	215.0	8.6	38	2520	8.6	33	2160
15	Philex No. 2 Damsite	271.0	-	-	-	8.1	26	360
16	"	271.8	-	-	-	8.1	26	320
17	"	272.0	-	-	-	8.1	26	140
18	"	272.4	8.6	26	60	8.0	26	60
19	"	272.6	-	-	-	7.9	26	50
20	"	276.2	8.0	29	130	8.4	26	120
21	Philex No. 1 Damsite	268.3	-	-	-	7.1	25	680
22	"	269.3	8.0	31	1040	7.8	26	170
23	"	270.0	8.2	30	130	8.0	26	120
24	Philex to Baguio Road	263.6	7.4	26	220	7.7	25	120
25	"	263.2	-	-	-	7.9	24	80
26	Binga to Baguio Road	278.0	8.4	28	70	8.3	25	180
27	"	275.4	8.6	29	250	8.2	25	250
28	"	275.4	8.2	28	260	8.5	25	240
29	"	273.5	-	-	-	8.4	26	200
30	"	271.9	-	-	-	8.1	24	180
31	"	270.5	7.5	24	250	7.9	26	240
32	"	264.0	-	-	-	8.3	24	140
33	"	262.8	6.9	24	220	6.9	25	270
34	"	260.2	7.4	23	180	7.4	24	180

WT: Water Temperature

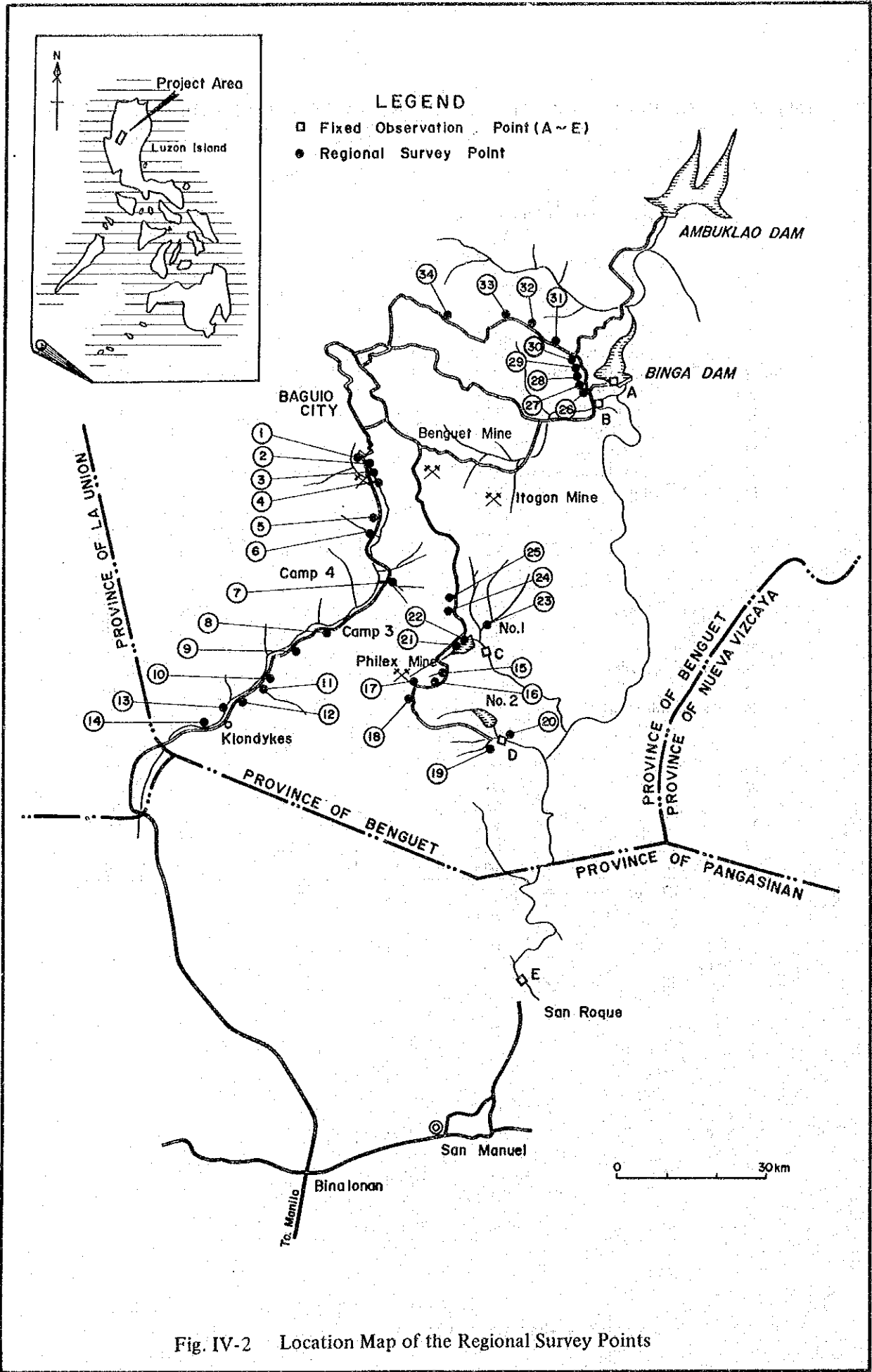


Fig. IV-2 Location Map of the Regional Survey Points

Note 2:

Cyanide Compounds

The cyanide compounds are dissolved in the water as cyanide ions and various cyano-complexes ions. CN analysed and recorded in the study is of Total Cyanogen (Hydrogen cyanide generated at pH not more than 2) and indicate concentration of all cyanide compounds included in the samples.

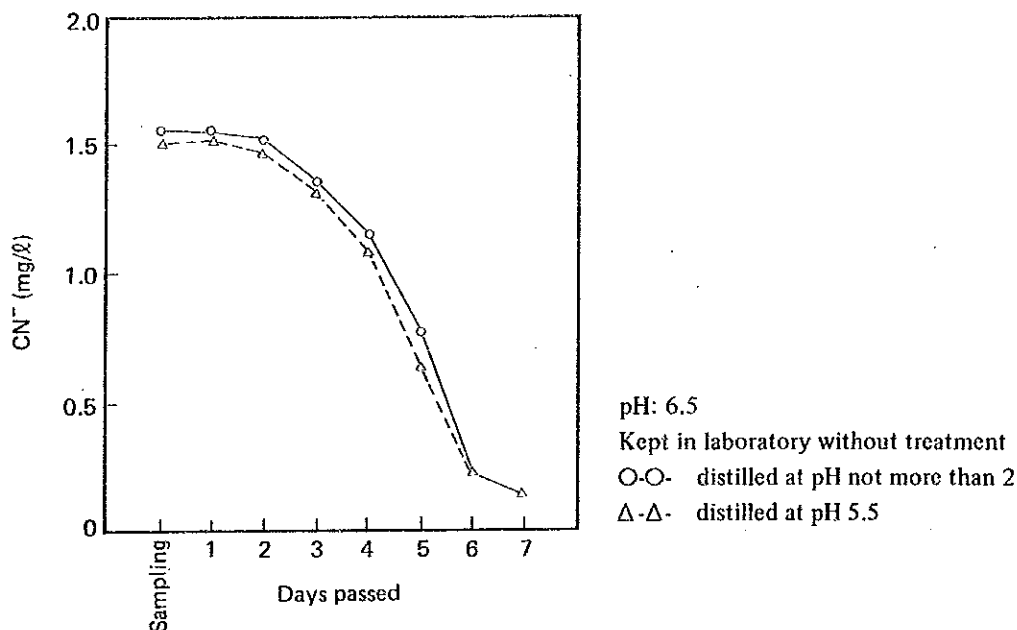
As CN values at the Fixed Point E are increased during the rainy season, analysis of Cyanide (Hydrogen cyanide generated under existence of Zinc Acetate at pH 5.5) were conducted to determine the ratio of the cyanide. In this pretreatment the hydrogen cyanide is generated almost completely from the cyanide ion and cyano-complexes of Zn and Cd of small formation constant, and partially from the cyano-complexed of Ni, Cu, etc. As shown in the table below, about 1/3 to 2/3 of the Total Cyanogen is dissolved in the water as stable cyano-complexes of Cu, Ni, Fe (I), Fe (II), etc.

No.	Sample No.	Locality	Date	Cyanide (mg/l)	Total Cyanogen (mg/l)
1	E07172	Fixed Point E	July 17	0.03	0.09
2	E07192	— ditto —	July 19	0.04	0.06
3	E07272	— ditto —	July 27	0.02	0.06
4	E07312	— ditto —	July 31	0.05	0.08
5	E08082	— ditto —	Aug. 8	0.08	0.21
6	E08102	— ditto —	Aug. 10	0.05	0.15
7	E08241*	— ditto —	Aug. 24	0.03	0.05
8	E08242	— ditto —	Aug. 24	0.03	0.05
9	E09232	— ditto —	Sept. 23	0.02	0.06
10	E10022	— ditto —	Oct. 2	0.03	0.05
11	E10172	— ditto —	Oct. 17	0.01	0.02
12	E10222	— ditto —	Oct. 22	0.02	0.03
13	E10242	— ditto —	Oct. 24	0.01	0.02
14	E10282	— ditto —	Oct. 28	0.02	0.04
15	B09232	Fixed Point B	Sept. 23	0.51	0.73
16	B10032	— ditto —	Oct. 3	0.33	0.43
17	B10132	— ditto —	Oct. 13	0.20	0.32
18	B11032	— ditto —	Nov. 3	0.08	0.39
19	B11212	— ditto —	Nov. 21	0.04	0.08

* Filtered by No. 3 filter

Cyanide ion is so unstable that it easily resolves and disappears.

An example of the observation record is shown in a figure below in which the decreasing of cyanide ion concentration is indicated.



Note 3:

Peculiarity of the cyanidation tailings

Tailings discharged from the cyanidation plants of Benguet and Itogon are of strong alkalinity and contain much CN.

The high concentrations of Cu and Zn, which are far higher than the solubility limit of Copper ion (Cu^{2+}) and Zinc ion (Zn^{2+}) in alkaline solution, exist in these tailings water.

This phenomenon is probably caused by the following conditions.

Cu

A significant positive correlation is observed between Cu concentrations and CN concentrations as shown in daily records of the fixed point E (a correlation coefficient between them: 0.74). Based on this fact, it is presumed that excess Cu may be dissolved and behave in the state of the Cyano-copper complex ion (ex. $\text{Cu}(\text{CN})_4^{3-}$).

Zn

As Zn concentration decreases rapidly when pH declines to weak alkalinity, it is considered that high Zn concentrations probably result from amphoteric zinc hydroxide dissolved in the state of zincate ion (ZnO_2^{2-}) in a strong alkaline solution.

Cyano-zinc complex ion may not be a main cause of high Zn concentrations, because it is more unstable than Cyano-copper complex ion and no significant correlation is observed between Zn concentrations and CN concentrations.

2.2 Findings of the Investigation of Pollution Sources

All data obtained by the investigation of pollution sources are described in the Appendix "C" "Data of the Investigation of Pollution Sources"

Only the main items directly related to the estimation of water quality are here indicated.

(1) Natural Pollution

To ascertain the nature of natural sand, sediments in the Ambuklao and Binga reservoirs were observed and chemically analyzed.

The results of chemical analysis are tabulated below.

As the average value obtained is low and considered capable of representing a natural sand, it is used to estimate the quality of the water.

Sample No.	Location	Cu (ppm)	Zn (ppm)	As (ppm)	S (%)	Pb (ppm)	Cd (ppm)	Hg (ppm)	Mn (ppm)	Fe (%)
AD 201	Ambuklao Dám	87	120	6.4	<0.10	15	0.4	0.01	900	4.78
AD 202	- ditto -	100	140	9.9	<0.10	25	0.5	0.02	1,000	5.55
AD 203	- ditto -	110	150	8.4	<0.10	29	0.5	0.01	880	4.72
AD 204	- ditto -	72	110	7.3	<0.10	13	0.3	0.01	780	4.58
AD 205	- ditto -	69	150	2.7	<0.10	23	0.4	0.01	1,100	4.76
AD 206	- ditto -	55	130	2.6	<0.10	17	0.3	<0.01	900	4.14
AD 207	- ditto -	37	76	1.9	<0.10	7.5	0.2	<0.01	520	4.11
BD 201	Binga Dam	45	70	3.3	<0.10	5.6	0.1	<0.01	600	4.37
BD 202	- ditto -	54	85	3.7	<0.10	7.4	0.2	<0.01	710	4.66
BD 203	- ditto -	48	82	3.5	<0.10	6.1	0.2	<0.01	720	4.96
BD 103	- ditto -	640	140	2	0.14	13	<2	<0.1	810	5.0
Average*		68	111	5.0	<0.10	15	0.3	0.01	810	4.66

* BD 103 excluded

(2) Pollution Caused by Mining Activities

Mine drainages

Observation and sampling of mine drainages were done 3 times, once during each stage of the survey.

The average values of observations and chemical analyses are shown in the following table.

Locality	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (µS/cm)	Cu (mg/l)	Zn (mg/l)	As (mg/l)	Ca (mg/l)	Mg (mg/l)	CN (mg/l)	SO ₄ (mg/l)
Philex 1020 ML Adit	0.085	21.3	7.5	380	0.005	0.018	0.0016	56	5.0	<0.01	114
Philex 745 ML Adit	0.32	21.8	7.9	890	0.023	0.016	0.0020	184	4.1	<0.01	380
Benguet Acupan Adit	0.17	35.4	8.0	2500	0.045	0.049	0.365	497	17.8	0.12	1171
Benguet Antamok Adit	0.42	26.8	5.8	2200	0.702	1.108	0.0049	541	50.9	0.36	1276
Itogon 1300 ML Adit	0.079	27.5	7.9	1600	0.005	0.017	0.037	310	31.5	<0.01	701

As shown in the table Cu, Zn, and CN concentrations are high in the mine drainages from Benguet Antamok Adit. Because CN is abnormally detected, it is deduced that contamination of CN, and probably Cu and Zn, is caused by the water seeping out of the tailings filled in the mine pits. "As" concentration is especially high in the drainage from Benguet Acupan Adit. Taking the unusual high temperature of the water into consideration, a high concentration of "As" may be led by mixing it with hot spring water which is rich in "As".

Mill tailings

Observation and sampling of mill tailings were carried out once in the 1st stage survey, twice each in the 2nd and 3rd stage surveys, and 5 times in total. Filtrates and solid samples were separately collected and chemically analyzed.

The average values of observations and chemical analyses are shown in the following tables.

Observations

Locality	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (µS/cm)	SS (mg/l)
Philex	1.13	26.3	10.3	2,300	250,000
Benguet	0.063	26.3	11.4	2,900	200,000
Itogon	0.039	22.3	10.7	890	86,000

Filtrates

Locality	Cu (mg/ℓ)	Zn (mg/ℓ)	As (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	CN (mg/ℓ)	SO ₄ (mg/ℓ)
Philex	0.015	0.009	0.0004	576	6.5	0.02	1,550
Benguet	23.2	13.2	0.0049	650	0.3	13.5	1,532
Itogon	4.4	2.4	0.075	72	0.6	20	129

Solids

Locality	Cu (ppm)	Zn (ppm)	As (ppm)	S (%)	Pb (ppm)	Cd (ppm)	Hg (ppm)	Mn (ppm)	Fe (%)
Philex	600	51	1.2	0.27	2.7	<0.1	<0.01	640	5.21
Benguet	250	700	72	2.57	220	2.2	0.32	3,000	3.62
Itogon	130	320	210	1.38	50	0.9	0.35	2,380	4.70

The Benguet and Itogon mills are refining by cyanidation and for this reason pH is controlled so as to obtain more or less 11. At the Philex floatation process, pH is also controlled so as to secure alkalinity in order to suppress the floating of pyrite.

The tailings from all the 3 mills are therefore alkaline.

As water for the mills is abundant, the concentrations of dissolved matter in the filtrates tend to be diluted during the rainy season. The values tabulated are those of an average flow rate.

Cu, Zn, and CN concentrations are high in the filtrates from the Benguet and Itogon mines, especially from Benguet. Dissolved metals in the filtrate from the Philex copper mine are scanty.

Solid materials from the Benguet and Itogon mines have higher Zn, Pb, As, Hg, and Cd contents and lower Cu content than those from the Philex mine, which might be the difference resulting from the nature of the ore deposits.

As tailings stored in tailings dams are considered to be different in the oxidation state from the ones which have just been discharged from the mill plant, tailings in dams are surveyed. However, no indication of an oxidation could be detected on the tailings in dams and no difference of an elution ratio was indicated in tailings dam samples from mill plant samples.

Seepage water at the Tailings Dams

Seepage water at the Philex Tailings Dam No. 1 and the Benguet Phase 2 Tailings Dam was observed and sampled for reference. As the results shown in the following table, the pH is lowered to neutral and Zn concentration is remarkably decreased from the seepage at the Benguet Phase 2 Tailings Dam in comparison with these values of tailings just discharged from the Mill to the Dam.

Locality	Flow Rate (m ³ /s)	Water Temp. (°C)	pH	EC (μS/cm)	Cu (mg/ℓ)	Zn (mg/ℓ)	As (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	CN (mg/ℓ)	SO ₄ (mg/ℓ)
Philex	0.14	25.0	6.8	2000	<0.005	0.014	0.0005	380	13.4	<0.01	966
Benguet	0.035	26.5	7.0	3100	10.8	0.26	0.137	560	19.2	15.8	1523

2.3 Results of Tests in the Field Laboratory

All data obtained by the tests conducted in the field laboratory are compiled in the Appendix "D" Data of the Tests in the Field Laboratory.

Only principal results are here indicated.

(1) Extraction test by the shaking method and extraction test by the aeration method

An extraction test by the shaking method aimed at determining the extent of elution of metals which may take place as the tailings flow down streams.

An extraction test by the aeration method aimed at determining the extent of elution of metals which may take place when the tailings are discharged in streams and come into contact with the oxygen contained in the air.

Cu, Zn and As are analysed in these tests. The results of tests are shown in the Table below.

Sample Locality	Method	Stage of Survey	Elution Ratio*		
			Cu	Zn	As
Philex	Shaking	2	0.33×10^{-3} (0.34×10^{-3})	—	0.26×10^{-2} (0.29×10^{-2})
		3	—	0.93×10^{-3}	—
	Aeration	2	—	—	0.65×10^{-3} (0.70×10^{-3})
		3	0.14×10^{-3}	—	—
		3	0.27×10^{-4}	0.54×10^{-3}	0.87×10^{-2}
		3	—	—	—
Benguet	Shaking	2	— (0.19×10^{-1})	—	0.20×10^{-4} (0.19×10^{-3})
		3	—	—	0.31×10^{-2} (0.32×10^{-2})
	Aeration	2	— (0.18)	— (0.83×10^{-2})	0.40×10^{-3} (0.59×10^{-3})
		3	—	—	0.19×10^{-2}
		3	—	—	0.14×10^{-2}
		3	—	—	—
Itogon	Shaking	2	— (0.12×10^{-1})	— (—)	0.31×10^{-2} (0.59×10^{-3})
		3	—	0.13×10^{-3}	0.12×10^{-2}
	Aeration	2	— (0.86×10^{-1})	—	0.10×10^{-1} (0.10×10^{-1})
		3	—	0.10×10^{-3}	0.43×10^{-3}
		3	—	0.19×10^{-3}	0.38×10^{-3}
		3	—	—	—

* Cu, Zn and As contents in the attached water are deducted after a calculation of the elution ratio, except when figures are in parenthesis.

Cu, Zn and As concentrations are so low as to be under the detection limit of chemical analysis in many cases.

There is no significant difference between the elution ratios in both extraction tests. It is estimated that an effect of aeration is slighter than a scattering of results of the tests. Taking the above results into consideration, either of the results can be used for calculation on the rate of elution.

The elution ratios of Philex mill tailings are in the range of $0.27 \times 10^{-4} \sim 0.33 \times 10^{-3}$ in Cu, $0.54 \times 10^{-3} \sim 0.93 \times 10^{-3}$ in Zn and $0.65 \times 10^{-3} \sim 0.87 \times 10^{-2}$ in As respectively. The As Elution ratio of Benguet mill tailings is $0.20 \times 10^{-4} \sim 0.31 \times 10^{-2}$ and no elution is occurred in Cu and Zn. The elution ratios of Itogon mill tailings are $0.10 \times 10^{-3} \sim 0.19 \times 10^{-3}$ in Zn and $0.38 \times 10^{-3} \sim 0.10^{-1}$ in As, no elution in Cu.

The shaking method and the aeration method are carried out on the mill tailings stored in the tailings dam at the 2nd stage survey. As the result, the following ratios were obtained.

Philex	Cu	0.22×10^{-4}	(average of shaking method results)
	Cu	0.23×10^{-4}	(average of aeration method results)
	Zn	0.11×10^{-2}	(average of shaking method results)
	As	0.14×10^{-2}	(average of shaking method results)
Benguet	Cu	0.59×10^{-4}	(average of shaking method results)
	Zn	0.98×10^{-4}	(average of shaking method results)
	As	0.19×10^{-3}	(average of shaking method results)
	As	0.61×10^{-3}	(average of aeration method results)

The figures obtained are in the same order with or even smaller than the ones acquired on the tailings taken directly at the mill outlets. Therefore, it is assumed that oxidation is not advanced so as to increase the elution ratio when tailings are stored in the tailings dam.

(2) Extraction test by wet and dry repetition

The tailings discharged and settled in the proposed dam will be subjected to dry and wet environmental conditions, alternatively, depending upon the water level. Oxidation may be more advanced and the rate of elution be much higher in these environments rather than in the ones submerged in the water.

These tests are aimed at determining the extent to which the elution occurs from the sediments settled in these conditions.

The results of the tests are tabulated below.

Sample Locality	Cycle	Elution Ratio		
		Cu	Zn	As
Philex	1	0.50×10^{-4}	0.32×10^{-3}	0.62×10^{-2}
	2	—	0.74×10^{-3}	—
	3	0.37×10^{-4}	0.43×10^{-3}	—
	4	0.81×10^{-4}	—	0.34×10^{-2}
	5	—	—	0.46×10^{-2}
Benguet	1	(0.53×10^{-1})	—	0.10×10^{-2}
	2	—	0.74×10^{-4}	0.16×10^{-2}
	3	—	—	0.12×10^{-2}
	4	0.65×10^{-4}	0.69×10^{-4}	0.25×10^{-2}
	5	—	0.87×10^{-4}	0.32×10^{-2}

The elution ratios of Cu in each of the cycles for the Philex mill tailings are in the range of $0.37 \times 10^{-4} \sim 0.81 \times 10^{-4}$, and Zn are $0.32 \times 10^{-3} \sim 0.74 \times 10^{-3}$ and As are $0.34 \times 10^{-2} \sim 0.62 \times 10^{-2}$.

The elution ratios of Cu in each cycles for the Benguet mill tailings are 0.65×10^{-4} , Zn are $0.69 \times 10^{-4} \sim 0.87 \times 10^{-4}$ and As are $0.10 \times 10^{-2} \sim 0.32 \times 10^{-2}$.

The above mentioned tests were carried out in a drying furnace with a temperature of 105°C in order to accelerate oxidation. Action of bacteria, which promotes oxidation of sulfide contained and elution of metals, may be extinguished in such a condition. Therefore, in order to estimate the effect of bacteria on the elution, a test by a bacteria addition was undertaken.

The results of an extraction test by a bacteria addition are shown in the following table.

Sample Locality	Cycle	Elution Ratio		
		Cu	Zn	As
Philex (without bacteria)	1	0.18×10^{-1}	0.66×10^{-1}	0.16×10^{-1}
	2	0.55×10^{-2}	—	0.17×10^{-2}
	3	—	0.19×10^{-1}	—
	4	0.31×10^{-2}	0.94×10^{-2}	—
	5	0.18×10^{-2}	0.43×10^{-2}	0.28×10^{-2}
Philex (with bacteria)	1	0.15×10^{-1}	0.53×10^{-1}	0.11×10^{-2}
	2	0.75×10^{-2}	—	—
	3	0.14×10^{-2}	0.20×10^{-1}	0.26×10^{-2}
	4	—	0.80×10^{-2}	—
	5	0.48×10^{-2}	0.16×10^{-1}	—
Benguet (without bacteria)	1	—	0.57×10^{-2}	0.61×10^{-3}
	2	0.35×10^{-3}	0.46×10^{-2}	0.58×10^{-3}
	3	—	0.11×10^{-2}	0.66×10^{-4}
	4	0.27×10^{-3}	0.21×10^{-2}	0.34×10^{-4}
	5	0.14×10^{-2}	0.18×10^{-2}	0.69×10^{-4}
Benguet (with bacteria)	1	—	0.96×10^{-2}	0.85×10^{-3}
	2	0.66×10^{-3}	0.21×10^{-2}	0.66×10^{-3}
	3	—	—	—
	4	0.13×10^{-2}	0.94×10^{-3}	—
	5	0.10×10^{-2}	0.25×10^{-2}	0.16×10^{-3}

As the elution ratios show, there is no significant difference between the two tests. Therefore, the effect of bacteria on the elution from the Philex and the Benguet mill tailings appears to be negative at least under the conditions performed at the laboratory.

The higher elution ratios than those by other methods are solely due to the acidic condition caused by the addition of HCl.

3) Model test

Dry and wet conditions are set in excess in the extraction test by dry and wet repetition in order to extend the rate of elution. Therefore, it is necessary to estimate that the rate of elution on one cycle of dry and wet repetition is proportionate to the ones of how long periods under natural conditions.

In this model test, the Philex mill tailings had been buried in the ground and sampling had been performed once a month to find out how many changes were in the elution.

The results are shown in the following table.

No.	Sampling Date	Elution Ratio		
		Cu	Zn	As
1	Mar. 4	0.11×10^{-4}	—	0.57×10^{-3}
2	Apr. 5	0.89×10^{-5} 0.14×10^{-4}	0.28×10^{-3} 0.91×10^{-3}	—
3	May 5	0.12×10^{-4} 0.17×10^{-4}	0.53×10^{-3} 0.57×10^{-3}	0.66×10^{-3}
4	June 5	0.14×10^{-4} —	0.71×10^{-3} 0.40×10^{-3}	—
5	July 5	0.82×10^{-5} 0.85×10^{-5}	0.85×10^{-3} 0.77×10^{-3}	0.64×10^{-3}
6	Aug. 5	0.90×10^{-5} 0.16×10^{-4}	0.97×10^{-3} 0.52×10^{-3}	—

Cu, Zn and As concentrations in the elute are fluctuated and do not show a regular tendency. It indicates that the rate of elution may be more effected by uncertain factors, such as moisture in the samples, rather than by a time factor. At any rate, the elution ratios are held to a limited range.

The sediments of the irrigation canal are kept moistened in a natural way. To compare the results obtained in the model test, samples were taken from the sediments in the irrigation canal bed once a month until June. The results of the tests are shown below.

No.	Sampling Date	Elution Ratio		
		Cu	Zn	As
1	Dec. 15	0.71×10^{-4}	0.16×10^{-2}	0.15×10^{-2}
2	Feb. 6	0.26×10^{-3}	0.84×10^{-3}	0.11×10^{-2}
3	Mar. 5	0.58×10^{-4}	—	0.17×10^{-2}
4	Apr. 5	0.67×10^{-4}	0.61×10^{-3}	0.28×10^{-2}
5	May 10	0.10×10^{-4}	0.53×10^{-3}	0.32×10^{-2}
6	June 8	0.53×10^{-4}	0.32×10^{-3}	0.15×10^{-2}

The As elution ratios are a little higher than those in the model test. The Cu and Zn elution ratios are in the same order as those in the model test.

Accordingly, it is concluded that the elution ratio obtained by the model test can be used as data for estimating the rate of metal eluted from mill tailings stored in the proposed San Roque reservoir.

(4) Grain size analyses

In order to get the grain size distribution of natural sand and mill tailings, a sieve analysis for sediment in the Binga reservoir; a precipitation test for sediment in the Ambukiao and Binga reservoirs; a grain-size analysis for natural sand and mill tailings; and a precipitation test over a long period for suspended solid taken at the Fixed Point E, were carried out.

As results indicate, the following points are confirmed:

Sediments settled at the upper reaches of the Ambuklao and Binga reservoir consist mainly of sands ranging from medium grain to very fine grain, while most of the particles of silt and clay size flowed down.

As the turbidity of water sampled at Fixed Point E and kept motionless in measuring cylinders goes down to more or less 10 ppm, the suspended solids which flow into the proposed reservoir will settle down proportionately to the drifting time in the reservoir and the water stored will be clean to some extent.

As mill tailings are ground to about 50μ – 74μ , it includes fine grains of under 1μ more or less 10%. The data of grain size distribution of the mill tailings were used for calculation of concentration of suspended solids in the outflow from the dam in estimation of the water quality.

(5) Extraction test for sieved samples under an acidic condition

In order to estimate elution ratios of Cu, Zn and As under an acidic condition, based on the assumption that a part of the suspended solids in the outflow from dam are settled in paddy field of an acidic condition, an extraction test under an acidic condition was undertaken.

This test is conducted on SS from the Fixed Point B, C, D and E, and the mill tailings from the Philex, Benguet and Itogon. Firstly, the samples are sieved, and divided into 4 classes. The sieved samples are supplied for an extraction test by 0.1 N hydrochloric acid solution.

A part of the results, the elution ratios of particles of $5\mu \sim 25\mu$ size which are used for the estimation of soluble metals in suspended solids in the outflow, from the dam, are here shown.

Sample Locality	Elution Ratio		
	Cu	Zn	As
Philex	0.25	0.53	0.14
Benguet	0.63×10^{-3}	0.49×10^{-1}	0.80×10^{-3}
Itogon	0.18×10^{-3}	0.54×10^{-1}	0.19×10^{-2}

3. CALCULATION OF ESTIMATED WATER QUALITY VALUES

3.1 Calculating Method

3.1.1 Concentration of Dissolved matters in Effluent

(1) Basic Formula

If it is considered that the concentration of the dissolved matters in the reservoir water is homogeneous and it is assumed that the concentration of the dissolved matters in the effluent is equal to it, then the concentration of the dissolved matters in the effluent (C_{out}) is expressed by the following basic formula.

$$C_{out} = \frac{L_{res.1}}{V_{res.1}} = \frac{L_{res.0} + L_{in} - L_{out} + L_{dis} - L_{pr}}{V_{res.0} + Q_{in} - Q_{out} - E}$$

$V_{res.1}$: Volume of stored water ($t = t_1$)

$V_{res.0}$: Volume of stored water ($t = t_0$)

Q_{in} : Inflow ($t = t_0 \sim t_1$)

Q_{out} : Outflow ($t = t_0 \sim t_1$)

E : Evaporation ($t = t_0 \sim t_1$)

$L_{res.1}$: Load in stored water ($t = t_1$)

$L_{res.0}$: Load in stored water ($t = t_0$)

L_{in} : Load in influent ($t = t_0 \sim t_1$)

L_{out} : Load in effluent ($t = t_0 \sim t_1$)

L_{dis} : Elution load from sediments ($t = t_0 \sim t_1$)

L_{pr} : Precipitation load from stored water ($t = t_0 \sim t_1$)

(2) Drawing of Variables

A.] The denominator of the basic formula represents the incoming and outgoing of stored water.

Q_{in} Inflow

The monthly average values obtained by the hydrologic analysis and considered reasonable were adopted, and for the fluctuation due to the dry years and wet years, the records for the past 21 years which were judged as reliable were input and analyzed.

Qout Outflow

This is to be controlled artificially, and the calculation was made in accordance with the optimum dam utilization plan studied by ELC. That is, from the required amount of power generation and dam design value and the above mentioned inflow, the amount of water for power generation was calculated by the following formula:

$$\text{Amount of water for power generation} = \frac{\text{required amount of power generation}}{\text{Efficiency} \times (\text{water level} - \text{Tailrace level} - \text{Head losses})}$$

The surplus amount of water for secondary power generation, if any was added, and any portion larger than the maximum discharge of power units was made as overflow. The dam design values and the rate of sand inflow used in the calculation were as follows.

i) Dam design values

Maximum capacity of reservoir V_{00} : $990 \times 10^6 \text{ m}^3$

Maximum water level in reservoir H_{max} : 290 m a. s. l.

Minimum water level in reservoir H_{min} : 225 m a. s. l.

Tailrace level L : 100m a. s. l.

Maximum discharge of power generating units R_{max} : $306 \text{ m}^3/\text{s}$

Head losses coefficient H_{los} : 0.000156

Efficiency of power generating units η : 0.85

Required amount of power generation W

(Unit: Gwh)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
W	102.96	102.96	102.96	43.24	43.24	43.24	43.24	43.24	43.24	70.57	70.57	70.57

ii) Calculation of rate of sand inflow

o Outflow of sand from Binga dam

From the results of the feasibility study (conducted by ELC) and measurement at Fixed-Point A, it was assumed that $1.5 \times 10^6 \text{ m}^3/\text{year}$ would flow out in the 6 months of the rainy season. From the real volume (apparent volume $\times 1.5/2.7$), $0.8 \times 10^6 \text{ m}^3/\text{year}$, the rate of inflow in June to November is $0.051 \text{ m}^3/\text{s}$.

o Outflow of sand from Binga – San Roque

From the feasibility study (ELC), it was assumed that $2.5 \times 10^6 \text{ m}^3/\text{year}$

would flow out in the 6 months of the rainy season, the real volume 1.4×10^6 m^3 /year, i.e. the inflow from June to November is $0.089 m^3/s$.

○ Amount of tailings from mines

The amount of tailings from the 3 mines; Benguet, Itogon and Philex, was calculated on basis of the production plan and filling up plan of the mines.

Name of mine	Amount of tailings t/day
Benguet	2,275
Itogon	350
Philex	32,000
Total	34,625
Real volume = $(34,625 \div 2.7) \times 365 = 4.7 \times 10^6 m^3$ /year	

E Evaporation

The evaporation per units area of each month as shown by the feasibility study (ELC) was used for the calculation.

(Unit: mm)												
Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Evapo- ration volume	269	275	293	245	203	180	166	140	140	219	251	259

If Q_{in} , Q_{out} and E are obtained as above, $V_{res.0}$ and $V_{res.1}$ can be obtained one after another by the following formula.

$$V_{res.1} = V_{res.0} + Q_{in} - Q_{out} - E$$

The direct rainfall in the reservoir and seepage losses from the dam were ignored by considering that they offset each other.

B.] The numerator of the basic formula represents the incoming and outgoing of the load.

Lin Load in Influent

$$\begin{aligned}
\text{Lin} = & \left\{ C_n \times (Q_{in} - Q_{BT} - Q_{IG} - Q_{PX}) \right\} + \left\{ (K_1 \times C_{BT} \times Q_{BT}) \right. \\
& + (K_2 \times C_{IG} \times Q_{IG}) + (K_3 \times C_{PX} \times Q_{PX}) + (K_4 \times D_{BT} \times S_{BT}) \\
& \left. + (K_5 \times D_{IG} \times S_{IG}) + (K_6 \times D_{PX} \times S_{PX}) \right\}
\end{aligned}$$

where

C_n : Concentration of dissolved matters in natural water

Q_{BT}, Q_{IG}, Q_{PX} : Amount of drainages from mines

S_{BT}, S_{IG}, S_{PX} : Amount of solid matters discharged from mines

C_{BT}, C_{IG}, C_{PX} : Concentration of dissolved matters in drainages from mines

D_{BT}, D_{IG}, D_{PX} : Content of metals in solid matters discharged from mines

K_1, K_2, K_3 : Residual rate of dissolved matters in drainages

K_4, K_5, K_6 : Elution rate of metals in solid matters while running down

The first term on the right side of the above formula is for calculating the natural load and the second term for calculating the load from the mines.

* For the C_n (concentration of dissolved matters in natural water), the annual average concentration at the Fixed-Point A was used.

(Cu mg/ℓ	Zn mg/ℓ	As mg/ℓ)
(0.0025	0.006	0.0024)

* For the $C_{BT} \times Q_{BT}, C_{IG} \times Q_{IG}, C_{PX} \times Q_{PX}, D_{BT} \times S_{BT}, D_{IG} \times S_{IG},$ and $D_{PX} \times S_{PX}$ (loads discharged from mines), the calculations were made on basis of the operating plans and the measured values collected from the mines. The Philex mine has a plan to increase the production from 27,000 tons/day to 32,000 tons/day by September 1985 and the Itogon mine increased the production from 300 tons/day to 350 tons/day from October, 1984. Therefore, in parallel with the increase in production, it was assumed that the amount of the pollutants as the mill tailings would increase. The production scale, style and life of the mines are to be affected by the future exploration results and the economic situation. It is very difficult to estimate them, and therefore, the calculations were made on the assumption that the mines would not change the production scale and style during the estimated period.

* K_1, K_2, K_3 (residual rate of dissolved matters in drainage) are calculated from the amount of dissolved metal in the mine drainages obtained by the pollution

source investigation and the amount of dissolved metals in the running-down water obtained by the fixed-point observation.

If both are compared, the latter is generally smaller than the former in the case of Cu and Zn, and the dissolved Cu and Zn are made insoluble in the course of running-down after discharged from the mines, i.e. the precipitation occurs. This phenomenon is caused by the peculiarity of the cyanidation tailings described in 2.1, and it is considered that the precipitation proceeds as follows.

The Zn dissolved in excess alkali as zincate ions (ZnO_2^{2-}) precipitates as zinc hydroxide (Zn(OH)_2) when the drainage is mixed with the natural water, and as the pH declines. Consequently the concentration of dissolved Zn rapidly decreases.

Although the cyano-copper complex ions are relatively stable complex ions and the dissociation constant is small, the dissociation occurs as $\text{Cu(CN)}_4^{3-} \rightleftharpoons \text{Cu}^+ + 4\text{CN}^-$ and in this formula the CN ions are unstable and are gradually decomposed promoting the reaction toward the right. Therefore, it is considered that the cyano-copper complex ions are gradually decreased in the long term. Cu^+ is oxidized into Cu^{2+} and the portion exceeding the solubility product of the copper hydroxide (Cu(OH)_2) precipitated.

As has the amphoteric characteristic and when the pH is low, it is dissolved as As^{3+} ions and when the pH increases, it is dissolved as AsO_3^{3-} but while it is changing, the hydroxide precipitation does not occur.

Thus, from the viewpoint of the chemical reaction only, the dissolved Zn decreases rapidly and the dissolved Cu decreases gradually, and As does not decrease. Thus, they behave differently. It is also considered that they may be adsorbed by the clay substance and behave together with the suspended solids.

From the above, the residual rate was assessed for the dissolved Cu and Zn discharged from both mines, Benguet and Itogon and added to the variables for the water quality estimation.

The residual rate of dissolved matters from the Benguet mine and Itogon mine is obtained by the following formula:

Residual rate =

$$\frac{\text{Load at Point E} - \text{Natural load} - \text{Load from Philex mine}}{\text{Load from Benguet mine} + \text{Load from Itogon mine}}$$

i.e. $K_1 = K_2 =$

$$\frac{CE \times Q_{in} - C_n \times (Q_{in} - Q_{BT} - Q_{IG} - Q_{PX}) - (C_{PX} \times Q_{PX})}{(C_{BT} \times Q_{BT}) + (C_{IG} \times Q_{IG})}$$

and the residual rate of the load from the Philex mine is $K_3 = 1$.

where, CE: Concentration of dissolved component at Point E (measured value for each month)

The K_1 and K_2 thus obtained month by month are changed by various factors. Here the α (constant) is sought by the method of least squares from the α_i of 12 months which is calculated by a formula $\alpha_i = \frac{K_1}{Q_{in}}$, K_1 and K_2 calculated by multiplying that α by monthly Q_{in} ($K_1 = K_2 = \alpha \times Q_{in}$) are used for calculating the appropriate estimated values. The highest value of the monthly α_i values is used as the worst value.

	Cu	Zn	As
Highest value (worst value)	$0.125 \times Q$	$0.236 \times 10^{-3} \times Q$	1
Intermediate value (appropriate estimated value)	$0.468 \times 10^{-3} \times Q$	$0.00 \times Q$	1

* For K_4 , K_5 and K_6 (elution rate of metals in solid matters while running down), the elution rates obtained by the extraction test by shaking method and the extraction test by aeration method were used.

The Cu and Zn for Benguet and Itogon precipitate as aforementioned, and it was assumed that the elution would not occur for the Cu and Zn for Benguet and Itogon.

Tailings	Cu	Zn	As
Benguet	0	0	0.19×10^{-2}
Itogon	0	0	0.10×10^{-1}
Philex	0.33×10^{-3}	0.93×10^{-3}	0.87×10^{-2}

Ldis Elution load from sediments

$$L_{dis} = \sum_{t=1}^{t_0} (C_{res.0BT} \times K_{7t} \times K_{8BTt}) + \sum_{t=1}^{t_0} (C_{res.0IG} \times K_{7t} \times K_{8IGt}) + \sum_{t=1}^{t_0} (C_{res.0PX} \times K_{7t} \times K_{9PXt}) + \dots \dots \dots \text{(when } C_{res.0} < C_0 \text{)}$$

where,

Tres.O_{BT}, Tres.O_{IG}, Tres.O_{PX}: Amount of tailings from mines accumulated above a dead water level in one month

K_{7t}: Ratio of accumulated tailings subject to elution reaction

K_{8BTt}, K_{8IGt}, K_{8PXt}: Elution rate related to the amount of tailings accumulated in the months and years of t = t.

It was assumed in the calculation that the sediments would be accumulated with the uniform thickness at the bottom of the reservoir lower than the water level when inflowing.

* Tres.O (amount of sediments) can be obtained by $\sum_1^n (S_{BT} \times d_{BT} + S_{IG} \times d_{IG} + S_{PX} \times d_{PX})$ from the start of impounding to n months. For the natural sediments, the elution rate is removed from this formula because it is small enough to be ignored. d is an assessed rate for the sediments of 5 μ or more in size which is deposited at the bottom of the reservoir, and is d_{BT} 0.819, d_{IG} 0.811 and d_{PX} 0.855.

* For K₇ (ratio of sediments subject to reaction), it was considered that the elution would occur from the portion of the sediments submerged anew during t = t₀ ~ t₁ and the ratio in volume was calculated.

* For K₈ (elution rate for sediments), the elution rate obtained by the model test and the extraction test by dry and wet repetition method is used. The elution rates K₈ were sought by the method of least squares assuming the formula of

$$K_8 = \frac{K_9}{K_{10} - K_9} (e^{-K_9 t} - e^{-K_{10} t}).$$

Tailings	Coefficient	Cu	Zn	As
Philex	K ₉	0.554 × 10 ⁻²	0.242 × 10 ⁻²	0.444 × 10 ⁻¹
	K ₁₀	0.48954 × 10 ⁺³	0.36674 × 10 ⁺¹	0.79644 × 10 ⁺²
Benguet	K ₉	0.55 × 10 ⁻²	0.3215 × 10 ⁻³	0.4502 × 10 ⁻¹
Itogon	K ₁₀	0.61662 × 10 ⁺³	0.491 × 10 ⁺¹	0.50362 × 10 ⁺³

* For Co (solubility limit), the solubility of Cu (OH)₂ and Zn (OH)₂ at pH 8 (average) and pH 7.5 (minimum) was calculated from the solubility products, etc. The pH 8 and pH 7.5 were used for the reason described in 2.2.

	Solubility limit (mg/ℓ)		Solubility Products
pH	7.5	8.0	
Cu	0.014	0.0014	2.2 × 10 ⁻²⁰
Zn	4.6	0.46	7.0 × 10 ⁻¹⁸
As	Sufficiently High	Sufficiently High	—

Lpr Precipitation load from stored water

$$Lpr = Vres.0 \times (Cres.0 - Co) \times K_{11} \quad (Cres.0 > Co)$$

K_{11} : Rate of precipitation reaction (0 ~ 1)

If the Lin , $Lout$ ($Cout \times Qout$), $Ldis$ and Lpr are obtained as the above, $Lres.0$ and $Lres.1$ can be obtained one after another by the following formula.

$$Lres.1 = Lres.0 + Lin - Lout + Ldis - Lpr$$

3.2.1 Concentration of Suspended Solids in Effluent

(1) Basic formula

If it is assumed that all the suspended particles which are not settled before the influent reaches the outlet will be flowing out in a suspended state, the concentration of the suspended solids in the effluent ($SSout$) can be expressed by the following formula.

$$SSout = \frac{S_{BT} \times K_{12} + S_{IG} \times K_{13} + S_{PX} \times K_{14} + S_N \times K_{15}}{Qout}$$

Where,

$Qout$: Rate of outflow

S_{BT} , S_{IG} , S_{PX} : Amount of inflowing tailings from mines

S_N : Amount of inflowing natural sands

K_{12} , K_{13} , K_{14} : Outflowing rate of tailings

K_{15} : Outflowing rate of natural sands

(2) Calculation of variables

Rate of outflow $Qout$ Already explained in 3.1.1

Amount of inflowing tailings from mines S_{BT} , S_{IG} , S_{PX}

The same amount as that of the solid matters discharged from the mines was used.

Amount of inflowing natural sands S_N

From the feasibility study (ELC),

- 1) amount of sand outflowing between Binga and San Roque
 $2.5 \times 10^6 \text{ m}^3/\text{year}$ (apparent volume)
- 2) amount of sand outflowing between Ambuklao and Binga
 $1.5 \times 10^6 \text{ m}^3/\text{year}$ (apparent volume)

were used, and as the Binga dam will be filled up with the sediments and it will no longer play the role of the debris barrier in the year of 2009 on the calculation basis, it was assumed that until 2009, the amount 1) only and after 2010, the amounts 1) + 2) flow during 6 months from June to November.

* They were converted into real volumes by the formula, apparent volume $\times 1.5/2.7 =$ real volume.

(Ambuklao dam is not filled up with the sediments during the investigated period.)

Outflowing rate of tailing K_{12}, K_{13}, K_{14}

Only the sinking movement following the Stokes' law is considered for the movement of the suspended particles^{Note)}. If it is assumed that the flow of the water in the reservoir covers all the layer excluding the dead water space (stagnant space) formed a little under the level of the intake, the residence time (T) of the water in the reservoir can be sought as the time for all the water above the dead water space to be discharged, i.e.

$$T = \frac{V_o - VL}{Q_{out}}$$

V_o : Volume of water stored

VL : Volume of water in dead water space

The sinking velocity v of the grain of size d is obtained by the Stokes' law:

$$v = \frac{(\rho - \rho_o) g \cdot d^2}{18 \mu}$$

ρ : particle density (2700 kg/m³)

ρ_o : water density (1000 kg/m³)

g : gravitational acceleration (9.8 m/s²)

μ : coefficient of viscosity (0.0009 Pa · s, at 25°C)

Therefore, the sinking distance of the grain of size d within the residence time is calculated as follows:

$$T \times v = \frac{V_o - VL}{Q_{out}} \times \frac{(\rho - \rho_o)gd^2}{18 \mu}$$

If the water level is H_o and the dead water level is HL , the grain size d to satisfy $H_o - HL = v \times T$, which is the maximum size of outflowing particle, is obtained by the formula:

$$d = \sqrt{(H_o - HL) \left/ \frac{(\rho - \rho_o)g}{18 \mu} \times \frac{V_o - VL}{Q_{out}} \right.}$$

Note: Other factors, such as water turbulence, water temperature, etc. are considered of no importance for particle settling.

Since the grain size distribution of the tailings of each mine is known by the grain size analysis, the distribution of grain which is finer than the seeked grain size d can be applied for the outflowing rate of the tailings.

Outflowing rate of natural sands K_{15}

Since the grain size distribution of the average natural sands is not known, 7% was uniformly used for all the calculations.

(3) Content of metals in outflowing suspended solids

The content of the metals in the outflowing suspended solids (C'out) can be obtained by the following formula.

C'out =

$$\frac{S_{BT} \times K_{12} \times D'_{BT} + S_{IG} \times K_{13} \times D'_{IG} + S_{PX} \times K_{14} \times D'_{PX} + S_N \times K_{15} \times D_N + P}{S_{BT} \times K_{12} + S_{IG} \times K_{13} + S_{PX} \times K_{14} + S_N \times K_{15}}$$

where

D'_{BT} , D'_{IG} , D'_{PX} : Metal content of fine particle portion in tailings discharged from mines.

D_N : Metal content in natural sand

P: Load of precipitated hydroxide

For the D'_{BT} , D'_{IG} and D'_{PX} , 2 kinds of values, total metal content and soluble metal content, of the analysis results of the particles of $5\mu - 25\mu$ size which were obtained from the result of the extraction test for sieved samples under an acidic condition, are used.

For the D_N , the analysis result of the sediments in the reservoirs of power plant dams is used.

The P is equal to the precipitation load from stored water.

3.2 List of Parameters (Input Data)

Inflow rate		Q _{in}	Hydrologic data: average values calculated by the hydrological sector and the measured values during a 21 year period	Jan.	Feb.	Mar.	Apr.	May	Jun.
Concentration of dissolved matters in natural water		C _n	Annual average concentration at fixed point A (Binga dam)	30.3	23.1	19.8	20.1	40.4	62.7
Flow rate and concentrations of dissolved matters of Benguet mine water		Q _{BT-tl} C _{BT-tl}	Pollution source investigation data (average of 3 measured values)	0.59 m ³ /s		0.513	0.804	0.109	
Flow rate and concentrations of dissolved matters of Itogon mine water		Q _{IG-tl} C _{IG-tl}	"	0.079 m ³ /s		0.005	0.017	0.037	
Flow rate and concentrations of dissolved matters of Philex mine water		Q _{PX-tl} C _{PX-tl}	"	0.32 m ³ /s		0.023	0.016	0.0020	
Flow rate and concentrations of dissolved matters of Benguet mill tailings (water)		Q _{BT-ml} C _{BT-ml}	Pollution source investigation data (average of 4 measured values)	0.063 m ³ /s		23.2	13.2	0.0049	
Flow rate and concentrations of dissolved matters of Itogon mill tailings (water)		Q _{IG-ml} C _{IG-ml}	(inverse calculation from an SS measured value × $\frac{350}{300}$)	0.046 m ³ /s		4.4	2.4	0.075	
Flow rate and concentrations of dissolved matters of Philex mill tailings (water)		Q _{PX-ml} C _{PX-ml}	(inverse calculation from an SS measured value × $\frac{32,000}{27,000}$)	1.34 m ³ /s		0.015	0.0091	0.00043	
Rate of outflow from Benguet mine		Q _{BT}	Mine water + mill tailings (water)	(Q _{BT-tl} + Q _{BT-ml})		0.653 m ³ /s			
Rate of outflow from Itogon mine		Q _{IG}	"	(Q _{IG-tl} + Q _{IG-ml})		0.125 m ³ /s			
Rate of outflow from Philex mine		Q _{PX}	"	(Q _{PX-tl} + Q _{PX-ml})		1.66 m ³ /s			

Amount of tailings (solid) and the contents of the components of the Benguet mill	SBT DBT	Future production and filling up plans Average of analyzed values of collected samples (number of samples: 5)	2,275 t/day	Cu (ppm) 250	Zn (ppm) 700	As (ppm) 72
Amount of the tailings (solid) and contents of the components of the Itogon mill	SIG DIG	Future production plan Average of analyzed values of collected samples (number of samples: 5)	350 t/day	Cu (ppm) 130	Zn (ppm) 320	As (ppm) 210
Amount of the tailings (solid) and contents of components of Philex mill	SPX DPX	Future production plan Average of analyzed values of collected samples (number of samples: 5)	32,000 t/day	Cu (ppm) 600	Zn (ppm) 51	As (ppm) (1.2)
Rate of sand outflow from the Binga dam	SBG	Feasibility study (ELC) and measurement results at fixed point A	1989-2009 : 2010-	Jan.-May; Dec. Jun.-Nov.	0 0.051 m ³ /s 0.8x10 ⁶	0 0
					= 183x24x60x60	
Rate of sand outflow between the Binga and the San Roque	SGS	Feasibility study (ELC)		Jan.-May; Dec. Jun.-Nov.	0 0.089 m ³ /s	0
Content of components in natural sand	SGS	Average of analyzed values of the sediments Binga/Ambuklao dams (Number of samples: 10)		Cu (ppm) 68	Zn (ppm) 111	As (ppm) 5.0
Residual rate of the dissolved matters in natural water	K0	It is assumed from data at fixed point A and values of dissolved matters that precipitation will not occur.		Cu (ppm) 1	Zn (ppm) 1	As (ppm) 1
Residual rate of the dissolved matters in tailings from the Benguet mine	K1	Given as a function of the flow rate of the basis of a balance of dissolved matters at pollution source and fixed point	Appropriate Maximum (worst value)	4.68x10 ⁻³ xQ 0.0125xQ	0.0xQ 2.36x10 ⁻³ xQ	1 1
Residual rate of dissolved matters in tailings from the Itogon mine	K2	"				
Residual rate of dissolved matters in tailings from the Philex mine	K3	"		1	1	1

Elution rate of metals in Benguet tailings	K4	Calculated from results of extraction tests (mainly by the aeration method)	BT	Cu	Zn	As	
				0	0	0.19×10^{-2}	
Elution rate of metals in Itogon tailings	K5	"	IG	0	0	0.10×10^{-1}	
Elution rate of metals in Philex tailings	K6	"	PX	0.33×10^{-3}	0.93×10^{-3}	0.87×10^{-2}	
Solubility limit	Co	Calculated from the solubility product, etc. (pH 7.5, 8)					
		Cu(OH) ₂		Cu (mg/l)	Zn (mg/l)	As (mg/l)	
		Zn(OH) ₂		0.014	4.6	Sufficiently high value	
				0.0014	0.46	"	
Rate of sediments subject to elution reaction of sediments in reservoir	K7						
Elution rate in reservoir	K8	Calculated from the results of tests (mainly by a model test and the dry and wet repetition method)	Tailings Philex	Coefficient	Cu	Zn	As
		$K = \frac{K_1}{K_2 - K_1} (e^{-K_1 t} - e^{-K_2 t})$	Benguet Itogon				
				K1	0.554×10	0.242×10	0.4444×10
				K2	0.48934×10	0.36674×10	0.79644×10
				K1	0.55×10	0.3215×10	0.4502×10
				K2	0.61662×10	0.491×10	0.50362×10
Rate of precipitation reaction	K11	Estimation on the basis on the reaction speed consideration and results of fixed point observation and the pollution source investigation					
	 1 Maximum					
	 0 Appropriate					

0.1 NHCl extraction

	Cu (ppm)	Zn (ppm)	As (ppm)
Philex	145	63	0.14
Benguet	0.15	41	0.08
Irogon	<0.05	28	0.33
OH	Cu and Zn are all eluted.		
Natural sand	0		

Grain size distribution

Mine	Amount of tailings (t)	Totalized passage distribution									
		1 μ	2 μ	3 μ	4 μ	5 μ	6 μ	7 μ	8 μ	9 μ	10 μ
Philex	32,000	8.7	10.9	12.2	13.5	14.5	15.6	16.4	17.3	18.0	18.7
Benguet	2,275 (3,250)	11.5	13.3	15.4	16.8	18.1	19.5	20.9	21.9	23.1	24.5
Irogon	350	10.9	13.8	15.6	17.4	18.9	20.1	21.1	22.2	23.0	24.1

Dead water level in an SS calculation

195 ml

Contents of metals in fine grain

	Cu (ppm)	Zn (ppm)	As (ppm)
Philex	590	120	1.0
Benguet	240	840	100
Irogon	140	520	170
Natural sand	68	111	5.0

3.3 Results of the Calculation

All the calculation results are summarized in the Appendix E. This will describe the representative portion of each calculation.

3.3.1 Concentrations of Dissolved Matters

Two different data for the rate of inflow are employed in the calculations. When the average rate of flow estimated by the hydrologic analysis is repeated for 30 years, it is called the average flow rate. When the measured values for 21 years that are considered to be reliable are applied, it is called the measured flow rate.

When the values to be considered the most appropriate among the available data are input, they are called the appropriate values. When the worst conditions in the conceivable range (value to increase the estimated value) are input for the 3 variables, i.e., solubility limit of hydroxide, the residual rate of dissolved matters running down on the way, and the rate of precipitation reaction in the reservoir, they are called the worst values.

Run-1

This is the most basic calculation combining the average flow rates and the appropriate values. By this calculation the trend of seasonal fluctuation and long-term change can be estimated. At the end of this chapter the values for every 5 years of Run-1 are extracted and shown. The maximum values, minimum values and annual average values for the 15th year obtained by this calculation are as follows:

	Maximum value	Minimum value	Average for the 15th year
Cu	0.0081 mg/l	0.0024 mg/l	0.0044 mg/l
Zn	0.0312 mg/l	0.0137 mg/l	0.0191 mg/l
As	0.0046 mg/l	0.0030 mg/l	0.0034 mg/l

Run-2

Run-2 is the calculation combining the average flow rates and the worst values. By this calculation the estimated values in the worst case can be obtained. For the Run-2, too, the values for every 5 years are extracted and shown at the end. The maximum values, minimum values and annual average values for the 15th year obtained by this calculation are as follows; The "As" has the same values as in the Run-1.

	Maximum value	Minimum value	Average for the 15th year
Cu	0.0276 mg/l	0.0146 mg/l	0.0192 mg/l
Zn	0.0324 mg/l	0.0148 mg/l	0.0200 mg/l
As	0.0046 mg/l	0.0030 mg/l	0.0034 mg/l

Run-3

Run-3 is the calculation combining the measured flow rate and the appropriate value.

Since the measured flow rates include the records in the wet years and the dry years, the fluctuation range of the values naturally increases and the actually possible fluctuation range in the future can be forecasted. The records in the 25th year, 27th year, 28th year and 29th year are shown as the examples of the dry year, and the records in the 15th year, 17th year, 18th year and 19th year as the examples of the wet year, at the end of this Chapter. The maximum values and minimum values obtained by this calculation are as follows.

	Maximum value	Minimum value
Cu	0.0089 mg/l	0.0021 mg/l
Zn	0.0547 mg/l	0.0085 mg/l
As	0.0061 mg/l	0.0026 mg/l

Run-4

This is the calculation combining the measured flow rates and the worst values where the fluctuation range is wide.

The highest values in all the estimations are obtained in this calculation. As in the case of the Run-3, the examples of the dry years and the wet years are shown at the end of this Chapter.

The maximum values and minimum values obtained by this calculation are as follows. The "As" has the same values as in the Run-3.

	Maximum value	Minimum value
Cu	0.0313 mg/l	0.0082 mg/l
Zn	0.0554 mg/l	0.0100 mg/l
As	0.0061 mg/l	0.0026 mg/l

Case 1

A calculation extending for a period of 5 years was made as Case 1, changing only the solubility limit of hydroxide to the pH 7.5. This is a calculation of Run-1 with the pH decreasing temporarily as a special case.

Only the value of Cu changes in the calculation this time, but the values of Zn and As remain the same as in the Run-1.

Case 2 and Case 3

The calculation combining the average flow rates and the appropriate values was made as Case 2 where both gold mines of Benguet and Itogon are supposed to be closed in the 21st year. Another calculation combining the average flow rates and the appropriate values was made as Case 3 where the Philex mine is supposed to be closed in the 21st year. Since the long-term change is small, it is possible, to estimate the water quality after the mines are closed through these examples.

The values in the 2nd to the 5th years of Case 1 and values in the 27th to the 30th years in of Case 2 and in Case 3 are shown at the end of this Chapter.

3.3.2 Concentration of Suspended Solids

For the suspended solids, too, the Run-1 of average flow rate and Run-3 of measured flow rate calculations were made. The representative examples are shown at the end of this Chapter. The maximum values, minimum values and annual average values for the 15th year obtained by both calculations are as follows.

Run-1

	Maximum value	Minimum value	Average for the 15th year
SS concentration	2350 mg/l	350 mg/l	720 mg/l
T-Cu	570 ppm	390 ppm	490 ppm
S-Cu	140 ppm	88 ppm	120 ppm
T-Zn	190 ppm	160 ppm	170 ppm
S-Zn	65 ppm	41 ppm	53 ppm
T-As	11 ppm	9 ppm	10 ppm

Note) T: Total S: 0.1N HCl Soluble

Run-3

	Maximum value	Minimum value
SS concentration	6380 mg/l	130 mg/l
T-Cu	570 ppm	380 ppm
S-Cu	150 ppm	85 ppm
T-Zn	190 ppm	160 ppm
S-Zn	65 ppm	39 ppm
T-As	11 ppm	9 ppm

In addition to above two calculations, another two calculations were made. The calculation for the average flow rates was made as Case 2 in which both Benguet and Itogon gold mines are supposed to be closed in the 21st year.

The other calculation for the average flow rates was made as Case 3 in which the Philex mine is closed in the 21st year.

The values in the 27th to the 30th years are shown at the end of this Chapter.

Table IV-2 RESULTS OF CALCULATION ON DISSOLVED MATTERS OF RUN-1 & RUN-2 (1/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 1			Run 2	
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			Cu (mg/l)	Zn (mg/l)	As (mg/l)	Cu (mg/l)	Zn (mg/l)
2	1	30.3	93.3	0.0	0.0	272.7	753.05	0.0025	0.0179	0.0033	0.0192	0.0182
2	2	23.1	114.2	0.0	0.0	250.5	527.38	0.0024	0.0208	0.0035	0.0201	0.0210
2	3	19.8	97.1	0.0	0.0	225.1	317.55	0.0028	0.0235	0.0038	0.0213	0.0238
2	4	20.1	19.6	0.0	0.0	225.0	316.80	0.0035	0.0270	0.0042	0.0229	0.0275
2	5	40.4	39.9	0.0	0.0	225.0	316.43	0.0046	0.0293	0.0043	0.0246	0.0302
2	6	62.7	57.5	0.0	0.0	226.6	328.00	0.0054	0.0275	0.0041	0.0260	0.0287
2	7	120.4	50.8	0.0	0.0	249.1	512.58	0.0069	0.0209	0.0036	0.0229	0.0226
2	8	226.9	41.2	9.1	0.0	290.0	983.26	0.0069	0.0156	0.0032	0.0168	0.0174
2	9	216.2	39.4	176.0	0.0	290.0	982.69	0.0053	0.0144	0.0030	0.0151	0.0156
2	10	139.3	60.9	77.3	0.0	290.0	982.11	0.0044	0.0139	0.0030	0.0158	0.0148
2	11	75.8	62.2	12.2	0.0	290.0	981.54	0.0033	0.0150	0.0031	0.0179	0.0156
2	12	39.2	60.8	0.0	0.0	286.0	919.99	0.0026	0.0171	0.0033	0.0191	0.0174
5	1	30.3	93.4	0.0	0.0	272.6	736.24	0.0025	0.0196	0.0034	0.0201	0.0199
5	2	23.1	114.4	0.0	0.0	250.2	510.20	0.0024	0.0224	0.0036	0.0210	0.0226
5	3	19.8	95.1	0.0	0.0	225.1	305.68	0.0028	0.0250	0.0039	0.0221	0.0253
5	4	20.1	19.6	0.0	0.0	225.0	304.94	0.0036	0.0283	0.0043	0.0236	0.0288
5	5	40.4	39.9	0.0	0.0	225.0	304.57	0.0047	0.0304	0.0044	0.0252	0.0312
5	6	62.7	57.5	0.0	0.0	226.6	316.15	0.0055	0.0281	0.0041	0.0265	0.0293
5	7	120.4	50.7	0.0	0.0	249.4	500.89	0.0070	0.0210	0.0036	0.0231	0.0227
5	8	226.9	41.2	11.0	0.0	290.0	966.53	0.0070	0.0157	0.0032	0.0168	0.0176
5	9	216.2	39.4	176.0	0.0	290.0	965.97	0.0053	0.0145	0.0030	0.0151	0.0158
5	10	139.3	60.9	77.3	0.0	290.0	965.38	0.0045	0.0140	0.0030	0.0158	0.0149
5	11	75.8	62.2	12.2	0.0	290.0	964.82	0.0034	0.0151	0.0031	0.0179	0.0156
5	12	39.2	60.8	0.0	0.0	286.0	903.26	0.0027	0.0172	0.0033	0.0191	0.0175
10	1	30.3	93.4	0.0	0.0	272.4	708.23	0.0025	0.0197	0.0034	0.0202	0.0200
10	2	23.1	114.7	0.0	0.0	249.6	481.56	0.0025	0.0225	0.0036	0.0211	0.0228
10	3	19.8	91.8	0.0	0.0	225.1	285.91	0.0029	0.0252	0.0039	0.0222	0.0256
10	4	20.1	19.6	0.0	0.0	225.0	285.17	0.0037	0.0286	0.0044	0.0238	0.0291
10	5	40.4	39.9	0.0	0.0	225.0	284.81	0.0049	0.0306	0.0044	0.0255	0.0315
10	6	62.7	57.5	0.0	0.0	226.7	296.42	0.0057	0.0280	0.0042	0.0267	0.0293
10	7	120.4	50.6	0.0	0.0	249.9	431.40	0.0072	0.0207	0.0036	0.0231	0.0225
10	8	226.9	41.2	14.2	0.0	290.0	938.65	0.0072	0.0157	0.0031	0.0168	0.0175
10	9	216.2	39.4	176.0	0.0	290.0	938.09	0.0054	0.0146	0.0030	0.0151	0.0159
10	10	139.3	60.9	77.3	0.0	290.0	937.50	0.0045	0.0140	0.0030	0.0157	0.0149
10	11	75.8	62.2	12.2	0.0	290.0	936.94	0.0034	0.0151	0.0031	0.0180	0.0157
10	12	39.2	60.8	0.0	0.0	286.0	875.37	0.0027	0.0172	0.0033	0.0192	0.0176
15	1	30.3	93.5	0.0	0.0	272.3	680.21	0.0026	0.0198	0.0034	0.0203	0.0201
15	2	23.1	114.9	0.0	0.0	249.1	452.88	0.0025	0.0227	0.0036	0.0212	0.0230
15	3	19.8	88.5	0.0	0.0	225.1	266.14	0.0030	0.0254	0.0040	0.0224	0.0258
15	4	20.1	19.6	0.0	0.0	225.0	265.41	0.0039	0.0289	0.0044	0.0241	0.0294
15	5	40.4	39.9	0.0	0.0	225.0	265.05	0.0051	0.0308	0.0044	0.0257	0.0318
15	6	62.7	57.5	0.0	0.0	226.7	276.68	0.0059	0.0279	0.0042	0.0269	0.0292
15	7	120.4	50.5	0.0	0.0	250.4	461.93	0.0074	0.0203	0.0036	0.0231	0.0222
15	8	226.9	41.1	17.4	0.0	290.0	910.78	0.0073	0.0156	0.0031	0.0167	0.0175
15	9	216.2	39.4	176.0	0.0	290.0	910.21	0.0055	0.0146	0.0030	0.0150	0.0159
15	10	139.3	60.9	77.3	0.0	290.0	909.63	0.0046	0.0140	0.0030	0.0157	0.0150
15	11	75.8	62.2	12.2	0.0	290.0	909.06	0.0035	0.0151	0.0031	0.0180	0.0157
15	12	39.2	60.8	0.0	0.0	286.0	847.49	0.0027	0.0173	0.0033	0.0193	0.0176

As is the same as Run 1

Table IV-3 RESULTS OF CALCULATION ON DISSOLVED MATTERS OF RUN-1 & RUN-2 (2/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 1			Run 2	
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			Cu (mg/l)	Zn (mg/l)	As (mg/l)	Cu (mg/l)	Zn (mg/l)
20	1	30.3	93.5	0.0	0.0	272.1	652.19	0.0026	0.0199	0.0034	0.0203	0.0202
20	2	23.1	115.2	0.0	0.0	248.4	424.16	0.0026	0.0228	0.0037	0.0213	0.0231
20	3	19.8	85.2	0.0	0.0	225.1	246.38	0.0031	0.0256	0.0040	0.0226	0.0260
20	4	20.1	19.6	0.0	0.0	225.0	245.66	0.0040	0.0291	0.0045	0.0243	0.0297
20	5	40.4	39.9	0.0	0.0	225.0	245.30	0.0053	0.0310	0.0045	0.0260	0.0320
20	6	62.7	57.5	0.0	0.0	226.8	256.96	0.0061	0.0277	0.0042	0.0271	0.0291
20	7	120.4	50.4	0.0	0.0	250.9	442.47	0.0076	0.0199	0.0036	0.0230	0.0218
20	8	226.9	41.1	20.6	0.0	290.0	882.90	0.0074	0.0155	0.0031	0.0165	0.0174
20	9	216.2	39.4	176.0	0.0	290.0	882.33	0.0056	0.0146	0.0030	0.0149	0.0159
20	10	139.3	60.9	77.3	0.0	290.0	881.75	0.0047	0.0139	0.0030	0.0157	0.0149
20	11	75.8	62.2	12.2	0.0	290.0	881.18	0.0035	0.0151	0.0031	0.0180	0.0157
20	12	39.2	60.8	0.0	0.0	285.9	819.60	0.0028	0.0173	0.0033	0.0193	0.0176
25	1	30.3	93.6	0.0	0.0	271.9	621.14	0.0027	0.0200	0.0034	0.0204	0.0203
25	2	23.1	115.6	0.0	0.0	247.7	392.30	0.0026	0.0230	0.0037	0.0214	0.0233
25	3	19.8	81.4	0.0	0.0	225.1	224.56	0.0032	0.0258	0.0040	0.0228	0.0262
25	4	20.1	19.6	0.0	0.0	225.0	223.86	0.0042	0.0294	0.0045	0.0246	0.0300
25	5	40.4	39.9	0.0	0.0	225.0	223.49	0.0055	0.0311	0.0045	0.0263	0.0322
25	6	62.7	57.5	0.0	0.0	226.8	235.06	0.0064	0.0274	0.0042	0.0273	0.0289
25	7	120.4	50.3	0.0	0.0	251.4	420.75	0.0078	0.0194	0.0036	0.0230	0.0213
25	8	226.9	41.0	24.1	0.0	290.0	851.64	0.0075	0.0153	0.0031	0.0164	0.0172
25	9	216.2	39.4	176.0	0.0	290.0	850.96	0.0057	0.0146	0.0030	0.0148	0.0159
25	10	139.3	60.9	77.3	0.0	290.0	850.24	0.0048	0.0138	0.0030	0.0156	0.0149
25	11	75.8	62.2	12.2	0.0	290.0	849.56	0.0036	0.0150	0.0031	0.0180	0.0156
25	12	39.2	60.8	0.0	0.0	285.9	787.96	0.0028	0.0173	0.0033	0.0194	0.0176
30	1	30.3	93.6	0.0	0.0	271.7	589.34	0.0027	0.0200	0.0035	0.0205	0.0204
30	2	23.1	115.9	0.0	0.0	246.9	359.59	0.0027	0.0231	0.0037	0.0216	0.0234
30	3	19.8	77.5	0.0	0.0	225.1	202.24	0.0034	0.0259	0.0041	0.0230	0.0263
30	4	20.1	19.6	0.0	0.0	225.0	201.54	0.0045	0.0296	0.0046	0.0250	0.0303
30	5	40.4	39.9	0.0	0.0	225.0	201.18	0.0058	0.0312	0.0046	0.0266	0.0324
30	6	62.7	57.5	0.0	0.0	226.9	212.79	0.0067	0.0270	0.0042	0.0276	0.0285
30	7	120.4	50.2	0.0	0.0	252.0	398.79	0.0081	0.0187	0.0035	0.0229	0.0208
30	8	226.9	41.0	27.8	0.0	290.0	820.02	0.0077	0.0150	0.0031	0.0162	0.0171
30	9	216.2	39.4	176.0	0.0	290.0	819.33	0.0058	0.0145	0.0030	0.0146	0.0158
30	10	139.3	60.9	77.3	0.0	290.0	818.62	0.0048	0.0137	0.0030	0.0155	0.0148
30	11	75.8	62.2	12.2	0.0	290.0	817.93	0.0036	0.0149	0.0031	0.0181	0.0156
30	12	39.2	60.8	0.0	0.0	285.9	756.32	0.0029	0.0173	0.0033	0.0194	0.0176

Table IV-4 RESULTS OF CALCULATION ON DISSOLVED MATTERS OF RUN-3 & RUN-4 (1/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 3			Run 4	
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			Cu (mg/l)	Zn (mg/l)	As (mg/l)	Cu (mg/l)	Zn (mg/l)
15	1	17.2	101.9	0.0	0.0	253.5	490.28	0.0024	0.0229	0.0037	0.0196	0.0231
15	2	18.8	110.9	0.0	0.0	225.1	262.91	0.0027	0.0262	0.0040	0.0207	0.0265
15	3	10.0	9.4	0.0	0.0	225.0	262.13	0.0032	0.0306	0.0046	0.0223	0.0309
15	4	24.1	23.5	0.0	0.0	225.0	261.78	0.0042	0.0369	0.0049	0.0241	0.0376
15	5	17.1	16.6	0.0	0.0	225.0	261.41	0.0038	0.0424	0.0052	0.0255	0.0429
15	6	21.4	20.9	0.0	0.0	225.0	260.85	0.0040	0.0467	0.0054	0.0267	0.0473
15	7	55.7	55.3	0.0	0.0	225.0	260.26	0.0058	0.0396	0.0049	0.0275	0.0408
15	8	502.1	47.4	211.0	0.0	290.0	910.78	0.0058	0.0130	0.0029	0.0100	0.0154
15	9	255.3	40.1	214.5	0.0	290.0	910.21	0.0054	0.0122	0.0029	0.0127	0.0136
15	10	282.2	64.1	217.0	0.0	290.0	909.63	0.0052	0.0107	0.0028	0.0120	0.0122
15	11	99.5	62.4	35.7	0.0	290.0	909.06	0.0039	0.0115	0.0029	0.0145	0.0123
15	12	57.0	60.2	0.0	0.0	289.2	896.48	0.0031	0.0135	0.0030	0.0166	0.0140
17	1	7.9	105.0	0.0	0.0	246.4	419.09	0.0021	0.0268	0.0039	0.0203	0.0269
17	2	8.0	74.4	0.0	0.0	225.0	254.60	0.0024	0.0313	0.0043	0.0212	0.0314
17	3	8.1	7.5	0.0	0.0	225.0	253.92	0.0031	0.0371	0.0050	0.0227	0.0374
17	4	8.6	8.0	0.0	0.0	225.0	253.57	0.0031	0.0479	0.0056	0.0241	0.0481
17	5	229.4	46.1	0.0	0.0	278.7	742.31	0.0086	0.0223	0.0036	0.0152	0.0246
17	6	175.9	39.5	74.1	0.0	290.0	900.79	0.0057	0.0198	0.0033	0.0150	0.0211
17	7	156.8	37.5	118.5	0.0	290.0	900.21	0.0049	0.0177	0.0032	0.0153	0.0187
17	8	178.6	37.7	140.2	0.0	290.0	899.62	0.0052	0.0156	0.0031	0.0149	0.0167
17	9	244.6	39.9	204.0	0.0	290.0	899.06	0.0053	0.0133	0.0029	0.0133	0.0147
17	10	60.0	60.1	0.0	0.0	289.8	895.07	0.0032	0.0143	0.0031	0.0163	0.0148
17	11	54.3	62.5	0.0	0.0	288.2	869.94	0.0030	0.0164	0.0032	0.0180	0.0169
17	12	58.5	60.8	0.0	0.0	287.6	859.94	0.0032	0.0180	0.0033	0.0197	0.0185
18	1	27.1	92.6	0.0	0.0	273.8	680.68	0.0025	0.0206	0.0035	0.0206	0.0208
18	2	14.5	114.5	0.0	0.0	248.6	433.32	0.0022	0.0239	0.0037	0.0214	0.0241
18	3	10.3	77.4	0.0	0.0	225.1	251.01	0.0026	0.0277	0.0042	0.0224	0.0279
18	4	14.9	14.4	0.0	0.0	225.0	250.29	0.0036	0.0324	0.0047	0.0240	0.0328
18	5	18.5	18.0	0.0	0.0	225.0	249.92	0.0040	0.0391	0.0051	0.0254	0.0396
18	6	15.7	15.2	0.0	0.0	225.0	249.36	0.0037	0.0458	0.0055	0.0266	0.0463
18	7	108.0	51.9	0.0	0.0	244.6	397.67	0.0074	0.0305	0.0042	0.0240	0.0323
18	8	561.1	45.7	260.3	69.0	290.0	894.05	0.0052	0.0129	0.0029	0.0100	0.0149
18	9	726.0	41.1	264.9	419.2	290.0	893.48	0.0041	0.0092	0.0026	0.0082	0.0105
18	10	275.0	63.9	210.0	0.0	290.0	892.90	0.0053	0.0085	0.0027	0.0092	0.0100
18	11	60.1	62.2	0.0	0.0	289.4	883.39	0.0032	0.0102	0.0028	0.0121	0.0107
18	12	24.9	61.4	0.0	0.0	282.4	781.82	0.0024	0.0133	0.0031	0.0146	0.0135
19	1	21.7	96.5	0.0	0.0	264.7	577.96	0.0024	0.0167	0.0033	0.0158	0.0169
19	2	20.4	123.4	0.0	0.0	235.6	323.88	0.0026	0.0202	0.0036	0.0172	0.0204
19	3	24.0	51.9	0.0	0.0	225.0	246.74	0.0038	0.0227	0.0040	0.0196	0.0233
19	4	10.0	9.4	0.0	0.0	225.0	246.23	0.0033	0.0304	0.0046	0.0213	0.0308
19	5	43.0	42.5	0.0	0.0	225.0	245.86	0.0054	0.0322	0.0045	0.0239	0.0333
19	6	64.3	57.4	0.0	0.0	227.4	261.99	0.0062	0.0281	0.0042	0.0259	0.0295
19	7	213.7	46.0	0.0	0.0	276.9	709.05	0.0088	0.0160	0.0032	0.0165	0.0183
19	8	244.8	39.1	137.8	0.0	290.0	888.47	0.0061	0.0144	0.0030	0.0140	0.0161
19	9	350.2	41.1	264.9	43.4	290.0	887.91	0.0050	0.0117	0.0028	0.0112	0.0134
19	10	188.3	61.7	125.5	0.0	290.0	887.32	0.0053	0.0110	0.0028	0.0131	0.0122
19	11	58.2	62.3	0.0	0.0	289.1	872.76	0.0031	0.0127	0.0030	0.0154	0.0132
19	12	18.2	61.8	0.0	0.0	280.6	752.34	0.0022	0.0158	0.0032	0.0164	0.0160

As is the same as Run 3

Table IV-5 RESULTS OF CALCULATION ON DISSOLVED MATTERS OF RUN-3 & RUN-4 (2/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 3			Run 4	
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			Cu (mg/l)	Zn (mg/l)	As (mg/l)	Cu (mg/l)	Zn (mg/l)
25	1	21.1	96.1	0.0	0.0	265.4	551.59	0.0024	0.0217	0.0036	0.0206	0.0219
25	2	18.0	123.4	0.0	0.0	234.9	291.66	0.0296	0.0251	0.0038	0.0215	0.0253
25	3	13.0	38.1	0.0	0.0	225.0	221.96	0.0033	0.0287	0.0044	0.0230	0.0290
25	4	18.7	18.1	0.0	0.0	225.0	221.45	0.0042	0.0346	0.0049	0.0248	0.0352
25	5	37.1	36.6	0.0	0.0	225.0	221.09	0.0054	0.0356	0.0048	0.0264	0.0366
25	6	56.3	55.8	0.0	0.0	225.0	220.40	0.0062	0.0313	0.0044	0.0274	0.0326
25	7	49.5	49.1	0.0	0.0	225.0	219.69	0.0060	0.0284	0.0043	0.0281	0.0296
25	8	180.6	47.8	0.0	0.0	267.9	573.49	0.0089	0.0165	0.0033	0.0184	0.0188
25	9	154.2	40.4	5.8	0.0	290.0	850.96	0.0061	0.0169	0.0032	0.0176	0.0183
25	10	139.1	60.9	77.1	0.0	290.0	850.24	0.0048	0.0167	0.0031	0.0176	0.0177
25	11	58.2	62.3	0.0	0.0	289.1	835.55	0.0032	0.0178	0.0032	0.0193	0.0183
25	12	31.8	61.3	0.0	0.0	283.4	752.71	0.0026	0.0202	0.0034	0.0204	0.0205
27	1	31.3	91.5	0.0	0.0	276.8	663.47	0.0026	0.0180	0.0033	0.0198	0.0183
27	2	19.6	111.4	0.0	0.0	254.3	436.22	0.0024	0.0212	0.0036	0.0207	0.0215
27	3	17.0	99.1	0.0	0.0	225.1	213.39	0.0029	0.0245	0.0039	0.0220	0.0248
27	4	18.8	18.4	0.0	0.0	225.0	212.58	0.0043	0.0279	0.0045	0.0240	0.0285
27	5	19.9	19.4	0.0	0.0	225.0	212.22	0.0044	0.0352	0.0049	0.0257	0.0359
27	6	24.1	23.6	0.0	0.0	225.0	211.53	0.0046	0.0401	0.0052	0.0270	0.0409
27	7	37.1	36.7	0.0	0.0	225.0	210.82	0.0055	0.0388	0.0050	0.0280	0.0398
27	8	148.8	49.3	0.0	0.0	259.0	475.48	0.0086	0.0217	0.0037	0.0204	0.0239
27	9	182.9	41.4	0.6	0.0	290.0	838.30	0.0070	0.0184	0.0033	0.0173	0.0201
27	10	121.0	60.6	59.2	0.0	290.0	837.59	0.0046	0.0185	0.0032	0.0181	0.0194
27	11	143.0	63.0	78.7	0.0	290.0	836.91	0.0048	0.0170	0.0032	0.0178	0.0181
27	12	65.4	60.1	3.9	0.0	290.0	836.54	0.0034	0.0178	0.0033	0.0197	0.0183
28	1	26.1	91.2	0.0	0.0	276.9	658.30	0.0025	0.0205	0.0035	0.0206	0.0207
28	2	18.6	111.5	0.0	0.0	254.0	428.24	0.0024	0.0237	0.0037	0.0215	0.0239
28	3	13.1	94.0	0.0	0.0	225.1	208.62	0.0027	0.0272	0.0041	0.0226	0.0274
28	4	11.3	10.9	0.0	0.0	225.0	207.81	0.0037	0.0323	0.0048	0.0243	0.0327
28	5	15.3	15.3	0.0	0.0	225.0	207.45	0.0042	0.0413	0.0053	0.0259	0.0418
28	6	21.5	21.0	0.0	0.0	225.0	206.76	0.0045	0.0464	0.0055	0.0272	0.0471
28	7	46.7	46.3	0.0	0.0	225.0	206.05	0.0061	0.0403	0.0050	0.0280	0.0415
28	8	84.3	53.5	0.0	0.0	236.7	286.76	0.0074	0.0281	0.0042	0.0276	0.0298
28	9	107.4	49.5	0.0	0.0	255.2	434.82	0.0070	0.0227	0.0037	0.0249	0.0244
28	10	81.4	73.2	0.0	0.0	257.4	453.78	0.0054	0.0227	0.0036	0.0261	0.0238
28	11	42.0	78.0	0.0	0.0	246.2	357.46	0.0039	0.0245	0.0038	0.0269	0.0252
28	12	17.2	73.7	0.0	0.0	225.0	203.83	0.0032	0.0285	0.0042	0.0276	0.0289
29	1	21.9	21.3	0.0	0.0	225.0	203.18	0.0047	0.0313	0.0047	0.0287	0.0320
29	2	14.3	13.6	0.0	0.0	225.0	202.85	0.0039	0.0406	0.0052	0.0297	0.0411
29	3	12.4	11.7	0.0	0.0	225.0	202.49	0.0039	0.0490	0.0058	0.0306	0.0495
29	4	18.1	17.5	0.0	0.0	225.0	202.14	0.0043	0.0547	0.0061	0.0311	0.0554
29	5	26.9	26.4	0.0	0.0	225.0	201.77	0.0050	0.0534	0.0059	0.0312	0.0543
29	6	24.0	23.5	0.0	0.0	225.0	201.09	0.0048	0.0535	0.0060	0.0313	0.0542
29	7	40.9	40.5	0.0	0.0	225.0	200.37	0.0059	0.0462	0.0054	0.0307	0.0474
29	8	82.6	53.6	0.0	0.0	236.0	276.19	0.0074	0.0312	0.0044	0.0291	0.0330
29	9	170.0	46.9	0.0	0.0	272.1	593.18	0.0082	0.0200	0.0035	0.0204	0.0220
29	10	84.2	65.6	0.0	0.0	276.2	639.49	0.0047	0.0214	0.0035	0.0224	0.0223
29	11	74.7	66.8	0.0	0.0	277.7	656.29	0.0041	0.0217	0.0035	0.0239	0.0225
29	12	54.7	64.8	0.0	0.0	275.1	625.83	0.0036	0.0227	0.0036	0.0249	0.0233

Table IV-6 RESULTS OF CALCULATION ON DISSOLVED MATTERS OF CASE-1

Year	Month	Case 1		
		Cu (mg/l)	Zn (mg/l)	As (mg/l)
2	1	0.0141	0.0179	0.0033
2	2	0.0142	0.0208	0.0035
2	3	0.0143	0.0235	0.0038
2	4	0.0144	0.0270	0.0042
2	5	0.0141	0.0293	0.0043
2	6	0.0138	0.0275	0.0041
2	7	0.0133	0.0209	0.0036
2	8	0.0127	0.0156	0.0032
2	9	0.0133	0.0144	0.0030
2	10	0.0136	0.0139	0.0030
2	11	0.0139	0.0150	0.0031
2	12	0.0141	0.0171	0.0033
3	1	0.0141	0.0195	0.0034
3	2	0.0142	0.0223	0.0036
3	3	0.0143	0.0249	0.0039
3	4	0.0144	0.0282	0.0043
3	5	0.0141	0.0302	0.0043
3	6	0.0138	0.0281	0.0041
3	7	0.0133	0.0211	0.0036
3	8	0.0127	0.0157	0.0032
3	9	0.0133	0.0145	0.0030
3	10	0.0136	0.0139	0.0030
3	11	0.0139	0.0151	0.0031
3	12	0.0141	0.0171	0.0033
4	1	0.0141	0.0196	0.0034
4	2	0.0142	0.0223	0.0036
4	3	0.0143	0.0250	0.0039
4	4	0.0144	0.0283	0.0043
4	5	0.0141	0.0303	0.0044
4	6	0.0138	0.0281	0.0041
4	7	0.0133	0.0211	0.0036
4	8	0.0127	0.0157	0.0032
4	9	0.0133	0.0145	0.0030
4	10	0.0136	0.0140	0.0030
4	11	0.0139	0.0151	0.0031
4	12	0.0141	0.0171	0.0033
5	1	0.0141	0.0196	0.0034
5	2	0.0142	0.0224	0.0036
5	3	0.0143	0.0250	0.0039
5	4	0.0144	0.0283	0.0043
5	5	0.0141	0.0304	0.0044
5	6	0.0138	0.0281	0.0041
5	7	0.0133	0.0210	0.0036
5	8	0.0127	0.0157	0.0032
5	9	0.0133	0.0145	0.0030
5	10	0.0136	0.0140	0.0030
5	11	0.0139	0.0151	0.0031
5	12	0.0141	0.0172	0.0033

Table IV-7 RESULTS OF CALCULATION ON DISSOLVED MATTERS OF CASE-2 & CASE-3

Year	Month	Case 2			Case 3		
		Cu (mg/l)	Zn (mg/l)	As (mg/l)	Cu (mg/l)	Zn (mg/l)	As (mg/l)
27	1	0.0018	0.0070	0.0024	0.0024	0.0196	0.0034
27	2	0.0019	0.0070	0.0025	0.0023	0.0225	0.0036
27	3	0.0021	0.0071	0.0025	0.0026	0.0251	0.0040
27	4	0.0026	0.0072	0.0025	0.0033	0.0286	0.0045
27	5	0.0026	0.0070	0.0025	0.0047	0.0304	0.0045
27	6	0.0025	0.0068	0.0025	0.0057	0.0269	0.0042
27	7	0.0025	0.0066	0.0024	0.0073	0.0192	0.0036
27	8	0.0024	0.0073	0.0024	0.0072	0.0150	0.0031
27	9	0.0021	0.0075	0.0024	0.0055	0.0142	0.0030
27	10	0.0020	0.0071	0.0024	0.0045	0.0136	0.0030
27	11	0.0019	0.0070	0.0024	0.0033	0.0147	0.0031
27	12	0.0018	0.0070	0.0024	0.0025	0.0169	0.0032
28	1	0.0018	0.0070	0.0024	0.0024	0.0196	0.0034
28	2	0.0019	0.0070	0.0025	0.0023	0.0225	0.0037
28	3	0.0022	0.0071	0.0025	0.0026	0.0251	0.0040
28	4	0.0026	0.0072	0.0025	0.0033	0.0286	0.0045
28	5	0.0026	0.0070	0.0025	0.0047	0.0304	0.0045
28	6	0.0026	0.0068	0.0025	0.0057	0.0269	0.0042
28	7	0.0026	0.0066	0.0024	0.0073	0.0191	0.0036
28	8	0.0024	0.0073	0.0024	0.0072	0.0149	0.0031
28	9	0.0021	0.0076	0.0024	0.0055	0.0142	0.0030
28	10	0.0020	0.0072	0.0024	0.0045	0.0135	0.0030
28	11	0.0019	0.0070	0.0024	0.0033	0.0147	0.0031
28	12	0.0018	0.0070	0.0024	0.0025	0.0169	0.0032
29	1	0.0018	0.0070	0.0024	0.0024	0.0195	0.0034
29	2	0.0019	0.0071	0.0025	0.0023	0.0225	0.0037
29	3	0.0022	0.0071	0.0025	0.0026	0.0251	0.0040
29	4	0.0026	0.0072	0.0025	0.0033	0.0286	0.0045
29	5	0.0026	0.0070	0.0025	0.0047	0.0304	0.0045
29	6	0.0026	0.0068	0.0025	0.0057	0.0269	0.0042
29	7	0.0026	0.0066	0.0024	0.0073	0.0191	0.0035
29	8	0.0024	0.0073	0.0024	0.0072	0.0149	0.0031
29	9	0.0021	0.0076	0.0024	0.0055	0.0141	0.0030
29	10	0.0020	0.0072	0.0024	0.0045	0.0135	0.0030
29	11	0.0019	0.0070	0.0024	0.0033	0.0147	0.0031
29	12	0.0018	0.0070	0.0024	0.0025	0.0169	0.0032
30	1	0.0018	0.0070	0.0024	0.0024	0.0195	0.0034
30	2	0.0019	0.0071	0.0025	0.0023	0.0225	0.0037
30	3	0.0022	0.0071	0.0025	0.0026	0.0251	0.0040
30	4	0.0026	0.0072	0.0025	0.0033	0.0286	0.0045
30	5	0.0026	0.0070	0.0025	0.0047	0.0304	0.0045
30	6	0.0026	0.0068	0.0025	0.0057	0.0269	0.0042
30	7	0.0025	0.0066	0.0024	0.0074	0.0190	0.0035
30	8	0.0024	0.0074	0.0024	0.0072	0.0148	0.0031
30	9	0.0021	0.0076	0.0024	0.0055	0.0141	0.0030
30	10	0.0020	0.0072	0.0024	0.0045	0.0135	0.0030
30	11	0.0019	0.0070	0.0024	0.0033	0.0146	0.0031
30	12	0.0018	0.0070	0.0024	0.0025	0.0169	0.0032

Note: The volume of stored water and others differ from Run 1 depending upon the volume of sediments.

Table IV-8 RESULTS OF CALCULATION ON SUSPENDED SOLIDS OF RUN-1 (1/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (×10 ⁶ m ³)	Run 1						
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			SS (mg/l)	T-Cu (ppm)	T-Zn (ppm)	T-As (ppm)	S-Cu (ppm)	S-Zn (ppm)	S-As (ppm)
2	1	30.3	93.3	0.0	0.0	272.7	753.05	551	597	190	11	172	68	0
2	2	23.1	114.2	0.0	0.0	250.5	527.38	475	614	192	11	189	70	0
2	3	19.8	97.1	0.0	0.0	225.1	317.55	558	617	195	11	193	73	0
2	4	20.1	19.6	0.0	0.0	225.0	316.80	2245	576	186	11	151	65	0
2	5	40.4	39.9	0.0	0.0	225.0	316.43	1222	592	191	11	168	68	0
2	6	62.7	57.5	0.0	0.0	226.6	328.00	1192	469	172	10	132	52	0
2	7	120.4	50.8	0.0	0.0	249.1	512.58	1326	453	170	10	118	50	0
2	8	226.9	41.2	9.1	0.0	290.0	983.26	1300	441	167	10	109	48	0
2	9	216.2	39.4	176.0	0.0	290.0	982.69	352	483	174	10	138	54	0
2	10	139.3	60.9	77.3	0.0	290.0	982.11	519	467	171	10	126	52	0
2	11	75.8	62.2	12.2	0.0	290.0	981.54	889	450	169	10	117	49	0
2	12	39.2	60.8	0.0	0.0	286.0	919.99	787	582	187	11	158	65	0
5	1	30.3	93.4	0.0	0.0	272.6	736.24	552	601	190	11	176	68	0
5	2	23.1	114.4	0.0	0.0	250.2	510.20	476	618	192	11	194	70	0
5	3	19.8	95.1	0.0	0.0	225.1	305.68	570	620	195	11	195	73	0
5	4	20.1	19.6	0.0	0.0	225.0	304.94	2258	577	186	11	152	65	0
5	5	40.4	39.9	0.0	0.0	225.0	304.57	1228	593	191	11	169	68	0
5	6	62.7	57.5	0.0	0.0	226.6	316.15	1196	470	172	10	133	53	0
5	7	120.4	50.7	0.0	0.0	249.4	500.89	1332	453	170	10	118	50	0
5	8	226.9	41.2	11.0	0.0	290.0	966.53	1261	442	168	10	109	48	0
5	9	216.2	39.4	176.0	0.0	290.0	965.97	352	483	174	10	138	54	0
5	10	139.3	60.9	77.3	0.0	290.0	965.38	520	467	172	10	126	52	0
5	11	75.8	62.2	12.2	0.0	290.0	964.82	890	451	169	10	117	49	0
5	12	39.2	60.8	0.0	0.0	286.0	903.26	788	582	188	11	158	65	0
10	1	30.3	93.4	0.0	0.0	272.4	708.23	554	601	190	11	176	68	0
10	2	23.1	114.7	0.0	0.0	249.6	481.56	477	619	192	11	194	70	0
10	3	19.3	91.8	0.0	0.0	225.1	285.91	590	619	195	11	194	73	0
10	4	20.1	19.6	0.0	0.0	225.0	285.17	2275	577	187	11	152	66	0
10	5	40.4	39.9	0.0	0.0	225.0	284.81	1238	593	191	11	169	69	0
10	6	62.7	57.5	0.0	0.0	226.7	296.42	1205	471	173	10	133	53	0
10	7	120.4	50.6	0.0	0.0	249.9	481.40	1342	454	170	10	118	50	0
10	8	226.9	41.2	14.2	0.0	290.0	938.65	1202	444	168	10	110	48	0
10	9	216.2	39.4	176.0	0.0	290.0	938.09	353	483	174	10	137	54	0
10	10	139.3	60.9	77.3	0.0	290.0	937.50	521	467	172	10	126	52	0
10	11	75.8	62.2	12.2	0.0	290.0	936.94	892	451	169	10	116	49	0
10	12	39.2	60.8	0.0	0.0	286.0	875.37	791	582	188	11	158	65	0
15	1	30.3	93.5	0.0	0.0	272.3	680.21	556	601	191	11	176	68	0
15	2	23.1	114.9	0.0	0.0	249.1	452.88	479	619	193	11	194	71	0
15	3	19.8	88.5	0.0	0.0	225.1	266.14	613	618	195	11	193	73	0
15	4	20.1	19.6	0.0	0.0	225.0	265.41	2291	577	187	11	153	66	0
15	5	40.4	39.9	0.0	0.0	225.0	265.05	1249	594	192	11	169	69	0
15	6	62.7	57.5	0.0	0.0	226.7	276.68	1214	472	173	10	133	53	0
15	7	120.4	50.5	0.0	0.0	250.4	461.93	1353	454	170	10	117	51	0
15	8	226.9	41.1	17.4	0.0	290.0	910.78	1149	445	168	10	110	49	0
15	9	216.2	39.4	176.0	0.0	290.0	910.21	354	482	174	10	136	54	0
15	10	139.3	60.9	77.3	0.0	290.0	909.63	522	467	172	10	125	52	0
15	11	75.8	62.2	12.2	0.0	290.0	909.06	894	451	169	10	116	49	0
15	12	39.2	60.8	0.0	0.0	286.0	847.49	793	582	188	11	158	66	0

Table IV-9 RESULTS OF CALCULATION ON SUSPENDED SOLIDS OF RUN-1 (2/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 1						
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			SS (mg/l)	T-Cu (mg/l)	T-Zn (mg/l)	T-As (mg/l)	S-Cu (ppm)	S-Zn (ppm)	S-As (ppm)
20	1	30.3	93.5	0.0	0.0	272.1	652.19	558	601	191	11	177	68	0
20	2	23.1	115.2	0.0	0.0	248.4	424.16	480	620	193	11	195	71	0
20	3	19.8	85.2	0.0	0.0	225.1	246.38	637	616	196	11	192	73	0
20	4	20.1	19.6	0.0	0.0	225.0	245.66	2308	578	187	11	153	66	0
20	5	40.4	39.9	0.0	0.0	225.0	245.30	1260	594	192	11	170	69	0
20	6	62.7	57.5	0.0	0.0	226.8	256.96	1223	472	173	10	133	54	0
20	7	120.4	50.4	0.0	0.0	250.9	442.47	1365	454	170	10	117	51	0
20	8	226.9	41.1	20.6	0.0	290.0	882.90	1102	447	169	10	110	49	0
20	9	216.2	39.4	176.0	0.0	290.0	882.33	355	481	174	10	135	55	0
20	10	139.3	60.9	77.3	0.0	290.0	881.75	524	467	172	10	125	52	0
20	11	75.8	62.2	12.2	0.0	290.0	881.18	896	451	169	10	116	49	0
20	12	39.2	60.8	0.0	0.0	285.9	819.60	795	582	188	11	157	66	0
25	1	30.3	93.6	0.0	0.0	271.9	621.14	560	601	191	11	177	69	0
25	2	23.1	115.6	0.0	0.0	247.7	392.30	481	620	194	11	196	71	0
25	3	19.8	81.4	0.0	0.0	225.1	224.56	667	615	196	11	190	74	0
25	4	20.1	19.6	0.0	0.0	225.0	223.86	2329	578	188	11	153	67	0
25	5	40.4	39.9	0.0	0.0	225.0	223.49	1274	594	192	11	170	70	0
25	6	62.7	57.5	0.0	0.0	226.8	235.06	1403	425	166	9	117	48	0
25	7	120.4	50.3	0.0	0.0	251.4	420.75	1571	407	163	9	102	45	0
25	8	226.9	41.0	24.1	0.0	290.0	851.64	1202	401	162	9	97	43	0
25	9	216.2	39.4	176.0	0.0	290.0	850.96	401	434	168	9	119	49	0
25	10	139.3	60.9	77.3	0.0	290.0	850.24	595	420	165	9	110	46	0
25	11	75.8	62.2	12.2	0.0	290.0	849.56	1028	403	162	9	101	43	0
25	12	39.2	60.8	0.0	0.0	285.9	787.96	798	582	188	11	157	66	0
30	1	30.3	93.6	0.0	0.0	271.7	589.34	562	601	191	11	177	69	0
30	2	23.1	115.9	0.0	0.0	246.9	359.59	482	621	194	11	196	72	0
30	3	19.8	77.5	0.0	0.0	225.1	202.24	701	613	196	11	189	74	0
30	4	20.1	19.6	0.0	0.0	225.0	201.54	2353	579	189	11	154	67	0
30	5	40.4	39.9	0.0	0.0	225.0	201.18	1290	595	193	11	170	70	0
30	6	62.7	57.5	0.0	0.0	226.9	212.79	1417	426	167	9	117	48	0
30	7	120.4	50.2	0.0	0.0	252.0	398.79	1587	408	164	9	102	45	0
30	8	226.9	41.0	27.8	0.0	290.0	820.02	1151	403	162	9	98	44	0
30	9	216.2	39.4	176.0	0.0	290.0	819.33	403	434	168	9	118	49	0
30	10	139.3	60.9	77.3	0.0	290.0	818.62	596	419	165	9	109	47	0
30	11	75.8	62.2	12.0	0.0	290.0	817.93	1031	403	162	9	101	43	0
30	12	39.2	60.8	0.0	0.0	285.9	756.32	801	582	188	11	157	66	0

Table IV-10 RESULTS OF CALCULATION ON SUSPENDED SOLIDS OF RUN-3 (1/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 3						
			Primary Generation	Secondary Generation (m ³ /s)	Over-flow			SS (mg/l)	T-Cu (ppm)	T-Zn (ppm)	T-As (ppm)	S-Cu (ppm)	S-Zn (ppm)	S-As (ppm)
15	1	17.2	101.9	0.0	0.0	253.5	490.28	525	615	193	11	190	70	0
15	2	18.8	110.9	0.0	0.0	225.1	262.91	505	631	196	11	206	74	0
15	3	10.0	9.4	0.0	0.0	225.0	262.13	4208	568	187	11	144	64	0
15	4	24.1	23.5	0.0	0.0	225.0	261.78	1963	586	188	11	162	67	0
15	5	17.1	16.6	0.0	0.0	225.0	261.41	2644	583	187	11	158	66	0
15	6	21.4	20.9	0.0	0.0	225.0	260.85	2971	449	167	9	121	48	0
15	7	55.7	55.3	0.0	0.0	225.0	260.26	1258	484	173	10	146	53	0
15	8	502.1	47.4	211.0	0.0	290.0	910.78	334	491	177	10	136	56	0
15	9	255.3	40.1	214.5	0.0	290.0	910.21	307	479	175	10	131	55	0
15	10	282.2	64.1	217.0	0.0	290.0	909.63	283	477	176	10	128	56	0
15	11	99.5	62.4	35.7	0.0	290.0	909.06	702	452	170	10	114	50	0
15	12	57.0	60.2	0.0	0.0	289.2	896.48	799	575	188	11	150	65	0
17	1	7.9	105.0	0.0	0.0	246.4	419.09	515	628	194	11	204	71	0
17	2	8.0	74.4	0.0	0.0	225.0	254.60	711	622	194	11	197	72	0
17	3	8.1	7.5	0.0	0.0	225.0	253.92	5131	568	187	11	144	63	0
17	4	8.6	8.0	0.0	0.0	225.0	253.57	4868	572	187	11	147	64	0
17	5	229.4	46.1	0.0	0.0	278.7	742.31	1113	577	187	11	152	65	0
17	6	175.9	39.5	74.1	0.0	290.0	900.79	628	472	171	10	132	51	0
17	7	156.8	37.5	118.5	0.0	290.0	900.21	470	481	173	10	138	53	0
17	8	178.6	37.7	140.2	0.0	290.0	899.62	419	480	173	10	136	54	0
17	9	244.6	39.9	204.0	0.0	290.0	899.06	319	484	175	10	136	55	0
17	10	60.0	60.1	0.0	0.0	289.8	895.07	1080	445	168	10	112	48	0
17	11	54.3	62.5	0.0	0.0	288.2	869.94	1045	449	168	10	116	49	0
17	12	58.5	60.8	0.0	0.0	287.6	859.94	796	583	188	11	158	65	0
18	1	27.1	92.6	0.0	0.0	273.8	680.68	359	603	191	11	179	68	0
18	2	14.5	114.5	0.0	0.0	248.6	433.32	480	624	193	11	199	71	0
18	3	10.3	77.4	0.0	0.0	225.1	251.01	687	618	195	11	193	73	0
18	4	14.9	14.4	0.0	0.0	225.0	250.29	2981	575	187	11	150	65	0
18	5	18.5	18.0	0.0	0.0	225.0	249.92	2484	582	187	11	157	66	0
18	6	15.7	15.2	0.0	0.0	225.0	249.36	3956	439	166	9	114	47	0
18	7	108.0	51.9	0.0	0.0	244.6	397.67	1334	468	171	10	130	51	0
18	8	561.1	45.7	260.3	69.0	290.0	894.05	235	504	178	10	148	58	0
18	9	726.0	41.1	264.9	419.2	290.0	893.48	126	500	182	10	142	60	0
18	10	275.0	63.9	210.0	0.0	290.0	892.90	290	466	176	10	117	56	0
18	11	60.1	62.2	0.0	0.0	289.4	883.39	1049	440	168	10	107	48	0
18	12	24.9	61.4	0.0	0.0	282.4	781.82	787	576	188	11	152	66	0
19	1	21.7	96.5	0.0	0.0	264.7	577.96	546	596	192	11	171	69	0
19	2	20.4	123.4	0.0	0.0	235.6	323.88	457	617	195	11	193	73	0
19	3	24.0	51.9	0.0	0.0	225.0	246.74	981	593	193	11	169	71	0
19	4	10.0	9.4	0.0	0.0	225.0	246.23	4239	568	187	11	144	64	0
19	5	43.0	42.5	0.0	0.0	225.0	245.86	1195	597	192	11	173	70	0
19	6	64.3	57.4	0.0	0.0	227.4	261.99	1226	473	173	10	133	54	0
19	7	213.7	46.0	0.0	0.0	276.9	709.05	1476	445	169	10	109	49	0
19	8	244.8	39.1	137.8	0.0	290.0	888.47	428	474	174	10	129	54	0
19	9	350.2	41.1	264.9	43.4	290.0	887.91	235	490	177	10	138	57	0
19	10	188.3	61.7	125.5	0.0	290.0	887.32	401	466	174	10	121	54	0
19	11	58.2	62.3	0.0	0.0	289.1	872.76	1048	443	168	10	111	49	0
19	12	18.2	61.8	0.0	0.0	280.6	752.34	784	581	188	11	157	66	0

Table IV-11 RESULTS OF CALCULATION ON SUSPENDED SOLIDS OF RUN-3 (2/2)

Year	Month	Rate of Inflow (m ³ /s)	Rate of Outflow			Water Level (m)	Volume of Storage (x10 ⁶ m ³)	Run 3						
			Primary Generation	Secondary Generation (m ³ /sec)	Over-flow			SS (mg/l)	T-Cu (ppm)	T-Zn (ppm)	T-As (ppm)	S-Cu (ppm)	S-Zn (ppm)	S-As (ppm)
25	1	21.1	96.1	0.0	0.0	265.4	551.59	550	608	192	11	183	69	0
25	2	18.0	123.4	0.0	0.0	234.9	291.66	459	632	196	11	207	74	0
25	3	13.0	38.1	0.0	0.0	225.0	221.96	1285	593	192	11	169	70	0
25	4	18.7	18.1	0.0	0.0	225.0	221.45	2496	580	188	11	155	66	0
25	5	37.1	36.6	0.0	0.0	225.0	221.09	1371	597	192	11	172	69	0
25	6	56.3	55.8	0.0	0.0	225.0	220.40	1441	428	166	9	121	48	0
25	7	49.5	49.1	0.0	0.0	225.0	219.69	1614	420	166	9	115	47	0
25	8	180.6	47.8	0.0	0.0	267.9	573.49	1654	402	162	9	97	44	0
25	9	154.2	40.4	5.8	0.0	290.0	850.96	1610	392	160	9	94	42	0
25	10	139.1	60.9	77.1	0.0	290.0	850.24	595	425	165	9	115	46	0
25	11	58.2	62.3	0.0	0.0	289.1	835.55	1206	401	161	9	102	42	0
25	12	31.8	61.3	0.0	0.0	283.4	752.71	793	587	188	11	163	66	0
27	1	31.3	91.5	0.0	0.0	276.8	663.47	568	596	191	11	171	68	0
27	2	19.6	111.4	0.0	0.0	254.3	436.22	494	614	193	11	189	71	0
27	3	17.0	99.1	0.0	0.0	225.1	213.39	562	622	197	11	197	75	0
27	4	18.8	18.4	0.0	0.0	225.0	212.58	2479	577	188	11	152	67	0
27	5	19.9	19.4	0.0	0.0	225.0	212.22	2363	582	188	11	157	67	0
27	6	24.1	23.6	0.0	0.0	225.0	211.53	3113	402	161	9	105	43	0
27	7	37.1	36.7	0.0	0.0	225.0	210.82	2097	417	164	9	115	46	0
27	8	148.8	49.3	0.0	0.0	259.0	475.48	1615	409	163	9	103	44	0
27	9	182.9	41.4	0.6	0.0	290.0	838.30	1773	392	160	9	94	41	0
27	10	121.0	60.6	59.2	0.0	290.0	837.59	675	424	164	9	116	46	0
27	11	143.0	63.0	78.7	0.0	290.0	836.91	582	428	165	9	118	47	0
27	12	65.4	60.1	3.9	0.0	290.0	836.54	764	582	188	11	158	66	0
28	1	26.1	91.2	0.0	0.0	276.9	658.30	569	601	191	11	176	68	0
28	2	18.6	111.5	0.0	0.0	254.0	428.24	494	620	193	11	195	71	0
28	3	13.1	94.0	0.0	0.0	225.1	208.62	588	626	197	11	201	75	0
28	4	11.3	10.9	0.0	0.0	225.0	207.81	3854	571	187	11	147	65	0
28	5	15.8	15.3	0.0	0.0	225.0	207.45	2912	581	187	11	156	66	0
28	6	21.5	21.0	0.0	0.0	225.0	206.76	3466	401	161	9	106	43	0
28	7	46.7	46.3	0.0	0.0	225.0	206.05	1709	429	166	9	124	47	0
28	8	84.3	53.5	0.0	0.0	236.7	286.76	1505	422	165	9	114	47	0
28	9	107.4	49.5	0.0	0.0	255.2	434.82	1568	407	163	9	104	44	0
28	10	81.4	73.2	0.0	0.0	257.4	453.78	1083	418	164	9	113	46	0
28	11	42.0	78.0	0.0	0.0	246.2	357.46	1022	426	166	9	120	47	0
28	12	17.2	73.7	0.0	0.0	225.0	203.83	730	615	196	11	191	74	0
29	1	21.9	21.3	0.0	0.0	225.0	203.18	2185	581	189	11	156	67	0
29	2	14.3	13.6	0.0	0.0	225.0	202.85	3226	578	187	11	153	65	0
29	3	12.4	11.7	0.0	0.0	225.0	202.49	3643	579	187	11	154	65	0
29	4	18.1	17.5	0.0	0.0	225.0	202.14	2599	591	188	11	166	67	0
29	5	26.9	26.4	0.0	0.0	225.0	201.77	1824	603	191	11	178	68	0
29	6	24.0	23.5	0.0	0.0	225.0	201.09	3135	408	162	9	112	43	0
29	7	40.9	40.5	0.0	0.0	225.0	200.37	1928	428	165	9	124	47	0
29	8	82.6	53.6	0.0	0.0	236.0	276.19	1505	425	165	9	118	47	0
29	9	170.0	46.9	0.0	0.0	272.1	593.18	1650	402	162	9	99	43	0
29	10	84.2	65.6	0.0	0.0	276.2	639.49	1174	409	163	9	107	44	0
29	11	74.7	66.8	0.0	0.0	277.7	656.29	1152	410	162	9	108	44	0
29	12	54.7	64.8	0.0	0.0	275.1	625.83	773	592	190	11	167	67	0

Table IV-12 RESULTS OF CALCULATION ON SUSPENDED SOLIDS OF CASE-2 & CASE-3

Year	Month	Case 2				Case 3			
		SS (mg/l)	Cu (ppm)	Zn (ppm)	As (ppm)	SS (mg/l)	Cu (ppm)	Zn (ppm)	As (ppm)
27	1	508	594	120	1	52	691	879	110
27	2	436	595	120	1	45	887	909	110
27	3	615	594	120	1	61	838	933	110
27	4	2122	591	120	1	214	452	857	110
27	5	1159	592	120	1	119	620	891	109
27	6	1319	409	117	2	548	164	238	22
27	7	1478	405	117	2	623	129	229	21
27	8	1110	404	117	2	487	117	224	21
27	9	376	423	117	2	149	167	248	23
27	10	558	413	117	2	229	146	237	22
27	11	966	400	117	2	419	129	223	21
27	12	725	592	120	1	74	494	850	109
28	1	508	594	120	1	52	691	879	110
28	2	437	595	120	1	45	888	910	110
28	3	621	594	120	1	62	837	933	110
28	4	2126	591	120	1	214	453	858	110
28	5	1162	592	120	1	119	621	892	109
28	6	1322	410	117	2	548	164	238	22
28	7	1481	405	117	2	623	129	229	21
28	8	1101	404	117	2	485	117	225	21
28	9	376	423	117	2	149	167	248	23
28	10	558	413	117	2	229	145	237	22
28	11	966	400	117	2	419	129	223	21
28	12	725	592	120	1	74	494	850	109
29	1	509	594	120	1	52	692	879	110
29	2	437	595	120	1	45	888	910	110
29	3	627	594	120	1	62	836	934	110
29	4	2130	591	120	1	214	453	858	110
29	5	1165	592	120	1	119	621	892	109
29	6	1324	410	117	2	548	164	238	22
29	7	1484	405	117	2	624	129	229	21
29	8	1092	404	117	2	483	117	225	21
29	9	376	423	117	2	149	167	248	23
29	10	558	413	117	2	229	145	237	22
29	11	967	400	117	2	419	128	223	21
29	12	726	592	120	1	74	494	850	109
30	1	509	594	120	1	52	692	880	110
30	2	437	595	120	1	45	889	911	110
30	3	633	594	120	1	62	835	934	110
30	4	2134	591	120	1	214	453	858	110
30	5	1168	592	120	1	119	621	892	109
30	6	1326	410	117	2	548	164	238	22
30	7	1487	406	117	2	624	129	229	21
30	8	1083	405	117	2	481	117	225	21
30	9	376	423	117	2	149	167	248	23
30	10	558	413	117	2	229	145	237	22
30	11	967	400	117	2	419	128	223	21
30	12	726	592	120	1	75	494	850	109

4. EVALUATION OF ESTIMATED WATER QUALITY VALUES

4.1 Ingredients to be Investigated

The ingredients subjected to investigation of water quality estimation are 3 elements, Cu, Zn and As.

The Pb, Cd and Hg contents in the solid matter are very small, i.e. the values for the Philex tailings which share about 90% of the mill tailings are 2.7 ppm for Pb and less than 0.1 ppm and 0.01 ppm for Cd and Hg respectively. The concentration of them dissolved in the water of the mill tailings and other water samples are also small as follows.

Pb – all less than 0.01 mg/l

Cd – all less than 0.01 mg/l

Hg – mostly less than 0.0005 mg/l, maximum value 0.0009 mg/l

Consequently it was judged that the investigation on Pb, Cd and Hg was not necessary.

CN (Total cyanogen) was detected in the water samples at Point E and annual average 0.02 mg/l and maximum 0.24 mg/l were obtained, but 1/3 to 2/3 to the total cyanogen is dissolved in the form of stable complex ions and the cyanide ion (CN⁻) does not become an accumulative pollutant because it is unstable and decomposed and gradually lost, and for such reasons, it was not subjected to the investigation.

4.2 Concentration of Dissolved Matters

4.2.1 Cu

The monthly concentrations for the 2nd year, the 15th year and the 30th year after the impounding is started for Run-1, the combination of the average flow rate – the appropriate values are graphed as Run-1-2, Run-1-15 and Run-1-30 in the following figure. The maximum value in each year appears in July and August when the rate of inflow increases, and subsequently the inflowing load increases and the minimum value appears in January and February when the rate of inflow is small, and therefore, the inflowing load is small and the water storage is relatively large, and this is the pattern of seasonal fluctuation of the Cu concentration. When the curves for the 2nd year, the 15th year and the 30th years are compared, the concentration increases for the later years and this is the pattern of the long-term change, and this is mainly because the storage capacity gradually decreases due to the accumulating sediments and the ratio of stored water, which has a lower con-

centration than the influent decreases. The load eluted from the tailings accumulated in the reservoir gradually increases, but it is 128×10^6 mg/month at maximum (August in the 30th year), 0.0002 mg/l in concentration and its contribution rate is less than 3%.

The maximum concentration of Cu for Run-1 is 0.0081 mg/l (July in the 30th year) and the minimum concentration is 0.0024 mg/l (February in the 2nd year) and the annual average for the 15th year is 0.0044 mg/l.

For the Run-3, the combination of the measured flow rate, the appropriate value, the fluctuation range of values becomes large. The maximum concentration 0.0089 mg/l appears in August in the 25th year and the second largest value 0.0088 mg/l appears in July in the 19th year and July in the 23rd year. They are all identical to the first half of the rainy season when the flow rate increases. On the other hand the minimum concentration 0.0021 mg/l appears 3 times, January and February in the 16th year and January in the 17th year, and the second smallest concentration 0.0022 mg/l appears 4 times, December in the 11th year, December in the 16th year, February in the 18th year and December in the 19th year. They are all identical to the first half of the dry season.

If the solubility limit of Cu at pH 8 is calculated from the solubility product of copper hydroxide, 0.0014 mg/l is obtained. If the copper ions (Cu^{2+}) in the stored water exceed this value and are supersaturated, they gradually precipitate as hydroxide and therefore, the concentration of the copper ions in the stored water does not become high. In Case 1 where the solubility limit of the copper ions for the pH of 7.5, the estimated values are around 0.014 mg/l. As the pH becomes smaller than 8, the estimated values approach this value, but such a phenomenon will occur only temporarily after a big flood.

Since the concentration of the copper ions does not increase, it is considered that most of the dissolved copper exists in the state of complex ions which are represented by the cyano-copper complex ions ($\text{Cu}(\text{CN})_4^{3-}$), and how much the complex ions decrease when they are running down and when they reside in the reservoir is an important point in estimating the concentration of the dissolved copper. If the lowest rate in the conceivable range is adopted for the decrease of the complex ions, namely the residual rate and rate of precipitation reaction are made worst, the same value as the Run-2 is obtained. For the Run-2, the combination of the average flow rate – the worst value, the monthly concentrations for the 2nd year, the 15th year and the 30th year after the impounding is started are illustrated as Run-2-2, Run-2-15 and Run-2-30. The maximum value in each year appears in June when the rate of inflow starts to increase and the minimum value

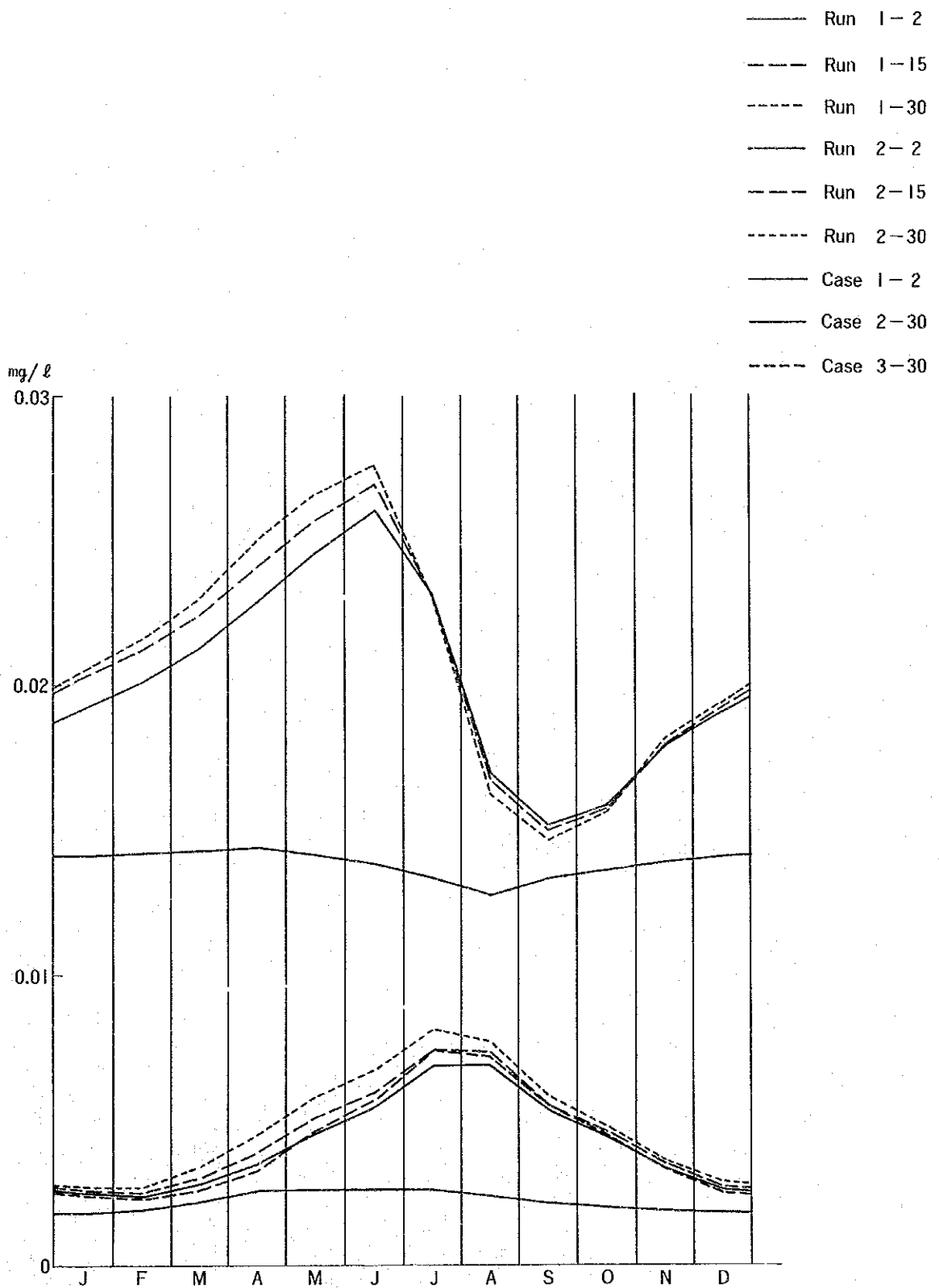


Fig. IV-3 Seasonal Fluctuation of Cu Concentration

appears in September when the high water level continues. The seasonal fluctuation is more strongly affected by the dilution grade than for the Run-1.

The pattern of long-term change is also different from that for the Run-1, and the concentration increases as the year proceeds in the concentration increasing period and decreases as the year proceeds in the concentration decreasing period. This is because of the adoption of the condition to restrain the decrease of the complex ions in the water resident in the reservoir. Such phenomenon occurs because the load in the stored water, which remains from the previous months, gradually decreases as the storage capacity gradually decreases due to the accumulating sediments.

The maximum concentration of Cu for the Run-2 is 0.0276 mg/l (June in the 30th year) and the minimum concentration is 0.0151 mg/l (September in the 2nd year) and the annual average for the 15th year is 0.0192 mg/l.

For the Run-4, the combination of the measured flow rate – the worst value, the maximum concentration is 0.0313 mg/l (June in the 29th year) and this is the highest value of the estimated values of Cu concentration.

A typical behavior of the dissolved copper is shown in the following figure. The load due to the copper ions is small, those which are discharged from 3 mines and the natural pollutant are dissolved in the effluent without showing much increase or decrease. The load due to the cyano-copper complex ions is mostly discharged from the Benguet Mill and partly from the Itogon Mill. It gradually decreases when running down and when residing in the reservoir and only part of it is remained and flows out as dissolved copper (It is considered that the amount of decreased copper is changed into copper hydroxide and suspended in the effluent).

The concentration of copper dissolved in the effluent including both copper ions and copper complex ions fluctuates between 0.002 mg/l and 0.009 mg/l. The annual average for the 15th year is 0.004 mg/l. The reason why the value is smaller than the measured value at the Fixed Point E (annual average 0.015 mg/l) is that the amount of the complex ions are considered to decrease while residing in the reservoir.

As seen in Case 2 and in Case 3, the concentration of the dissolved copper does not decrease so much even if the Philex Mine is closed, but if the Benguet and Itogon mines are closed, the cyano-copper complex ions will disappear and therefore, the concentration of the dissolved copper will remarkably decrease.

As aforementioned, the estimated concentration of Cu is far less than the Class D (agricultural water) water quality criterion^{Note} of 0.2 mg/l and is also less than the Class C (fishery water) water quality criterion of 0.02 mg/l.

Note) Provided in "The Rules and Regulations of the National Pollution Control Commission (1978)". The same shall apply hereinafter.

The Cu concentration increases when the ratio of the residing cyano-copper complex ions increases, and in the worst case, there is a possibility of Cu concentration increasing to the average 0.019 mg/l and maximum 0.031 mg/l. The Cu concentration may greatly increase only when the discharge of the cyano-copper complex ions increases for such a reason as the change of the operating style of the gold mines.

4.2.2 Zn

As in the case of Cu, the monthly concentrations for the 2nd year, the 15th year and the 30th year after the impounding is started are graphed in the following figure. All the curves show that the maximum value appears in May when the water storage is at the lowest and the minimum value appears in October when the high water level continues. This is the pattern of seasonal fluctuation for the Zn concentration and it is affected by the dilution rate. The peak position is shifted from that of the Run-1 of Cu and is near to the case of Run-2. The comparison of the curves for the 2nd year, the 15th year and the 30th year reveals that the concentration increases as the year proceeds in the concentration increasing period and decreases as the year proceeds in the concentration decreasing period. This is because the load in the stored water which remains from the previous months gradually decreases as the storage capacity gradually decreases due to the accumulating sediments, and this is the pattern for the long-term change.

The load eluted from the tailings accumulated in the reservoir gradually increases; but it is 108×10^7 mg/month at the maximum (August in the 30th year); 0.0013 mg/l in concentration and its contribution rate is about 9%.

The maximum concentration of Zn for the Run-1 is 0.0312 mg/l and the minimum concentration is 0.0137 mg/l, and both of them appear in May and October in the 30th year when the annual fluctuation range is the biggest. The annual average for the 15th year is 0.0191 mg/l.

In the Run-3, the fluctuation range of values becomes large. The maximum concentration 0.0547 mg/l appears in April in the 29th year and the concentration exceeds 0.05 mg/l in the period from April to June in the 8th year, from April to May in the 11th year and from April to June in the 29th year (repetition of the same flow rate as that in the 8th year). All of them correspond to the years when abnormal shortage of water occurred in the dry season. On the other hand, the minimum concentration 0.0085 mg/l appears in October of the 18th year and the concentration falls below 0.01 mg/l only in September and October of the 18th year during which period a big flood water amount was input.

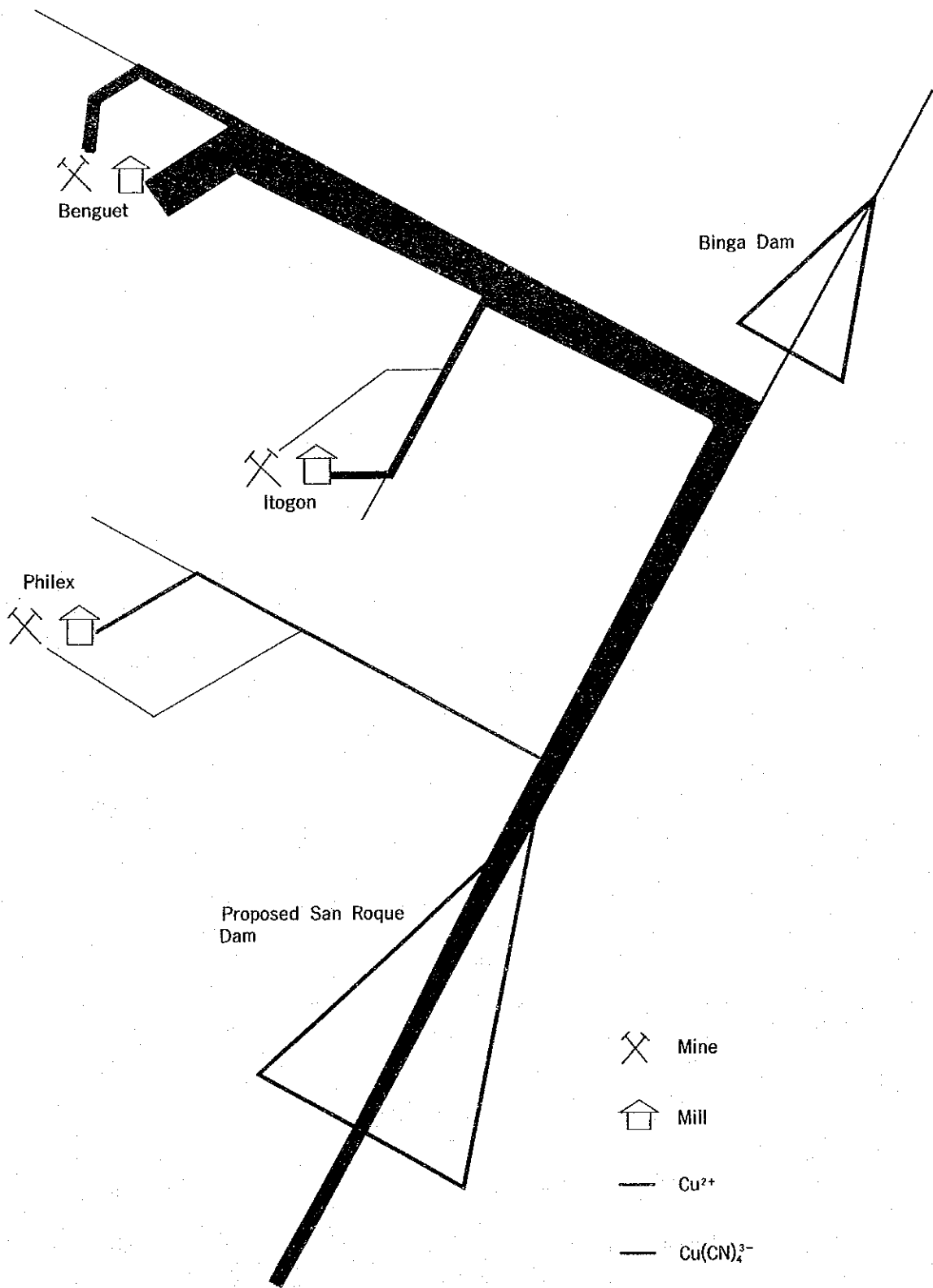


Fig. IV-4 Behavior of Dissolved Cu

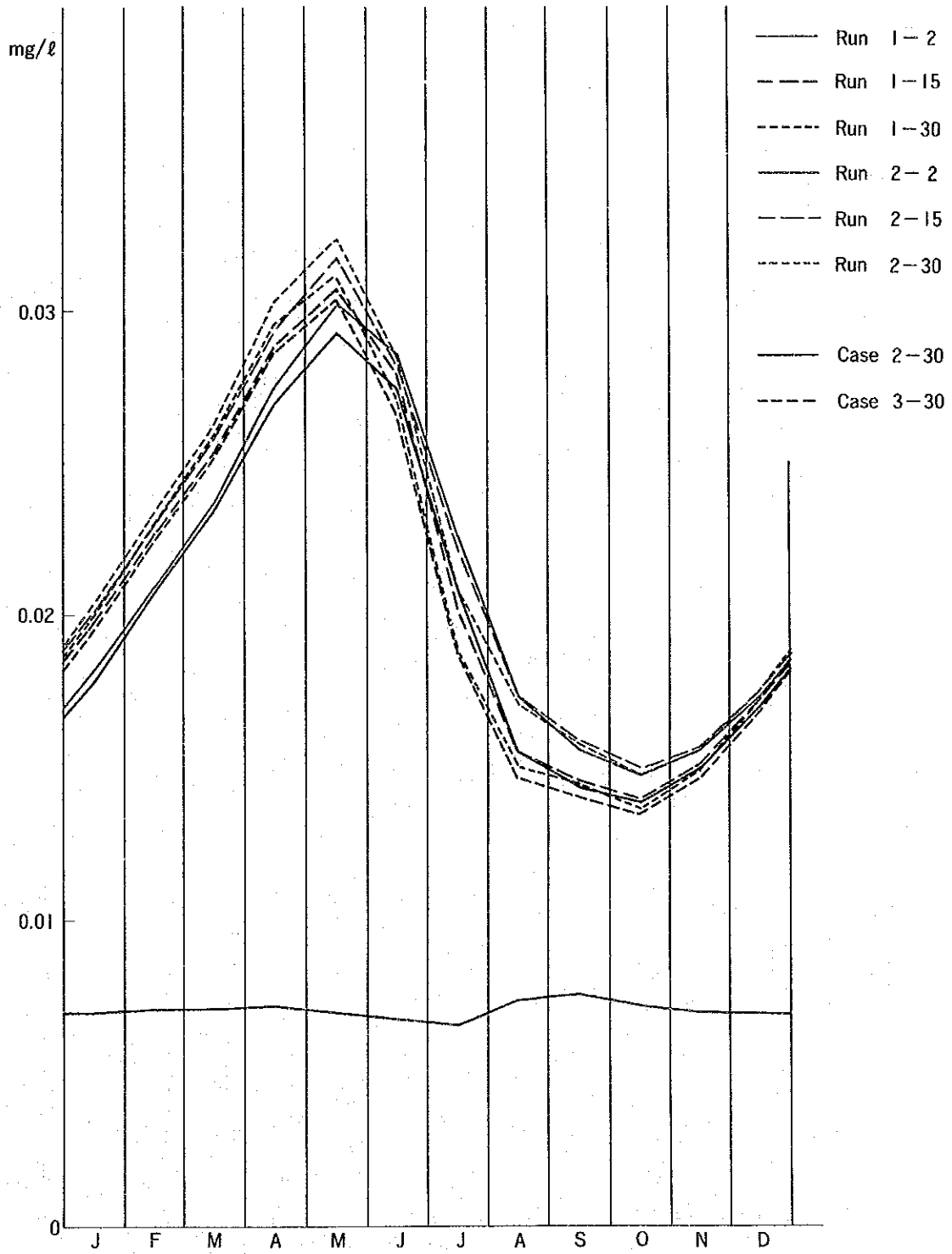


Fig. IV-5 Seasonal Fluctuation of Zn Concentration

If the solubility limit of Zn ions at pH8 is calculated from the solubility product of the zinc hydroxide, 0.46 mg/l is obtained. Since all the estimated values are lower than this value, it is considered that the dissolution of the zinc hydroxide is promoted in the reservoir and no precipitation occur. Since the calculation is made on the assumption that the zinc hydroxide temporarily precipitated while running down is dissolved again while residing in the reservoir, the Zn concentration will not increase so much even if the worst values are used for the calculation.

The graph of the Run-2 for the 2nd year, the 15th year and the 30th year after the impounding is started shows the same tendency as that of the Run-1 except that the maximum concentration is 0.012 mg/l and the minimum concentration is 0.0011 mg/l higher than those of the Run-1. The maximum concentration for the Run-4 is 0.0554 mg/l (April in the 29th year) and this is the highest value of the estimated values of Zn concentration.

A typical behavior of the dissolved zinc is shown in the following figure. About 2/3 of the load is discharged in the state of zincate ions from the Benguet Mill and this rapidly precipitates as zinc hydroxide when the pH becomes weak alkaline. It is gradually dissolved again when it is mixed with a lot of water in the reservoir, and finally the amount similar to the amount discharged from the mine is dissolved and discharged as zinc ions. The remaining 1/3 is a natural load which flows out without increase or decrease.

The zinc concentration in the effluent fluctuates between 0.008 and 0.055 mg/l. The annual average for the 15th year is 0.019 mg/l. The reason why it is higher than the annual average 0.004 mg/l measured at the Fixed Point E is that the zinc hydroxide which precipitated while running down (there is a possibility that some part of it is presently captured in the tailings dam of the mine) is considered to be dissolved again while residing in the reservoir.

As seen in Case 2 and Case 3, the zinc concentration does not decrease so much even if the Philex mine is closed, but if the Benguet and Itogon mines are closed, it will remarkably decrease.

The estimated zinc concentration is far less than 2 mg/l of Class C water quality criterion and Class D water quality criterion. The Zn concentration will increase when the elution rate from the tailings accumulated in the reservoir increases, but this is not a factor to cause a big increase because the highest value obtained in the field test was already input. Therefore, a big increase of the Zn concentration is conceivable only when the outflowing dissolved load is increased for such reason as the change of the operating style of the mines. The major Zn source is considered to be the zinc dust which is charged in the cyanidation process

to precipitate the gold and its consumption (presently 0.08 kg/ton ore) will have an effect.

4.2.3 As

As in the case of Cu and Zn, the concentrations for the Run-1 in the 2nd year, the 15th year and the 30th year after the impounding is started are graphed in the following figure. All the curves show that the maximum value appears in the period from April to May when the water storage is at the lowest level and the minimum value appears in the period from September to October when the high water level is kept. That is, the pattern of the seasonal fluctuation of As concentration shows the same tendency as the pattern of the Zn concentration and is affected by the rate of dilution. The difference in concentration between the 30th year and the 2nd year is $+ 0.0004 \text{ mg/l} \sim -0.001 \text{ mg/l}$; the value is very small and it can be said that the long-term change is almost none.

According to the Run-1, the maximum concentration is 0.0046 mg/l (April, May, etc. in the period from the 28th to the 30th years) and the minimum concentration is 0.0030 mg/l (September and October in each year) and the annual average concentration in the 15th year is 0.0034 mg/l.

According to the Run-3, the maximum concentration is 0.0061 mg/l (April in the 29th year) and the minimum concentration is 0.0026 mg/l (September in the 18th year) and these show the same tendency as in the case of Zn.

The typical behavior of the dissolved arsenic is shown in the following figure, and this case is very simple. That is, just the load dissolved in the mine water of the Benguet mine and the natural water is discharged without increase or decrease. The concentration is fluctuated only by the rate of dilution.

The arsenic concentration in the effluent fluctuates in the range of 0.0026 to 0.0061 mg/l, and the annual average for the 15th year is 0.0034 mg/l. No significant difference is recognized between this value and the annual average 0.0026 mg/l measured at the Fixed Point E.

The estimated As concentration is far lower than the Class D water quality criterion 0.1 mg/l and the Class C water quality criterion 0.05 mg/l. Since the As content in the Philex mill tailings is small (1.2 ppm), the elution from the tailings accumulated in the reservoir does not increase even if the elution rate is changed. A big increase of the As concentration is conceivable when the As concentration in the hot spring water and/or the amount of the hot spring water flowing out increase.

4.3 Concentration of Suspended Solids and Metal content in Suspended Solids

The monthly concentrations for the average flow rate Run-1 in the 2nd year,

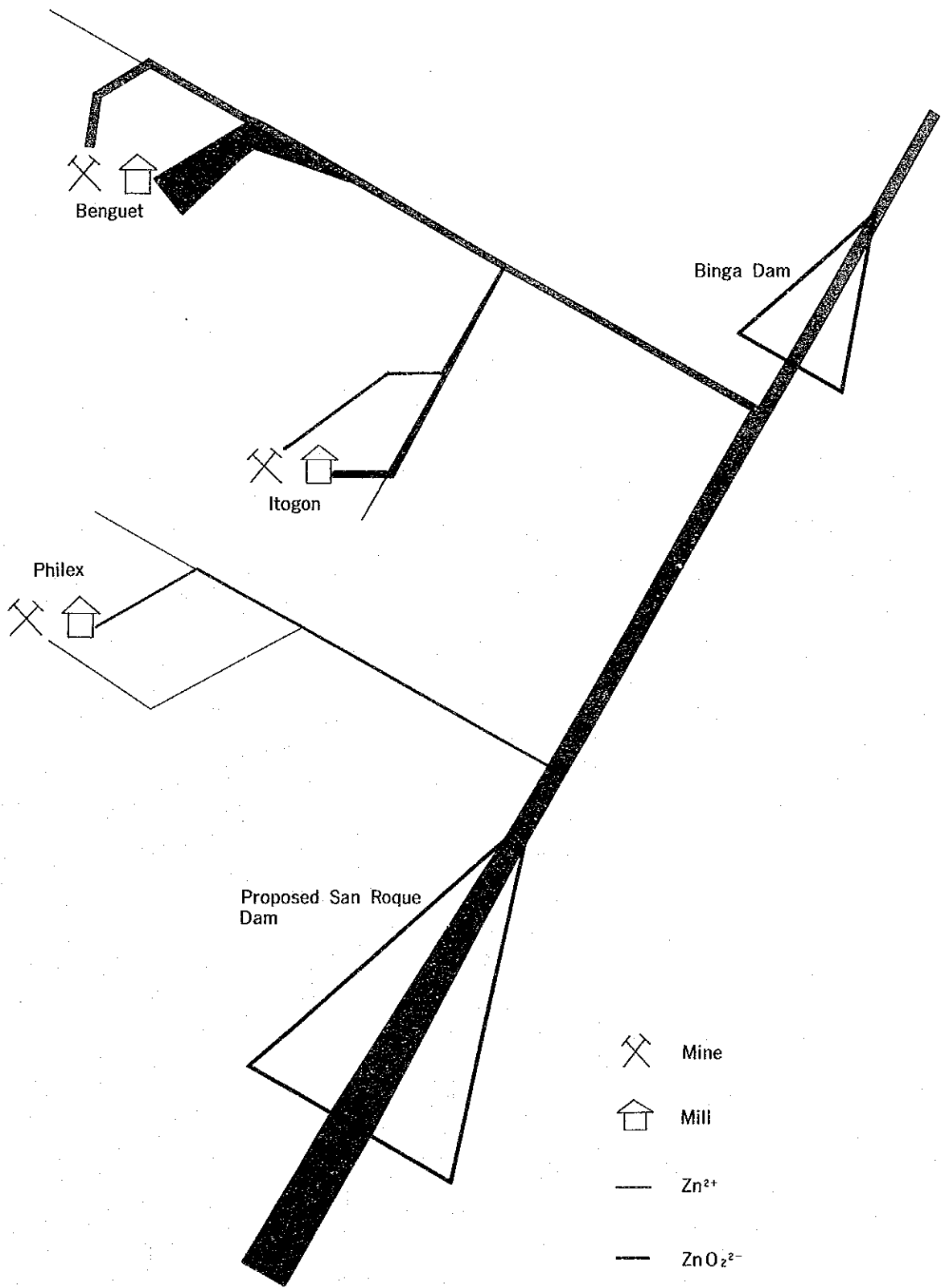


Fig. IV-6 Behavior of Dissolved Zn

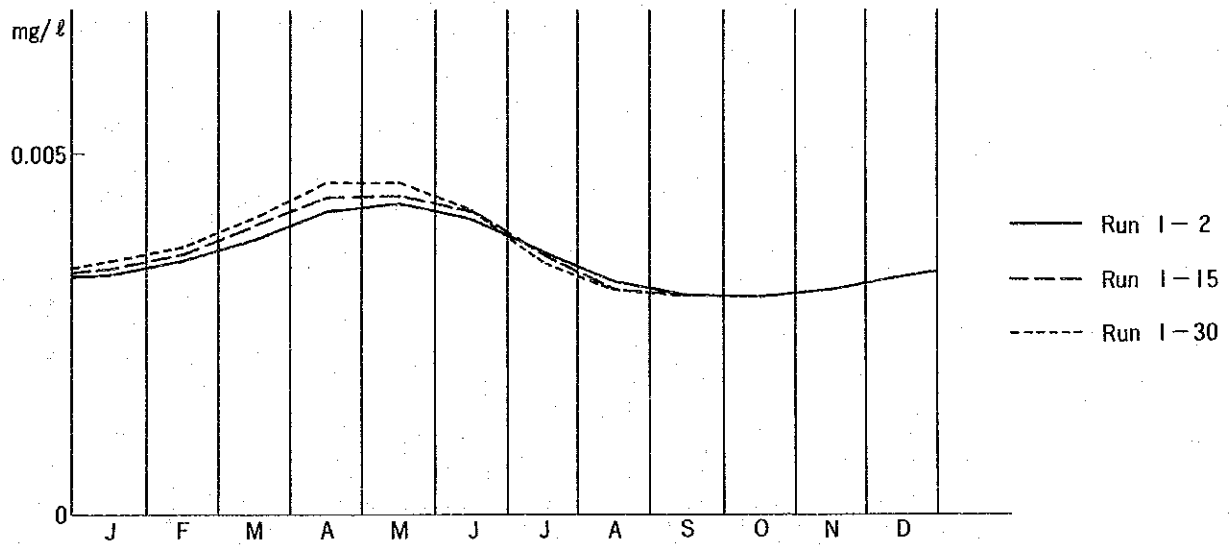
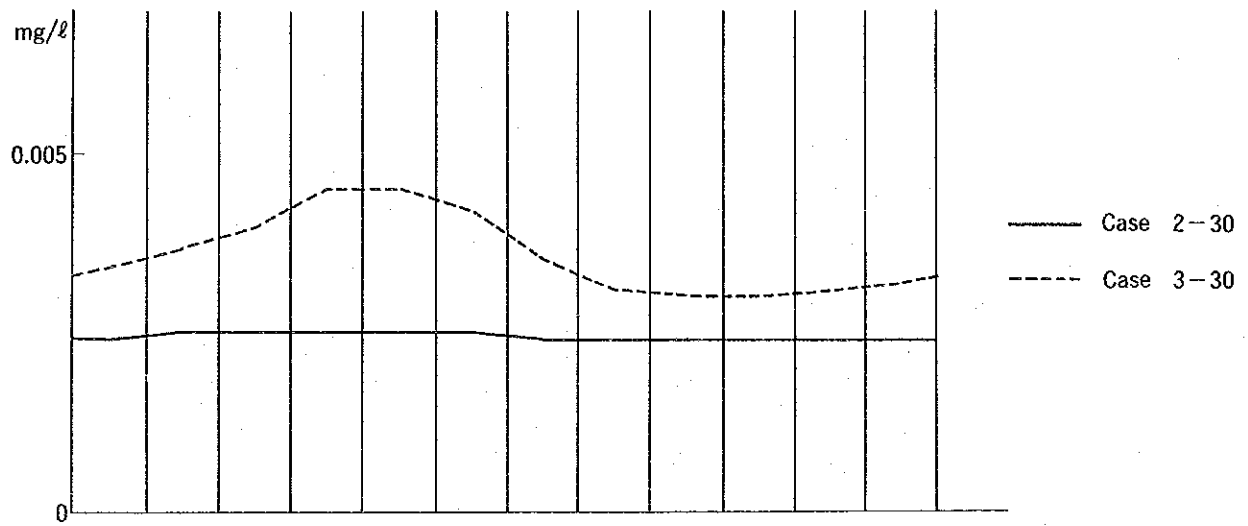


Fig. IV-7 Seasonal Fluctuation of As Concentration

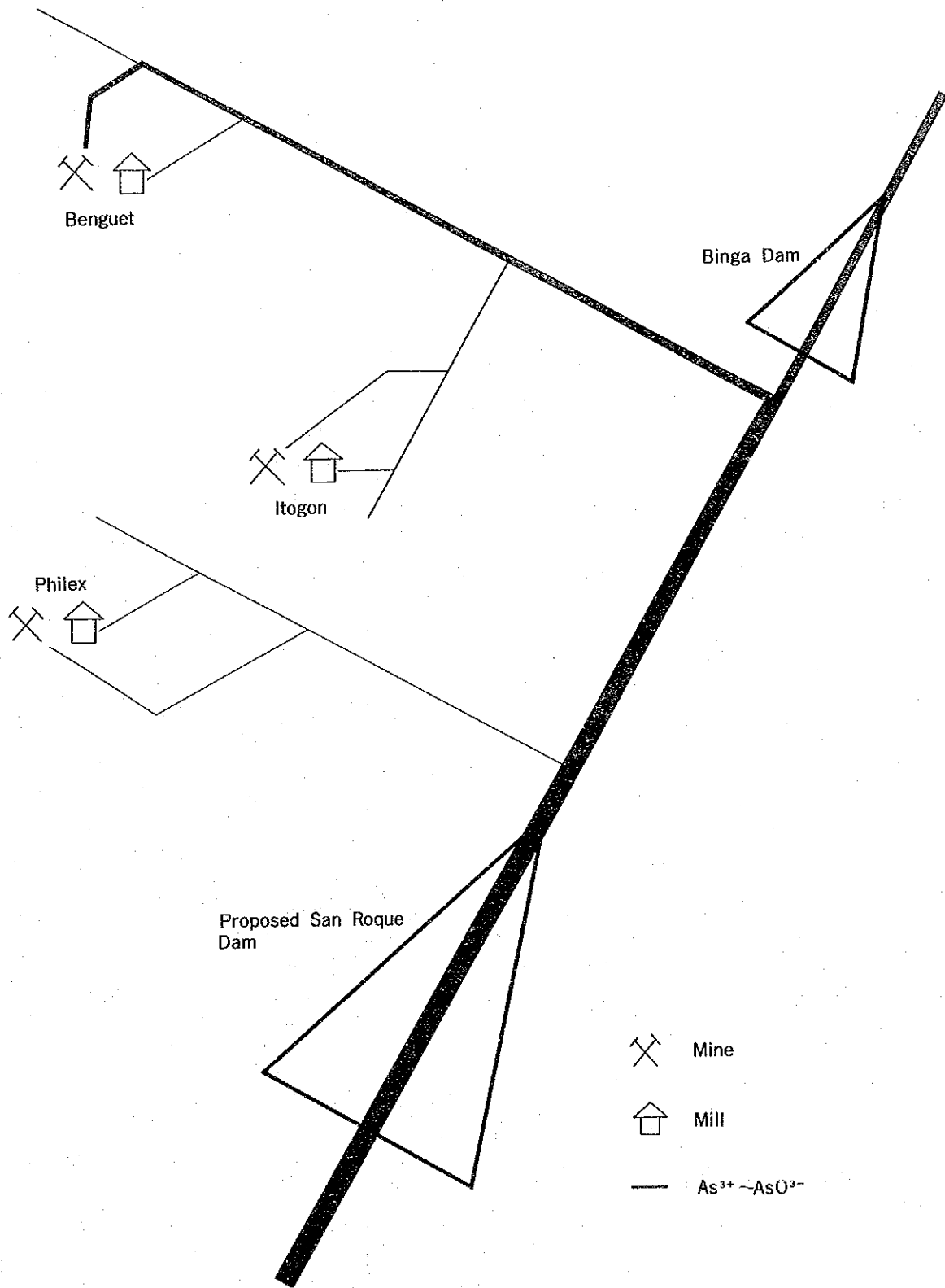


Fig. IV-8 Behavior of Dissolved As

the 15th year and the 30th year after the impounding is started are graphed in the following figure.

The maximum value in each year appears in April when the water level is lowered to the Minimum Water Level and the rate of outflow becomes extremely low. The minimum value appears in September when the water level is high and the rate of outflow becomes high. This is the pattern of the seasonal fluctuation of the SS concentration and it is mainly affected by the rate of dilution.

The comparison of the curves for the 2nd year, the 15th year and the 30th year reveals the tendency that the concentration slightly increases as the year proceeds.

According to the Run-1, the highest concentration is 2350 mg/l (April in the 30th year) and the minimum concentration is 350 mg/l (September in the 2nd year), and the annual average for the 15th year is 720 mg/l.

According to the Run-3 of the measured flow rate, the fluctuation range increases and the maximum concentration 6380 mg/l (May in the 16th year) and the minimum concentration 130 mg/l (September in the 18th year) are obtained by calculation.

This highest value occurs when the record of the abnormal shortage of water with an extremely low rate of inflow is used, and the calculated rate of outflow is very low at $5.8 \text{ m}^3/\text{s}$, and in practice, the water intake will have to be stopped. The calculated rate of outflow falls below $10 \text{ m}^3/\text{s}$ for 6 months during the 30 years, and the highest value when the records in these months are excluded is 3960 mg/l.

On the other hand, the lowest value occurs when a lot of overflow due to a big flood is calculated and the calculated overflow is an enormous amount of $420 \text{ m}^3/\text{s} \times 86,400 \text{ s} \times 30 \text{ days} = 1090 \times 10^6 \text{ m}^3/\text{month}$. In this estimation, it was assumed that the natural sands flow in on an average rate during the 6 months of the rainy season, but actually the peak inflow occurs during a big flood. Therefore, it is necessary to consider that the SS concentration at the time of a big flood is increased by the natural sands. In the calculation, the overflow occurs in 7 months during the 30 years, and the lowest value when the records for these months are excluded is 290 mg/l.

From the above, it is judged appropriate to consider that the fluctuation of the SS concentration in the effluent can be confined to the range of 290 to 3960 mg/l.

The typical behavior of SS is shown in the following figure, and of 400 kg/s of mine tailings and 120 kg/s of natural sands (annual average) which flow in, 14%± of the former and 7% of the latter remain suspended and flow out. The 92% of the tailings are discharged from the Philex mine, and if it is assumed as shown in Case 2 that the Philex mine is closed, the SS concentration is remarkably reduced.

The SS concentration calculated here is that in the water to be intaken through the intake for power generation and discharged from the power plant. The surface water in the reservoir is forecasted to become clear up to the turbidity of 10 ppm if the result of the long-term precipitation test is referred to.

The metal content in the SS is affected by the content in the fine particle portion of the tailings of the Philex Mine which is the largest load source. Though it slightly decreases in June to November when the natural sands are added, its fluctuation range is not so big.

As aforementioned, the estimated SS concentration is high and, although the SS concentration is not stipulated in the Class D water quality criteria it was analyzed that such turbid water as not found in the ordinary rivers will be discharged throughout the year. The sedimentation velocity of the SS by the Stokes' law is about 36 cm/day for 2μ and about 220 cm/day for 5μ , and in order for the concentration to decrease, it is necessary to consider a special case such as coagulating of fine particles.

If such a situation that the inflowing turbid water reaches the intake faster as a particular stratified flow should occur, the concentration will increase.

The measured SS concentration in the water now running down at the Fixed Point E is 1600 mg/l on the average, but this SS mostly consists of the grains of larger than 5μ in size while the SS which is assumed to flow out of the dam in this estimation consists mostly of the gains of smaller than 5μ . Therefore, it is necessary to pay attention to the difference in behavior, e.g. it is carried to the water end while the present SS is deposited only in the irrigation canal and near the water inlet of the paddy filed.

5. SUMMARY AND CONCLUSIONS

Objective and Scope of the Study

The objective of the study of the reservoir water sector is to evaluate the water quality of the effluent from the dam by forecasting the seasonal and long-term changes of the quality of the water stored in the reservoir on the assumption, conforming to ELC's Feasibility Study, that all the mine tailings discharged from the mines operating within the watershed of the San Roque Dam are trapped in the reservoir.

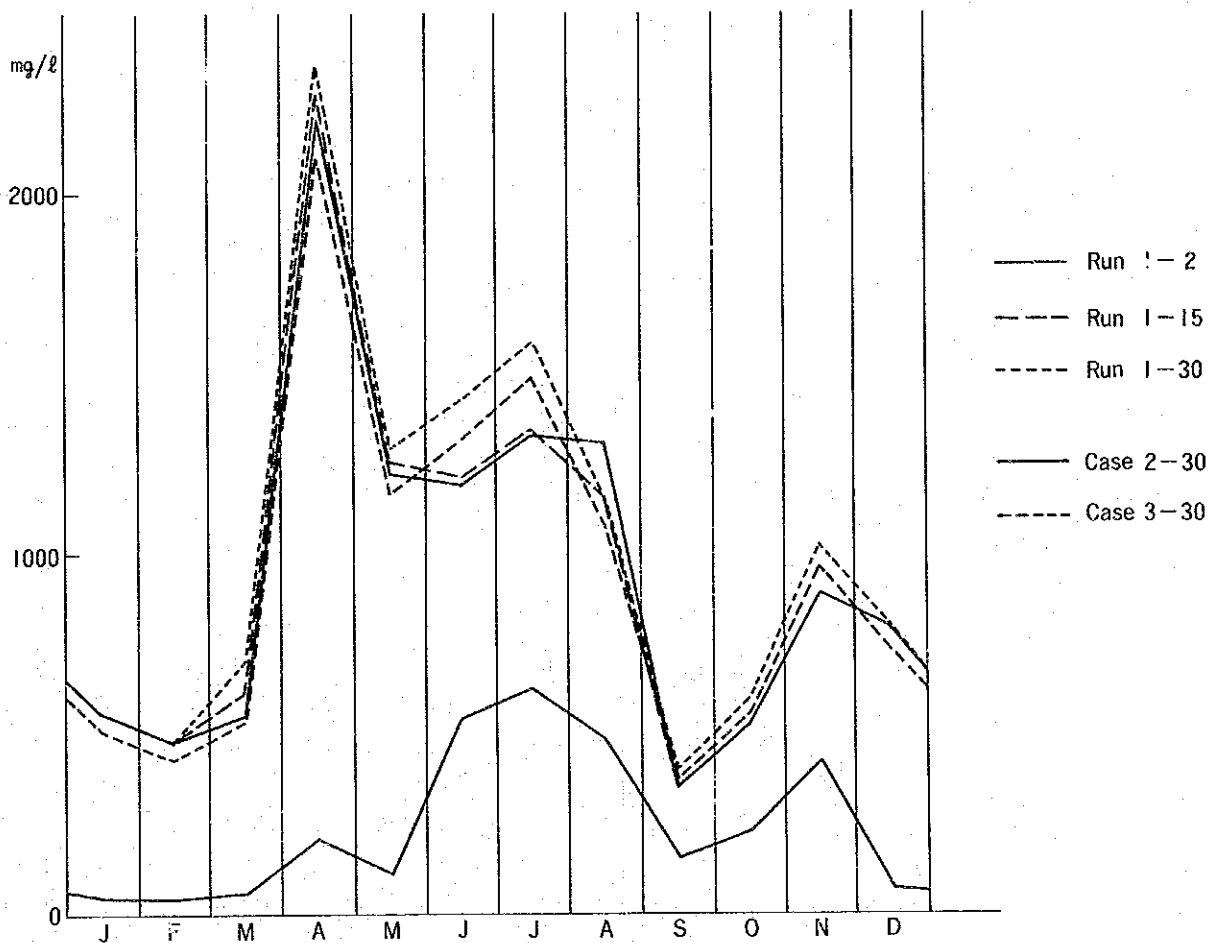
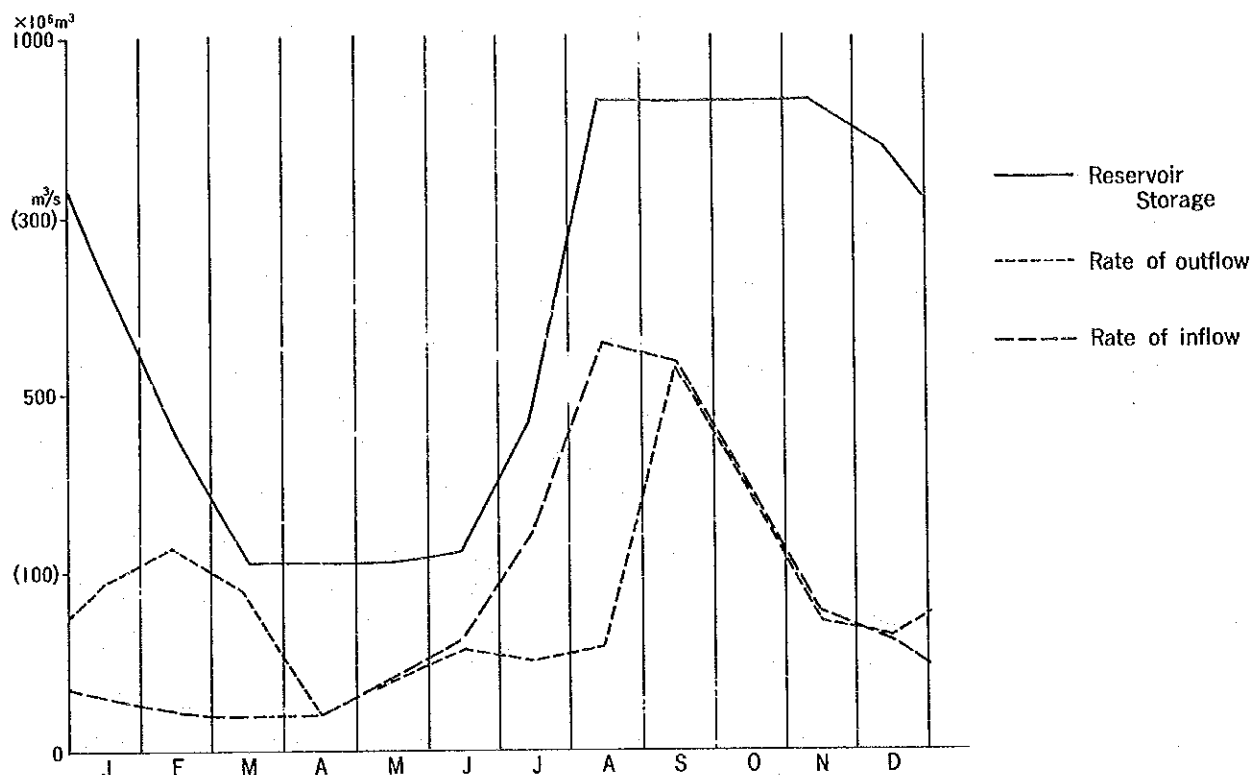


Fig. IV-9 Seasonal Fluctuation of SS Concentration

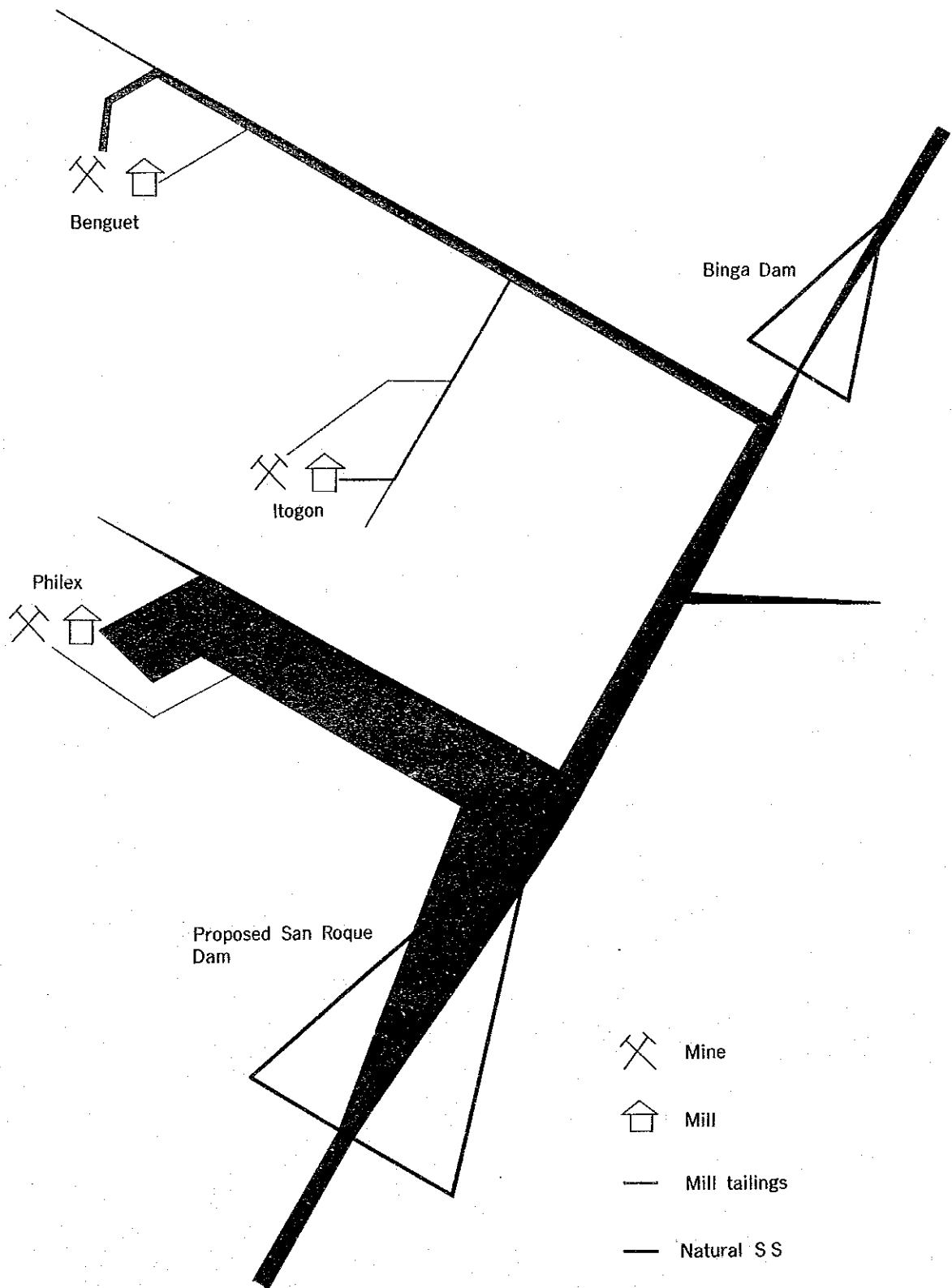


Fig. IV-10 Behavior of Suspended Solids

In order to achieve this objective, the following surveys were conducted;

- * A fixed point observation – to grasp the present condition of the water quality
- * A pollution source investigation – to grasp the actual condition of the pollution sources

and various tests and chemical analyses were carried out on the collected samples.

Based on the data thus obtained and additionally collected, monthly estimated values for 30 years were calculated.

Conditions for Estimation

The rate of flow and the load of pollutants to calculate the estimated values were set as follows;

- * For the rate of inflow the values reviewed by the hydrologic analysis are used.
- * The rate of outflow is calculated in accordance with the optimum dam utilization plan studied by ELC.
- * It is assumed that the operating scale and style of the mines will be maintained without modification during the estimation period and the load of pollutants discharged from the mines will remain constant.

The calculating method is based on the following assumption.

- * It is considered that concentrations of the dissolved matters in the stored water are homogeneous within the reservoir and the concentrations of the dissolved matters in the effluent from the dam are the same.
- * The concentration of suspended solids in the effluent from the intake for power generation was considered and it is regarded that those particles which are not settled during the residence time while the influent reaches the intake are discharged in a suspended state.

Results of the Estimation

The estimated values are shown in the following tables.

Concentration of Dissolved Matters and Suspended Solids

		Cu (mg/ℓ)	Zn (mg/ℓ)	As (mg/ℓ)	SS (mg/ℓ)	
Estimated values	Fluctuation range ¹⁾	0.002-0.009	0.008-0.055	0.0026-0.0061	290-3960 ³⁾	
	Average value ²⁾	0.004	0.019	0.0034	720	
	Seasonal fluctuation	High	Jul.-Aug.	Apr.-May	Apr.-May	Apr.-May
		Low	Jan.-Feb.	Sept.-Oct.	Sept.-Oct.	Sept.-Oct.
Long-term change	Not remarkable	Not remarkable	Not remarkable	Not remarkable		
Measured values	Fluctuation range	0.010-0.036	0.003-0.014	0.0018-0.0049	410-2900	
	Average value	0.015	0.004	0.0026	1600	
Quality criteria of agricultural water	Philippines	0.2	2	0.1	-	
	Japan	0.02	0.5	0.05	100	

		T-Cu (ppm)	S-Cu (ppm)	T-Zn (ppm)	S-Zn (ppm)	T-As (ppm)	S-As (ppm)
Estimated values	Fluctuation range ¹⁾	400-621	97-196	162-196	43-74	9-11	nil
	Average value ²⁾	520	140	180	58	10	nil

Note 1: Fluctuation range, when the measured values for the 21 years was taken as the rate of inflow is shown.

Note 2: Annual average for 15th year after the start of impounding when the rate of inflow is calculated using the average flow rate, is shown.

Note 3: Excluding abnormal values, which are caused by abnormal shortage of water or big flood.

Discussion

1) Behavior of Cu, Zn and As

The load of pollutants discharge from the mines are summarized in Table IV-13.

Cu

The Cu discharged from pollution sources and flowing down is considered to be in the following state:

- (1) Dissolved in the state of copper ions.
- (2) Suspended as copper-hydroxide.
- (3) Contained in suspended solids.

The Cu is considered to change as shown in the following table when it flows down and goes through the San Roque Dam.

			Discharge from pollution source			Run-down as dam effluent		
			Cu (g/s)	Zn (g/s)	As (g/s)	Cu (g/s)	Zn (g/s)	As (g/s)
1 Dissolved metals	Mine source		2.0	1.4	0.1	0.4	1.6	0.3
	Natural		0.2	0.5	0.2			
2 Hydroxide	Note 1)		—	—	—	1.9	0.4	—
1 + 2			2.2	1.9	0.3	2.3	2.0	0.3
In suspended solids	Soluble	Mine source	25.9	17.2	—	6.8	3.2	—
		Natural	—	—	—	—	—	—
	Insoluble	Mine source	203.4	21.4	3.2	22.1	6.3	0.6
		Natural	8.2	13.3	0.6	0.6	1.0	—
	Subtotal		237.5	51.9	3.8	29.5	10.5	0.6
Total			239.7	53.8	4.1	31.8	12.5	0.9

Note 1: Those which are in the state of hydroxide when discharged from the mine are considered as soluble in the suspended solids. Only the hydroxides which were precipitated during the run-down are shown in this column. Finally they should be added to the soluble in the suspended solids.

As shown in the table, most of the dissolved Cu is converted to hydroxide when it flows down, and discharged from the dam in a suspended state.

The Cu load contained in the suspended solids is reduced in proportion to the load contained in the sediments in the reservoir and the trap efficiency is 88%. The trap efficiency for the total copper load is 87%.

Most of the dissolved Cu discharged from the cyanidation plant is considered to be dissolved as cyano-copper complex ions. Based on the observations on the present condition of the water quality, cyano-copper complex ions are gradually resolved into copper ions, and copper ions thus formed are precipitated into copper-hydroxide when amount of copper ions exceed its limit of solubility.

Since the limit of solubility of copper ions in alkaline solution is very small (in case of pH8:0.0014 mg/l), it is considered that this reaction is promoted and resulted that dissolved Cu is changed into suspended copper-hydroxide.

As the natural water in this area shows a weak alkalinity of about pH 8, the amount of Cu eluted from the sediments is very little, it means that most of Cu contained in the sediments is captured in the dam and not discharged, even if it is soluble in an acidic state.

Zn

The Zn discharged from pollution sources and flowing down is considered to be in the following state so as to Cu.

- (1) Dissolved in the state of zinc ions
- (2) Suspended as zinc-hydroxide
- (3) Contained in suspended solids

The Zn is considered to change as shown in the table above when it flows down and goes through the dam.

As shown in the Table, a part of dissolved Zn is converted to hydroxide.

The Zn load contained in the suspended solids is reduced in proportion to the load contained in the sediments in the reservoir and the trap efficiency is 80%. The rate is lower than one of copper because zinc content tends to be high in the very fine particles. The trap efficiency for the total zinc load is 77%.

Most of the dissolved Zn is discharged from the Benguet Mill in the state of zincate ions.

The zincate ions are rapidly converted into zinc-hydroxide according to the decreasing of pH, and hydroxide flows down to the San Roque dam in a suspended state.

Since all of the Zn concentrations estimated in the study are below the limit of solubility which is calculated in case of pH 8. It is considered that zinc-hydroxide drifting in the reservoir may be gradually re-dissolved into zinc ion. Therefore, the zinc-hydroxide flowing out from the dam is lesser than copper-hydroxide.

As the natural water in this area shows a weak alkalinity, so as in the case of Cu, the amount of Zn eluted from the sediments is very little, and most of Zn contained in the sediments is captured in the dam and not discharged even if it is soluble in an acidic state.

As

The As discharged from pollution sources and flowing down is considered to be in the following state.

- (1) Dissolved in the state of ions.
- (2) Contained in suspended solids

The As is considered to change as shown in the table above when it flows down and goes through the dam.

As shown in the table, dissolved As, large part of which is of natural process, goes through the dam without changing the state. The "As" load contained in the suspended solid is of insoluble one in the mill tailings. The trap efficiency for the total As load is 78%.

2) Changes of Concentrations of Dissolved Metals and Suspended Solids

Seasonal Fluctuation: The seasonal fluctuation of the Cu concentration shows a pattern of high values in July and August, during the first half of the rainy season and low values in January and February, during the first half of the dry season. The

seasonal fluctuation is affected by both the amount of inflowing dissolved Cu and the dilution rate in the reservoir.

The seasonal fluctuation of concentrations of Zn and As shows a pattern of high values in April and May, during the low water period and low values in September and October during the high water period. This is affected by the dilution rate in the reservoir.

The seasonal fluctuation of the suspended solids concentration shows the same tendency with one of Zn and As. Namely, although the rate of outflowing suspended solids and the rate of the outflow have the same tendency of fluctuation, the range of fluctuation of the rate of outflow is much larger than of the rate of outflowing suspended solids. Accordingly, the fluctuation of the suspended solids concentration shows a pattern of high values in April when rate of outflow is small, and low values in September and October when rate of outflow is large.

Long-term change: Since the elution of Cu, Zn and As from the mill tailings accumulated in the reservoir is low, the concentration increases only slightly even in the latter years when the accumulation of the mill tailings increases. That is, the long-term change is not very remarkable.

The fluctuation for a period of 30 years of the flow rate and the concentrations calculated by Run-3 are graphed in Fig. IV-11 as reference.

As mentioned above, the estimated concentration fluctuates due to the variation in the rate of inflow and outflow; and in addition, it also fluctuates if there is any factor to vary the load.

As factors to greatly increase the load of the outflowing dissolved matters, the following 2 factors can be considered.

- * The rate of change into hydroxide becomes low.
- * The rate of elution from the sediments in the reservoir becomes high.

Concerning the first factor, Run-2 and Run-4 are calculated in which the lowest values in the foreseeable range for the changing rate of the dissolved metals are used.

By such calculations, the following values were obtained:

Cu: average 0.019 mg/l, maximum 0.031 mg/l

Zn: average 0.020 mg/l, maximum 0.055 mg/l

In the case of Zn, the amount of Zn flowing out of the dam in the form of zinc hydroxide is small and therefore, the value changes only slightly, but in the case of Cu, the amount of Cu flowing out in the form of copper hydroxide is large and if the changing rate decreased, the concentration of dissolved Cu increase greatly. The resulting highest value of 0.031 mg/l is the worst value conceivable in the data presently made available.

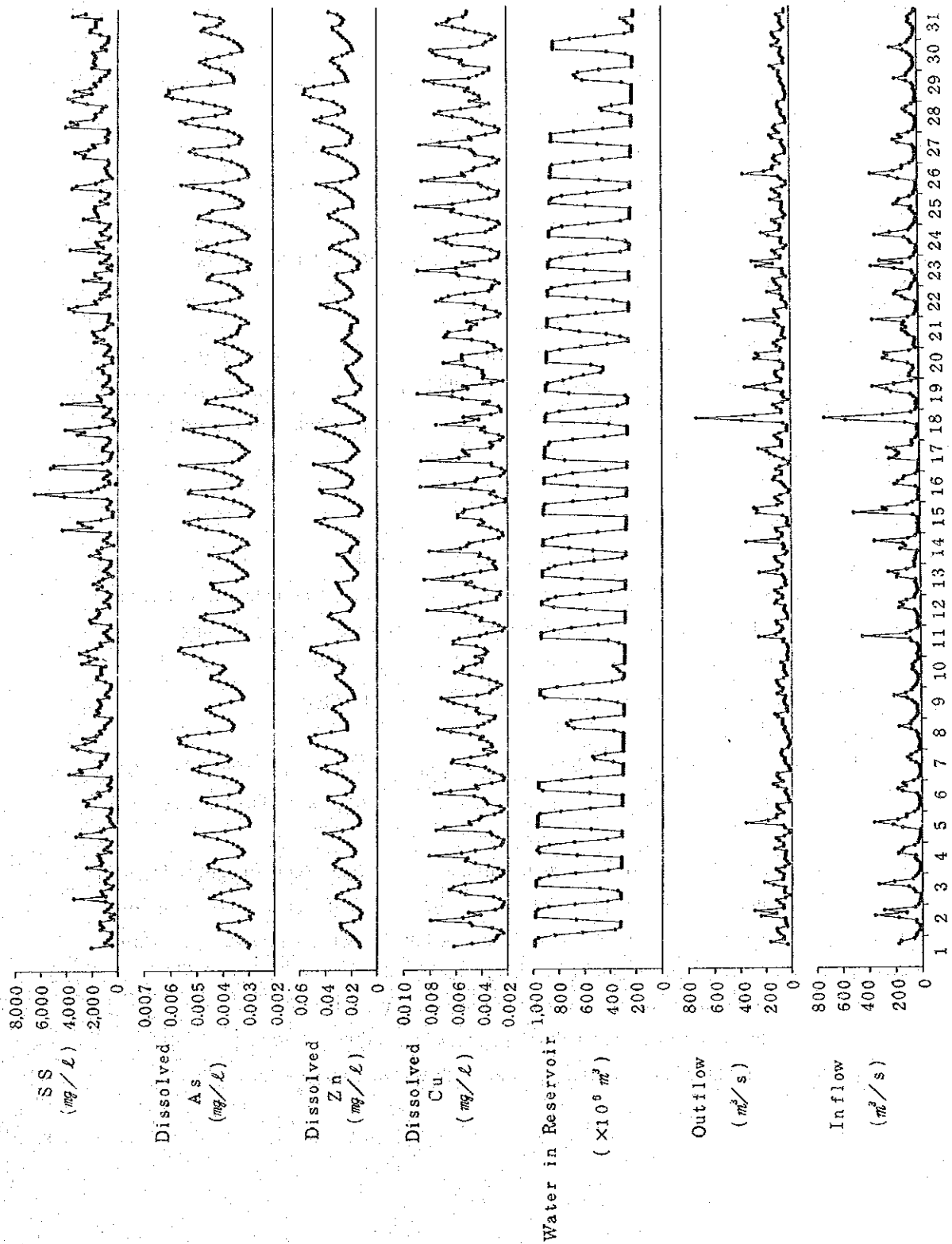


Fig. IV-11 Fluctuation of Calculated Values in Run-3

Concerning the second factor, the amount of metals to be eluted from the sediments in the reservoir is so small that even if the elution rate now adopted is multiplied 10 times, the estimated value will hardly change. Therefore, it is considered that the estimated value will not be changed so much by this factor so long as the stored water maintains a weak alkalinity.

As the factors to greatly increase the amount of the outflowing suspended solids, the following 2 factors can be considered.

- * The time for the suspended solids to reside in the reservoir becomes short.
- * In the grain size distribution of the suspended solids the fine particles increase.

The first factor may occur when the inflowing turbid water reaches the intake faster as a particular stratified flow, but at the moment we have no data to determine whether such phenomenon occurs or not.

The second factor may occur when the milling process is changed at the mine. In case that the mine change the operating style, however, there will be many other factors to be considered, and therefore, it was decided that this point would not be taken into consideration.

3) Contents of Metals in Suspended Solids

Since the Cu content in the natural sands is small, the content in the total suspended solids decreases in the rainy season when the suspended solids derived from the natural sands are added, i.e. the Cu content is divided into 2 groups:

Dry season: Total Cu 600 ppm \pm , Soluble Cu 170 ppm \pm

Rainy season: Total Cu 460 ppm \pm , Soluble Cu 120 ppm \pm

It is also the same with Zn and As.

Dry season: Total Zn 190 ppm \pm , Soluble Zn 70 ppm \pm , Total As 11 ppm \pm

Rainy season: Total Zn 170 ppm \pm , Soluble Zn 50 ppm \pm , Total As 10 ppm \pm

4) Comparison between Estimated Concentration and Measured Concentration

If the estimated concentration values of the dissolved matters are compared with the measured values of the dissolved matters in water now running down through the proposed dam site, it is forecasted that

Cu estimated values are lower than the measured values

Zn estimated values are higher than the measured values

As estimated values are almost the same with the measured values

The above forecast is explained by the following process:

Cu — While the dissolved Cu resides in the reservoir, it is changed into copper hydroxide, and therefore it decreases.

Zn — While the suspended and flowed-down zinc hydroxide resides in the reservoir, it dissolves again and becomes dissolved Zn.

As — It remains dissolved without changing its state.

The comparison of concentrations between the suspended solids estimated to be discharged and the suspended solids actually measured has no substantial meaning, because most of the suspended solids actually measured have the particle size of more than 5μ , and most of the suspended solids estimated to be discharged have the particle size of less than 5μ . Attention should be paid to the difference in behavior caused by the difference in the particle size during the run-down (although the present suspended solids are settled only in the irrigation canal and near the water inlet of the paddy, the estimated suspended solids will be delivered to the outlet of the paddy).

Conclusion

As a result of the assessment of the reservoir water quality, it was found, that the concentration of Cu, Zn and As dissolved in the effluent are all low, far lower than the water quality criteria for agricultural water (Class D.)

It is also revealed that the suspended solids in the effluent have such characteristics as:

- * the concentration is high throughout the year.
- * particle size is small.
- * they contain soluble Cu of more than 20 times the dissolved Cu.

The above results suggest that the effect on the agriculture when the soluble Cu in the suspended solids and dissolved Cu are accumulated in the paddy soil should be investigated.

V. ASSESSMENT OF THE IRRIGATION WATER QUALITY

V. ASSESSMENT OF THE IRRIGATION WATER QUALITY

1. Scope of the Study

1.1 Objectives of the Study

The main objective of the Study in the irrigation sector is to evaluate the projected quality of released water from the proposed San Roque dam as planned in the ELC's Feasibility Study from the view-point of agricultural use.

1.2 Outline of the Study

Field observation works were conducted to examine the influences of physical, chemical and mineral properties of mine tailings on (1) irrigation water, (2) paddy soils and (3) rice plant growth and its yield. For one year up to November 1984, the field observation works were continuously undertaken in the two existing irrigation systems managed by the National Irrigation Administration (herein referred to as NIA). The one is the Agno River Irrigation System (herein referred to as ARIS) diverting polluted river water for irrigation and the other is the Ambayoan-Diapolo Rivers Irrigation System (herein referred to as ADRIS) taking clear river water. In addition, relevant informations and data were collected from NIA's Headquarters, Region I Office and ARIS and ADRIS Project Offices during the field work period.

In respect to irrigation water quality, monitoring works were carried out to observe quality and quantity of canal water and to take water samples for laboratory tests at 12 monitoring points in total in the ARIS and ADRIS areas. Among these monitoring points, four were established for the year-round observation work in the ARIS area and also two in the ADRIS area. The remaining six were supplemented for the wet season observation work in the ARIS area as shown on Fig. VI. As regards soils, master pit survey was performed at 10 places selected in the proposed San Roque irrigation development area for observing soil profile and taking soil samples. Laboratory tests of soil samples taken were made to determine natural background of heavy metals quantitatively and to clarify vertical changes in heavy metal contents of soils. Random sampling of soils was done at an inlet portion of the existing irrigated paddy fields in the ARIS area to check accumulation of heavy metals and at each plot of monitoring paddy fields to clarify horizontal change in heavy metal contents of soils. Furthermore, sediments on canal bed in the ARIS area were sampled for laboratory tests on heavy metal contents. With regard to crop,

growing condition of the dry and wet seasons rice plants was observed at five monitoring paddy fields in the ARIS area and one in the ADRIS area. At harvesting time, condition of the dry and wet seasons rice plants was observed at five monitoring paddy fields in the ARIS area and one in the ADRIS area. At harvesting time, sampling works were conducted for yield survey and yield component analysis. Rice plant samples were tested for determination of nutrient and heavy metal uptakes. In the ARIS area, additional sampling works for yield component analysis were made at eight places in the dry season and 18 places in the wet season.

Based on the results of the above-mentioned field observation works and laboratory tests as well as the projected quality of released water from the proposed San Roque dam, problem heavy metals were selected among copper, lead, zinc, cadmium and arsenic for the further evaluation study. The irrigation plan proposed in the ELC Feasibility Report and the output from the hydrologic review in the Study were employed to calculate irrigation diversion requirement for the proposed San Roque irrigation development area. From the projected water quality of the proposed San Roque reservoir and the calculated irrigation water demand, the annual inflow of problem heavy metals into paddy field of 1 ha was estimated for the proposed San Roque irrigation development area. By referring to the result of this estimate, cumulative amount of problem heavy metals in paddy soils was projected and compared with the preceding data in Japan for evaluation purposes.

1.3 Available References for the Study

Various references were employed for the evaluation of projected water quality in addition to the results of field observation works and laboratory tests. Of these, the following data were fully referred to; (1) the results of hydrologic review and assessment of reservoir water quality in the Study, and (2) two Feasibility Reports prepared by ELC, one for NPC submitted in 1979 and the other for NIA transmitted in 1981.

2. Results of Field Observation Works

2.1 Present Situation of Existing Irrigation Systems

In the proposed San Roque irrigation development area, there exist three large-scale irrigation systems under the management of NIA and 36 communal irrigation schemes utilizing springs or small rivers as irrigation water sources. Among the whole paddy fields of approximately 84,000 ha distributed in the proposed San Roque irrigation development area, 46,800 ha or 55% are equipped with irrigation facilities.

In the remaining paddy fields of 37,200 ha, rice plant is grown under rainfed condition to some extent during the wet season.

Typical cropping patterns are double cropping of rice in the area where irrigation water is secured throughout the year. Among the remaining areas to which no irrigation water is supplied, the dry season crops are diversified to some extent by introducing industrial crops such as tobacco and cotton as well as cash crops like corn, mungo, peanuts and vegetables. Paddy fields totalling about 52,000 ha are, however, used for single cropping of the wet season rice following by fallow period for the dry season due to lack of irrigation water resources.

As for the NIA's existing irrigation systems, ARIS has been operated since 1957 covering the total net irrigation area of 20,200 ha. The irrigation water is diverted from the Agno River at the ARIS intake dam which is located at 2.5 km downstream from the proposed San Roque dam site. It is distributed to paddy fields through the main canal of 46 km and laterals of 207 km in total. The overall canal density is about 33 m/ha on an average. As the irrigation water also contains sand and silt in large quantities which are transported from the upper catchment area of the Agno River, the NIA ARIS Project Office is always suffering from siltation of the main canal and laterals in its service area and entails an annual expenditure to large extent for desiltation. Furthermore, annual volume of siltation in the ARIS area exceeds over the physical and financial capabilities of the NIA ARIS Project Office resulting in reduction of the design capacity of the main canal and laterals as well as expansion of sub-laterals and farm ditches buried under sand and silt. According to the report of NIA ARIS Project Office, the actual irrigation service area in 1983 was 10,300 ha for the wet season cropping and 2,000 ha for the dry season cropping.

The Lower Agno River Irrigation System (herein referred to as LARIS) provides irrigation water to its service area of 10,200 ha by diverting water from the Agno River through an intake dam located at the point of 20 km downstream from the ARIS intake dam. The canal system consists of the main canal of 31 km and laterals with the total length of 161 km. The overall canal density is 73 m/ha on an average. The Agno River is very wide and its river channel undergoes many changes at the LARIS intake dam site so that stable intake of water is hardly secured every year. The actual results of irrigation water supply in 1983 was reported to be 7,400 ha for the wet season cropping and 2,900 ha for the dry season.

There are two intake dams in the ADRIS area each of which diverts clear river water for irrigation purposes. The irrigation service area totals 10,500 ha out of which 5,200 ha in the wet season and 1,200 ha in the dry season are actually pro-

vided with irrigation water due to seasonal fluctuation of run-off from the small catchment areas of the Ambayoan and Diapolo Rivers. The total length of canal is 41 km for the main and 135 km for laterals. The overall canal density is 53 m/ha on an average.

2.2 Irrigation Water Quality Survey

Throughout 1983, the watershed of the Agno River had a little rainfall and also the release from the existing Ambuklao and Binga dams was reduced. As a result, the discharge at the ARIS intake dam site was remarkably declined when the dry season irrigation water supply was commenced in November 1983. Under such a water shortage condition, the NIA ARIS Project Office revised its irrigation water distribution plan for the dry season cropping and reduced its irrigation service area from 5,600 ha to 2,500 ha. In line with the final irrigation water distribution plan of NIA ARIS Project Office, four monitoring points were set up in the ARIS area. In addition, another two monitoring points were established in the ADRIS area for comparison purposes of irrigation water quality. The monitoring works of irrigation water quality were principally made once a week. The monitoring items were water temperature, pH, electric conductivity, dissolved oxygen and turbidity. Water sampling, once every two weeks, and discharge measurement, once to three times a week, were conducted at the respective monitoring points. All of the water samples collected were analyzed in Japan in terms of suspended solid and heavy metals such as copper, lead, zinc, cadmium and arsenic. The results of laboratory tests of the water samples taken during the dry season are as summarized in Table V-1 and the details are as compiled in APPENDIX F.

From the middle of April 1984, the ARIS area had periodically plentiful rainfall up to July though the total precipitation was below the average of the same period for the last five years from 1978 to 1982. The supplemental irrigation water supply program to the wet weason cropping covered 8,400 ha in the ARIS area and the actual water distribution was smoothly done to meet the paddling water requirement throughout the planned area. Desiltation of the main canal was continuously carried out by the NIA ARIS Project Office during the wet season. As the six new monitoring points were added to the ARIS area, irrigation water quality observation works were conducted at 10 monitoring points in the ARIS area and two in the ADRIS area for the wet season cropping. The items of monitoring works and laboratory tests were quite same as those taken during the dry season with the only one exception that arsenic was omitted from heavy metal analysis of water samples. The

results of laboratory tests are as summarized in Table V-1 and the details are as compiled in APPENDIX F.

In the later part of wet season from August to October, storms and rising of river occurred frequently in the ARIS and ADRIS areas by the effect of typhoon. During such periods, muddy stream flow into the service areas of ARIS and ADRIS through the canals unless the intakes of river water were stopped. The results of laboratory tests on water samples collected at the aforesaid period indicate that suspended solid contents sharply increase.

The quality of water resources for the communal irrigation schemes operated in the proposed San Roque irrigation development area is very clear with suspended solid concentration of less than 10 ppm and turbidity of less than 60 ppm. In case that source water is contaminated by the surface drainage from paddy fields in the ARIS area, water quality in several communal irrigation schemes becomes worse to some extent.

2.3 Soil Survey

The master pit survey was undertaken at 10 sites selecting from the whole of the proposed San Roque irrigation development area. Soil profiles were observed with soil sampling at the respective pits. In general, soils are deep with good permeability and less water holding capacity. In paddy fields distributed over the flood plain, the typical soil texture of surface soils is silty clay loam and that of subsurface soils varies from sand to silty loam depending on micro topography. Soils of gentle sloping areas on lower hills have a texture of sandy clay loam throughout the layer. According to the results of laboratory tests done by the NIA Engineering Laboratory, surface soils are acid to weakly acid and have a rather high value of electric conductivity. On the contrary, subsurface soils are weakly acid to neutral and have a low value of electric conductivity.

Heavy metals were determined quantitatively in Japan. The results of heavy metal analysis make it clear that the behaviour of soluble copper and zinc in soils of the ARIS and ADRIS areas indicates the effect of siltation caused by mining activities in the upper Agno River basin to a certain extent. However, variation of lead and arsenic contents of soils has no good correlation with the siltation of mine tailings in the ARIS and ADRIS areas. As cadmium contents are very low in each soil sample, the necessity for assessment study of cadmium is not recognized. Variation of zinc contents of soils taken at 10 master pits is similar to that of copper contents. Therefore, natural background and artificial accumulation of heavy metals in soils were

analyzed by referring to the behaviour of copper. The low hills, located in the center of the proposed San Roque irrigation development area, have not been under the flooded water of the Agno River and also no trace of tillage for crop cultivation is found through the soil profile observation. Thus, it can be considered that the results of laboratory tests on soils sampled at the low hills are mostly equivalent to the natural background of the heavy metals in the soils of the proposed San Roque irrigation development area. Compared with such natural background level of copper, there exist a distinct difference in copper contents of soils between paddy fields and hills in the ARIS area as shown in Table V-2. Soils of paddy fields in the ARIS and other rainfed areas have, however, a slightly higher level of copper contents than the natural background. The copper contents of subsoils in the ARIS area also become lower to the bottom.

In order to control siltation, farmers set up a settling basin by reshaping a small portion of their paddy field of which inlet connects directly to farm ditches or sub-laterals. Siltation in such a settling basin has good correlation with the actual duration of irrigation water supply to paddy fields. Random soil sampling works were made in the ARIS area to take surface soils of 15 cm from 249 settling basins and the inlet portion of paddy fields if no settling basin was introduced. These soil samples were tested to determine soluble copper, lead, zinc, cadmium and arsenic quantitatively. The soluble heavy metals are defined to be easily absorbed by crops. As shown in Table V-3, soluble copper contents of 249 soils indicate the wider variation and, as illustrated in Figure V-2, the distribution of soils with higher contents of soluble copper in the ARIS area show the similar tendency in the actual irrigation water supply for the past 25 years.

Sand and silt are deposited in each settling basin to large extent, but fine silt is transported to main paddy fields together with irrigation water. If the settling basin has been already filled with sediments, sand and silt mostly flow into the main paddy field. Hence, surface and subsurface soils were sampled at each plot of monitoring paddy fields from the inlet side nearby the farm ditch to the outlet side facing the drainage channel. The results of laboratory tests on the aforesaid samples indicate that copper contents of irrigated soils in the ARIS area decrease in order from the inlet to outlet parts of the main paddy field as illustrated in Figure V-2.

According to the heavy metal analysis by particle size of sediments on canal bed in the ARIS area, the contents of soluble copper, lead and zinc are a rather higher in the silt portion than in the coarse sand portion. As the coarse sand portion has a share of 90% in particle size distribution of sediments, however, this can be considered as the main source providing heavy metals to paddy fields at present. The