CHAPTER VII. ENVIRONMENTAL ASSESSMENT

CHAPTER VII. LATENT ENVIRONMENTAL POLLUTION CAUSED BY MINING DEVELOPMENT

As mentioned in paragraph 3.8.2, "Sohar Copper Project" is now under construction, and the survey team observed the progress in the construction of the underground facilities and surface plants when the team visited the site in February, 1982. Its commercial operation is scheduled to be started in the middle of 1982. Under the circumstances, the environment surrounding the copper mines has not been degraded yet because of no mining drainage, gas or fume from the underground ore dressings and smelting plants, with the exception of Lasail mine underground development where acidic effluents containing heavy metal is generated to a certain extent as a result of the process of the ore body drifting.

In due consideration of the above conditions, the negative effect in the future of the said on-going copper project could be easily prevented if appropriate treatment of the latent pollution is provided at present stage.

7.1. Survey

The purposes of the survey are to examine and forecast the magnitude of the environmental degradation that would be brought about by the on-going mining development and to establish proper countermeasures of the environmental conservation for successful execution of the proposed agricultural development.

The general survey on the topography and geology of the Project Area and its surrounding areas has clarified that Bayda and Aarja mines being situated outside the Project Area have caused no environmental damages to the Project Area. Accordingly, the above two mines were excluded from the survey.

The Wadi Jizzi flows eastward in the upstream portion to gather the effluents from the processing plants in the catchment area, and joins a tributary at the point 25 km upstream from the estuary. The tributary, originating at the southwest of the confluence of the main stream, joins two small streams before being joined with the main stream. And these tributaries have some relation with effluents from Lasail mine.

The area extending from the above-mentioned confluence of the Wadi to Lasail mine and the area surrounding its processing plants have topography of several dissected valleys and hilly lands with an elevation ranging from several meters to some ten meters, excepting a mountain area with an elevation of 300 meters. Surface of the area is covered with the terrace deposits and sand and gravel of the Quaternary.

The ground surface of the area is always dry excepting when the rain falls. Around Lasail mine, sand and gravel layers between the surface and the bed rocks appear to be thin and there exists no groundwater.

Along the main stream of the Wadi Jizzi and its comparatively large tributaries, the groundwater has been observed, although the water table lies low except rainy days.

In careful consideration of those topographic and geological conditions as well as the local conditions of the copper mining project, fundamental conditions considered to cause the mine pollution in the area will be those generated by copper mining operation as well as the following.

- Environmental pollution by waste water;

- Irrigation water pollution and soil contamination by downflow movement of surface runoff discharge and groundwater created by rainfalls;

- Waste smoke pollution, and

- Generation of those conditions resulting in atmospheric flow to the Sohar area from the processing plants site where the plant operation will produce pollutants which may touch or be absorbed in farm products.

The current survey has been carried out in view of those conditions.

7.1.1. Survey Items

a) Survey on Waste Water Emission

The waste water drainage out of Lasail mine was surveyed for the following items.

(1) Status of the underground development and the mining method;

(2) Drainage method, present treatment of mining waste water quality or its future development plan; (Appendix M-5)

(3) Topography and geology of the areas surrounding the mining project site and the related catchment area;

(4) Forecasting the waste water quality, and

(5) Present water turbidity and contamination caused by waste water.

The drainage by the ore dressing works was surveyed for the following items.

(1) Method of ore dressing;

(2) Forecast of quality and quantity of waste water emitted from the ore dressing plant; and,

(3) Locational conditions of the treatment pond and the relation of the pond with the topography and geology of the catchment area.

b) Survey related to Smoke emitted out of the Smelting Plants

(1) Method of ore smelting; and,

(2) Locational conditions of the smelter used and the relation of the smelter with the topography and geology of the catchment area.

To investigate the above items, data were obtained from the Oman Mining Co., LLC., and the Public Authority for Water Resources.

The underground conditions of Lasail mine were surveyed to confirm the development and the mining method, and sampling of the rock and ore was simultaneously made.

The catchment area was also surveyed to have knowledge on the locational conditions, topography, and geology. Samples of water, sands, and gravels were again taken in the area.

The Law for Conservation of Environment and Prevention of Pollution, which was enforced during the field survey, was also obtained from the Council for the Conservation of Environment and Prevention of Pollution (refer to Appendix M-1).

7.1.2. Status of the Area as of February, 1982

The Copper Mining Project, operated by the Oman Mining Co., LLC., is now under construction and expected to take some time before commencing its commercial operation.

The underground development of Lasail mine, however, has been emitting acidic underground water containing several kinds of heavy metals, since development works have reached the ore bodies by sub-level caving method which will be applied when the commercial operation is commenced.

The underground waste waters can be classified into two by water quality and specific features (including the waste water pumped up from the bore holes in the pit areas) and these waters are pumped up and emitted to the disposal ponds provided on the ground (see Figure 7-1).

One kind of the waste water is discharged into the disposal pond, Number ③. Part of water will evaporate or infiltrate into sands and gravels. A greater part of water is neutralized by lime resulting in producing the hydroxide deposits, mainly ferrous hydroxides. Part of these waste water is being discharged into the Wadi (1) together with some deposits. Waste water flowed into the Wadi (1) will infiltrate into the wadi bed at some ten meters downstream and join the groundwater of wadi (observed on February 14, 1982).

The other kind of the waste water is discharged into the disposal pond, Number ②, and is proceeded to three stages of disposal ponds where copper content in the water is removed by using

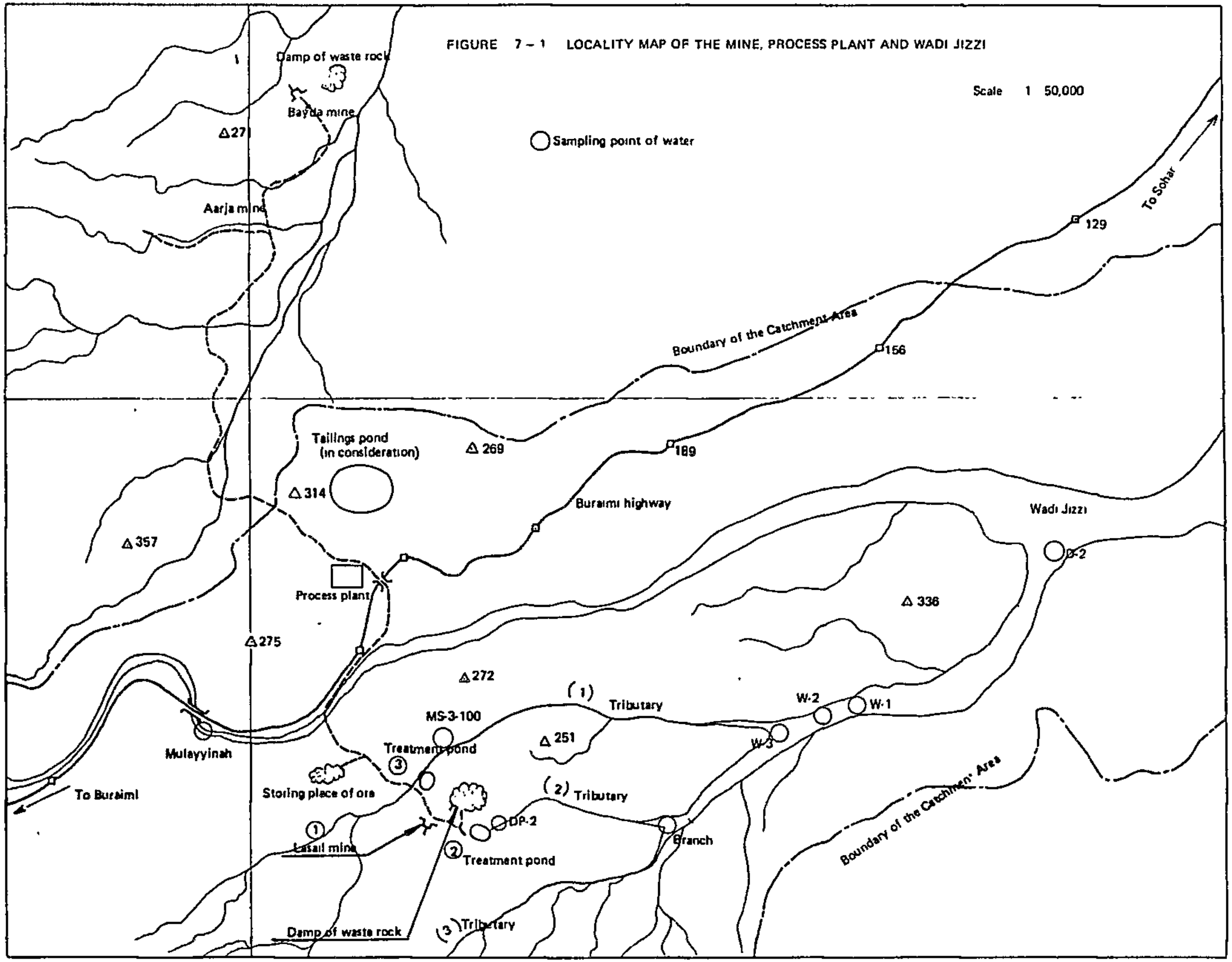


FIGURE 7 – 1 LOCALITY MAP OF THE MINE, PROCESS PLANT AND WADI JIZZI

the reaction of $Cu^{++} + Fe \rightarrow Cu + Fe^{++}$, and finally again discharged into the depressed ground for neutralization with lime. After the neutralization, part of waste water will naturally evaporate or infiltrate into the ground.

The waste water discharged in the disposal ponds, Number ① and ②, was not collected as samples for chemical analysis, However, the water overflowed from the disposal pond by the local downpour of February 11, 1982, and some sands and gravels which were supposed to be contaminated by the water were collected as useful samples in studying the nature of water in the disposal ponds. The following are these.

- Light-brown coloured water was collected from a pool on the surface of wadi bed two days after the rainfall.

- The wet sands and gravels at the surface of wadi (2), which is located 40 m from the concrete wall built in the downstream of the disposal pond ②, were collected three days after the rainfall. These collected sands and gravels excluding gravels bigger than bean-size and used-water for washing sands and gravels were used as samples.

The results obtained from the analyses of the water sample taken at the wadi (1) and the sample of sands and gravels taken from the wadi (2) showed the values of metal contents as follows: The former samples indicate, Fe: 150 mg/lit, Cu: 12 mg/lit, Zn: 0.6 mg/lit, Cd: 0.008 mg/lit, while the latter, Fe: 8.21%, Cu: 0.02%, Zn: 0.02% in the total weight. Water used for washing sands and gravels showed the values of metal contents as follows: Fe: 2,100 mg/lit, Cu: 12 mg/lit, Zn: 3.2 mg/lit, Pb: 0.09 mg/lit, As: 0.02 mg/lit and Cd: 0.017 mg/lit.

Because these samples analyzed were all obtained downstream of the mining disposal bonds, the relevant values show that the pollutants flowed the downstream through normal leakage from the ponds or rainfall.

7.1.3. Sampling

In order to collect the fundamental data for analyzing the nature of waste water and injurious substances contained in smoke, samples of ores, rocks, sands and gravels, surface water, and groundwater were collected as shown in Table 7-1.

7.1.4. Items of Analyses

The pollutants are considered to be produced through the methods of mining, ore dressing and smelting with the heavy metals and other elements contained in ores of Lasail mine (for smoke, the ores from Aarja mine and Bayda mine are included).

Accordingly, the kinds and quantity of the elements contained in the ores and minerals which are handled in the Copper Project should be confirmed.

As described before, the purpose of survey is to look into the possibility of pollution harmful to the agricultural development and to establish the countermeasures of pollution control. Consequently, microscopic observation and chemical analysis of collected ores, rocks, sands, gravels, and water, were carried out to confirm the quality and quantity of elements which will become the pollutants.

(1) Microscopic Observation

The results obtained from observation on the constituents of ores and rocks have been employed as a guideline to the chemical analyses.

Table 7 - 1 Collected Samples

No. of Sample	References
Ore 1	Boulder obtained from the bed of tributary No.(3), situated at the south of Lasail mine. (Omitted from analysis)
" 2	From the underground of Lasail mine. — 62.5mbgs. Foot wall side. Appearently rich in chalcopyrite.
" 3	Ditto. Hanging side. Appearently poor in chalcopyrite.
" 4	Ditto. Foot wall side. Appearently rich in chalcopy-rite.
" 5	Ditto. Hanging side. Appearently poor in chalcopyrite.
" 6	Ditto. Foot wall side. Magnetite rich, appear. rich in chalco.
" 7	Ditto. Foot wall side. Magnetite poor, appear. poor in chalco.
DP 2	Sands & gravels of Wadi(2) (exclude gravells bigger than a bean size) collected 40m downstream from con-crete wall of the waste water pond②.
" 2 (pond)	Precipitates occured by neutralization collected near the pond②
Rock Hanging Wall 1	From the underground of Lasail mine. — 62.5mbgs. Hanging side.
" " " 2	Ditto.
" " " 3	Ditto.
" Middle	Middle part of ore body in Lasail mine.
" Foot Wall	Foot wall of ore body in Lasail mine.
Water MS-3-100	From a pool at the surface of river bed of Wadi(1), situated about 100m downstream of waste water dispo-sal pond③
" DP-2	Water used to wash sands and gravels of DP-2
" W-1	Daily used water of local inhabitants.
" 2	" "
" 3	" "
" D-2	" "
" Branch	" "
" Mallayyinah	River water collected at the water level observation point, Mullayinah, on the main stream.
" MS-3-100 (filtered)	Filtered MS-3-100 water
' DP-2 (filtered)	" DP-2 "

(2) Quantitative Chemical Analyses

The results of the microscopic observation have allowed to determine the items of analysis for ores and rocks and to select the appropriate samples. The necessary quantitative chemical analysis was carried out on the appropriate items selected for the sands and gravels seemingly contaminated by the underground waste water and the precipitates produced in neutralization.

(3) Qualitative Chemical Analyses

Quantitative analyses were conducted of the ores and rocks excluded from the quantitative chemical analysis and municipal water of the local inhabitants around Lasail mine.

(4) Dissolution Analysis of Heavy Metals into Water

A dissolution analysis of heavy metals into water was carried out for ores, sands and gravels and precipitates produced through neutralization in the ponds.

(5) Quantitative Chemical Analyses of Filtrate

The quantitative chemical analysis was made of the filtrates of the waste water leaked from the disposal ponds into the wadi, the water used for washing the sands and gravels polluted by the waste water, and the precipitates in the ponds. The analysis was carried out of the filtrates obtained by filtering the aforesaid sample waters.

Table 7-2 shows the relation between the items of analyses and the kinds samples used.

Table 7 - 2 Collected Samples and the Kinds of Analyses

Sample	Kinds of Analyses Micros. Observ.	Quant. Chem. Analy.	Quali. Chem. Analy.	Solution (Quant.Chem.Analy.)	Filtrate (Quant.Chem.Analy.)
Ore 2	o	o	-	o	-
" 3	o	o	-	-	-
" 4	o	o	-	o	-
" 5	o	o	-	-	-
" 6	o	o	-	o } one sample	-
" 7	o	o	-	o	-
DP-2	-	o	-	o	-
DP-2(Pond)	-	o	-	o	-
Rock Hang. Wall 1	o	o	-	-	-
" 2	o	-	o	-	-
" 3	o	-	o	-	-
" Middle	o	-	o	-	-
" Foot Wall	o	-	o	-	-
Water MS-3-100	-	o	-	-	-
" DP-2	-	o	-	-	-
" W-1	-	-	o	-	-
" -2	-	-	o	-	-
" -3	-	-	o	-	-
" D-2	-	-	o	-	-
" Branch	-	-	o	-	-
" Mullay.	-	-	o	-	-
" MS-3-100 Filtrate	-	-	-	-	o
" DP-2 Filtrate	-	-	-	-	o

Kinds of samples and items of chemical analyses are shown below:

(1) Elements of heavy metals and sulphur contained in the ores were quantitatively analyzed for 13 items indicated below, all or part of them, depending upon the cases.
Cu, Pb, Zn, Fe, As, Cd, Ni, Mn, Au, Ag, Cr, Hg and S.

(2) Elements of heavy metals and sulphur contained in the rocks, sands and gravels, precipitates, and water were quantitatively analyzed for seven items indicated below, all or part of them.
Cu, Pb, Zn, Fe, As, Cd and S.

(3) Elements of heavy metals contained in the rocks and water were qualitatively analyzed for 35 items indicated below.
Cr, Zr, Ca, Ti, Zn, Na, Ag, Cu, V, Mo, Al, Ni, Co, Fe, Si, Mg, Pb, Mn, W, Cd, Bi, Ge, Sn, Pt, Sb, Hg, B, Au, Te, As, Rh, Ir, Ru, Pd and Ba.

(4) Potential of hydrogen (pH) was examined for ores, rocks and sands and gravels.

7.1.5. Results of Analyses

a) Results of Microscopic Observation (refer to Appendix M-2)

Microscopic observations were carried out for the sections of rocks and polished surfaces of ores. From the ore samples, chalcopyrite, pyrite, magnetite, hematite, zincblende and goethite were confirmed. The fact shows that the ores examined contain the elements of heavy metals such as Cu, Fe, Pb, Zn, As and Cd, all of which having the possibility of causing environmental pollution through mining operation. From the rock samples, the existence of plagioclase and chlorite as main components and quartz, albite, sphene, and calcite as accessories were observed.

The said observation suggests that the origin of the environmental pollution would be restricted to ores only. However, as the iron sulphide crystals were visually recognized in a part of samples taken from the hanging wall of underground, this part was quantitatively analyzed. As the result, existence of Cu, Fe, and Zn were recognized. The result seems to be different from that obtained from microscopic observations, but perhaps impregnation of iron sulphide might have been locally combined.

The rocks partly containing heavy metals will be excluded from the study items on the problem of environmental pollution by the mining project.

b) Results of Chemical Analyses

The results of quantitative and qualitative chemical analyses and the methods of estimation are shown in Tables 7-3, 7-4 and 7-5, respectively.

(1) Results of Quantitative Chemical Analyses of Ores

The samples are mainly composed of iron sulphide. From the ores numbered 2, 3, 4 and 5, 39 - 49 percent of S, 34 - 45 percent of Fe, 0.8 - 4.1 percent of Cu and small quantities of Pb and Zn were recognized, and from some parts of samples 0.01 percent of As was observed. From the samples composed chiefly of magnetite (numbered 6 and 7), 59 - 62 percent of Fe, 0.1 - 2.0 percent of Cu, and 0.5 - 1.8 percent of S were detected.

Measurement of the potential hydrogen (pH) for ores (excluding sample of No.7) shows the value of less than four, namely acidic.

Table 7 - 3 Results of Quantitative Chemical Analyses

Samples: ores, rocks, sands and gravels, waste water in the mine.

Name of Sample	Locality of Sample	Analytical Items														Remarks
		Cu	Pb	Zn	Fe	As	Cd	Ni	Mn	Au	Ag	Cr	Hg	S	PH	
		%	%	%	%	%	%	%	%	g/t	g/t	%	ppm	%		
Ore 2	In underground of Lasail mine	3.52	0.01	0.07	40.6	0.01	<0.01	<0.01	<0.01	0.4	34	0.02	<0.1	45.8	4.0	
" 3	"	1.00	0.01	0.11	43.6	<0.01	"	-	-	-	-	-	-	39.6	3.9	
" 4	"	4.12	<0.01	0.10	34.9	"	"	<0.01	<0.01	0.2	15	0.02	<0.1	49.3	3.3	
" 5	"	0.80	"	0.05	45.0	"	"	-	-	-	-	-	-	49.4	3.6	
" 6	"	2.06	"	<0.01	62.0	"	"	<0.01	0.04	0.1	3	<0.01	<0.1	1.89	3.6	
" 7	"	0.14	"	"	59.5	"	"	-	-	-	-	-	-	0.50	7.3	
Sand & gravels DP-2	Sands & gravels in area 2	0.02	"	0.02	8.21	"	"	-	-	-	-	-	-	0.42	6.7	
Precipitates DP-2 (pond)	Hydroxide at the lowermost of the setting pond 2	0.06	"	0.03	12.1	"	"	-	-	-	-	-	-	-	-	
Rock Hanging Wall 1.	Hanging wall of the ore body in underground of Lasail mine	0.06	"	0.02	8.41	"	"	-	-	-	-	-	-	4.12	7.9	
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ									
Water MS-3-100	Flowing water in Wadi, 100m downstream of the setting pond 1	12	<0.01	0.60	150	<0.02	0.008	-	-	-	-	-	-	-	-	Water with precipitates.
Water DP-2	Water washed sands and gravels of DP-2	12	0.09	3.2	2,100	0.02	0.017	-	-	-	-	-	-	-	-	

Method of calcuration (ores, rodks and sands+gravels)

Cu : JIS M8127 7 Atomic absorption spectro- photometry
Pb : " M8124 5.3 "
Zn : " M8124 5.4 " (Apply correspondingly)
Fe : " M8123 5.3 " (Apply correspondingly)
As : " M " " " "
Cd : " M8135 5 " "
Ni : " M8123 5.3 " "
Mn : " M " " " "

Au : JIS M8111 Dry assay method
Ag : " " "
Cr : Method to examine the precipitates at bottom
S : JIS M8122 Burning method
PH : Glass electrode method

(Waste water in the mine)

Cu : JIS K0102 37.2 At.ab.sp.
Pb : " " 39.2 "
Zn : " " 38.2 "
Fe : " " 47.2 "
As : " " 48.2 "
Cd : " " 40.2 "

Table 7 - 4 Results of Quantitative Chemical Analyses

Samples: Solution of ores, sands and gravels, filtrates water.

	Name of Samples		Items of Analyses									
			Cu^{++} (mg/ℓ)	Fe^{++} (mg/ℓ)	Fe^{+++} (mg/ℓ)	Pb (mg/ℓ)	Zn (mg/ℓ)	As (mg/ℓ)	Cd (mg/ℓ)	Mn (mg/ℓ)	Cr (mg/ℓ)	Hg (mg/ℓ)
Solutions	Ore	2	23	<0.1	<0.1	0.14	1.1	<0.02	0.004	<0.1	<0.03	<0.0005
	Ore	4	4.7	4.9	0.1	<0.01	0.72	<0.02	0.002	<0.1	<0.03	<0.0005
	Ore	6	16	2.8	0.6	<0.01	0.10	<0.02	<0.002	0.4	<0.03	<0.0005
	Sands + Gravels DP-2		<0.01	0.2	<0.1	<0.01	0.22	<0.02	<0.002	-	-	-
	Precipitates DP-2 (Pond)		<0.01	<0.1	<0.1	<0.01	<0.01	<0.02	<0.002	-	-	-
Filtrates	Water MS-3-100		12	41	<0.1	<0.01	0.60	<0.02	<0.002	-	-	-
	" DP-2		0.01	<0.1	<0.1	<0.01	0.07	<0.02	0.007	-	-	-

Method of Analysis

Solutions

Cu^{++}	JIS	K0102	37.2	Atomic absorption spectrophotometry
Fe^{++}	"	M0202	17.3.2	Spectrophotometry
Fe^{+++}	"	"	17.4	"
Pb	"	K0102	3.4(1) 39.2	Resolution Atomic absorption spectrophotometry
Zn	"	"	38.2	"
As	"	"	3.4(1) 48.2	Resolution Spectrophotometry
Cd	"	"	3.4(1) 40.2	Resolution Atomic absorption spectrophotometry
Mn	"	"	46.2	"
Cr	"	"	51.11	Spectrophotometry
Hg	Method mentioned on the Notice No.64, Environment Agency, 1974. Attached table II. Atomic absorption spectrophotometry.			

Filtrates

Cu^{++}	JIS	K0102	37.2	Atomic absorption spectrophotometry
Fe^{++}	"	M0202	17.3.2	Spectrophotometry
Fe^{+++}	"	"	17.4	"
Pb	"	K0102	39.2	Atomic absorption spectrophotometry
Zn	"	"	38.2	"
As	"	"	48.2	Spectrophotometry
Cd	"	"	40.2	Atomic absorption spectrophotometry

Table 7 - 5 Results of Qualitative Chemical Analyses

Samples : Rocks, Water
Method of Calcuration : Spectroscopic Analysis

Name of Sample	Locality of Sample		Cr	Zr	Ca	Ti	Zn	Na	Ag	Cu	V	Mo	Aℓ	Ni	Co	Fe	Si	Mg	P	Mn
			Items of Analyses																	
Rock up 2	In under-ground of Lasail mine	Ore body hanging wall	++	(±)	+++++	+++++	+	+++++	±	+++++	++	(±)	+++++	±	±	+++++	+++++	+++++	(±	+++++
" middle		Ore body middle part	++	(±)	+++++	+++	-	+++++	++	+++++	++	(±)	+++++	+	±	+++++	+++++	+++++	±	+++++
" up 3		Ore body hanging wall	+	(±)	+++++	+++	±	+++++	++	+++++	++	±	+++++	+	±	+++++	+++++	+++++	(±)	+++++
" foot wall		Ore body foot wall	++	(±)	+++++	+++	-	+++++	(±)	+++	+	-	+++++	±	±	+++++	+++++	+++++	-	+++
Water W-1	Well for daily use		(±)	-	+++++	-	-	+++++	(±)	+	+	-	+	±	(±)	+	+++++	+++++	-	-
" W-1-2	"		(±)	-	+++++	(±)	-	+++++	±	+	+	(±)	++	(±)	(±)	++	+++++	+++++	-	±
" W-3	"		-	-	+++++	-	-	+++++	(±)	±	+	-	+	(±)	-	+	+++++	+++++	-	(±)
" D-2	"		±	-	+++++	-	-	+++++	±	±	+	-	+	(±)	-	+	+++++	+++++	-	(±)
" Branch	"		(±)	-	+++++	-	-	+++++	+	±	+	(±)	+	(±)	-	+	+++++	+++++	-	(±)
" Mullaynah	Water level observation point in main stream of Wadi Jizzi		-	-	+++++	-	-	+++++	(±)	±	(±)	-	(±)	-	-	±	+++++	+++++	-	-

Name of Sample	W	Cd	Bi	Ge	Sn	Pt	Sb	Hg	B	Au	Te	As	Rh	Ir	Ru	Pd	Ba
	Items of Analyses																
Rock up 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
" middle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
" up 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
" foot wall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water W-1	-	-	(±)	-	-	-	-		+++	-	-	-	-	-	-	-	-
" W-1-2	-	-	-	-	-	-	-		+++	-	-	-	-	-	-	-	-
" W-3	-	-	-	-	-	-	-		+++	-	-	-	-	-	-	-	-
" D-2	-	-	-	-	-	-	-		+++	-	-	-	-	-	-	-	-
" Branch	-	-	±	-	-	-	-		++	-	-	-	-	-	-	-	-
" Mullaynah	-	-	-	-	-	-	-		+	-	-	-	-	-	-	-	-

Remarks

Symbol shows a grade of strength of spectrum line of each element on the dry plate.

- \- Not recognized
- (±) Weakly recognized
- ± Clearly recognized, but weak
- \+ Strongly recognized
- ++ More strong. Increasing of vertical bar depends on strength.

(2) The Results of Quantitative Chemical Analyses of Rocks

The sample is a rock, in which impregnated iron sulphide is visually observed in parts. From the sample numbered "rock, hanging wall 1", eight percent of Fe, four percent of S and small quantities of Cu, Zn were observed (pH = 7.9).

(3) The Results of Quantitative Chemical Analyses of Sands and Gravels

Eight percent of Fe, and small quantities of Cu, Zn and S were detected (pH = 6.7).

(4) The Results of Quantitative Chemical Analyses of Precipitates

Twelve percent of Fe and small quantities of Cu, Zn were recognized.

(5) The Results of Quantitative Chemical Analyses of Test Water

From the sample, MS-3-100, 150 mg/lit of Fe, 12 mg/lit of Cu, 0.6 mg/lit of Zn, and a small amount of Cd were detected. From the sample DP-2, 2,100 mg/lit of Fe, 12 mg/lit of Cu, 3.2 mg/lit of Zn, 0.09 mg/lit of Pb, 0.02 mg/lit of As, and 0.017 mg/lit of Cd were detected.

(6) The Results of Quantitative Chemical Analyses of Sample Waters for Ore Dissolution

Cu-rich ores, numbered 2, 4 and 6, were dissolved. From the said waters, 4.7 - 23 mg/lit of Cu^{++}, 2.8 - 4.9 mg/lit of Fe^{++}, 0.1 - 0.6 mg/lit of Fe^{+++}, and 0.1 - 1.1 mg/lit of Zn were detected. From the water containing dissolved ore 2, 0.14 mg/lit of Pb was detected. From the water containing dissolved ore 2 and 4, a small amount of Cd was detected.

(7) The Results of Quantitative Chemical Analyses of Sample Water containing Dissolved Sands and Gravels and Some Precipitates.

From test water dissolved sands and gravels, only 0.2 mg/lit of Fe^{++} and 0.22 mg/lit of Zn were detected.

(8) The Results of Quantitative Chemical Analyses of Filtrate

From the sample MS-3-100, 41 mg/lit of Fe^{++}, 12 mg/lit of Cu^{++}, and 0.6 mg/lit of Zn were detected. From the sample DP-2, a small quantity of Cu^{++} and Zn and a small amount of Cd were detected.

(9) The Results of Qualitative Analyses of Rocks and Water

From the rock sample, elements of Ca, Ti, Na, Cu, Al, Fe, Si, Mg and Mn were detected. From municipal water, elements of Ca, Na, Si, Mg, and B were rather heavily detected.

(10) Comparison of the Results of Quantitative Chemical Analyses of Sands and Gravels (DP-2) and Precipitates (DP-2 (pond))

Sands and gravels, precipitates, and also their filtrates were quantitatively analyzed for heavy metals and sulphide contained. The results are shown in Table 7-6.

The sample DP-2 has some possibility of having been contaminated by waste water coming through the disposal

Table 7-6. Results of Chemical Analyses of Water DP-2 and DP-2 (Pond)

Samples			Cu	Pb	Zn	Fe	As	Cd	S	(pH)
DP-2	Quant. chem. analysis	%	0.02	<0.01	0.02	8.21	<0.01	<0.01	0.42	(6.7)
	Filtrates	mg/ℓ	Cu^{++} <0.01	<0.01	0.22	Fe^{++} 0.2 Fe^{+++} <0.1	<0.02	<0.002	-	-
DP-2 (pond)	Quant. chem. analysis	%	0.06	<0.01	0.03	12.1	<0.01	<0.01	-	-
	Filtrates	mg/ℓ	Cu^{++} <0.01	<0.01	<0.01	Fe^{++} <0.1 Fe^{+++} <0.1	<0.02	<0.002	-	-

Table 7-7. Results of Chemical Analyses of Water MS-3-100 and DP-2

Samples			Cu	Pb	Zn	Fe	As	Cd
Water NS-3-100	Quant. chem. analysis	mg/ℓ	12	<0.01	0.6	150	<0.02	0.008
	Quant. chem. analysis of filtrates	mg/ℓ	Cu^{++} 12	<0.01	0.6	Fe^{++} 41 Fe^{+++} <0.1	<0.02	<0.002
Water DP-2	Quant. chem. analysis	mg/ℓ	12	0.09	3.2	2,100	0.02	0.017
	Quant. chem. analysis of filtrates	mg/ℓ	Cu^{++} 0.01	<0.01	<0.07	Fe^{++} <0.1 Fe^{+++} <0.1	<0.02	0.007

pond. Because the sample DP-2 was taken at the downstream side of the disposal pond (2) of waste water from the underground. The sample DP-2 (pond) is precipitate which was produced by neutralization and was taken from the surroundings of disposal pond (2). Quantity and kinds of heavy metal elements contained in the both samples have some relations. Therefore, it is considered that the sample DP-2 might be sands and gravels which were contaminated by waste water flowing out of the disposal pond.

(11) Comparison of the Results obtained by the Quantitative Chemical Analyses of Water MS-3-100 and Water DP-2

The results of analyses are shown in Table 7-7 of the two kinds of sample water, one is taken from the wadi, at the downstream of the disposal pond (3) of the underground waste water, and the other is the filtrates, DP-2, of the sands and gravels.

As mentioned already, the sample MS-3-100 is the water that flowed through the disposal pond (3), and DP-2 is the water that has certain relations with the characteristics of the water in the disposal pond (2). However, the results of chemical analyses suggested that the two kinds of the underground waste water would have the similar characteristics after passing through the disposal ponds. The precipitates taken from the sample MS-3-100 are considered to be hydroxide of iron, and those taken from the sample DP-2 are that of iron and copper.

c) Summary of the Results obtained from the Series of Analyses

The results obtained from the observation with microscope and the chemical analyses are summarized as follows:

(1) The ores of Lasail mine are chiefly composed of chalcopyrite, pyrite, and magnetite, and contain some factors of the environmental degradation such as heavy metals of Cu, Pb, Zn, Fe, As, Cd, Mn, Cr and Sulfur.

(2) Contents of injurious Pb, As and Cd in the ores are quite small in quantities.

(3) Fe and S contents in the ores are large.

(4) Heavy metals contained in the rocks are so small in quantities that it seems possible to eliminate them from the investigation of the environmental degradation caused by mining operation.

(5) The ores dissolve a considerable amount of Cu^{++} into water.

(6) The waste water leaked out of the disposal ponds with some precipitates resulting from neutralization which are chemically stable against the water.

(7) The precipitates in the waste water which are chemically stable against the water contain Fe in large quantity, Cu, and Zn in medium amount, and also Pb, As and Cd in a very small quantity.

(8) The sands and gravels, which were contaminated by precipitates in the waste water or waste water leaked from disposal ponds, contain Fe, Cu, Zn and S.

(9) The heavy metal elements contained in the municipal water are very small in quantity.

7.2. Kinds of Mine Pollution

The mine pollution to agriculture will result from the direct or indirect harmful effect of such pollutant to crops as generated by waste water from the underground and ore dressing works and smoke by plant operation, etc.

The pollution mechanism to the agriculture in the Project Area by Lasail Copper Mining Project is illustrated in Figure 7-2.

7.2.1. The Underground Waste Water

a) Anticipation of Water Quality

The underground waste water in Lasail mine is considered to be acidic in quality containing heavy metals such as Cu, Fe, Pb, Zn, As, and Cd as revealed by the results of analyses of ores, rocks, sands and gravels or water in wadi.

The process through which water samples with such quality have been obtained is as follows:

1) The procedures in Occurrence of Acid

<u>In the case of oxidation of pyrite</u>

i) Mined pyrite chemical reacts in the following processes when it touches air. $FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2$
Next, by groundwater or by water used to rock drill, the following reaction is progressed;

ii) $FeS_2 + 7O + H_2O \rightarrow FeSO_4 + H_2SO_4$.

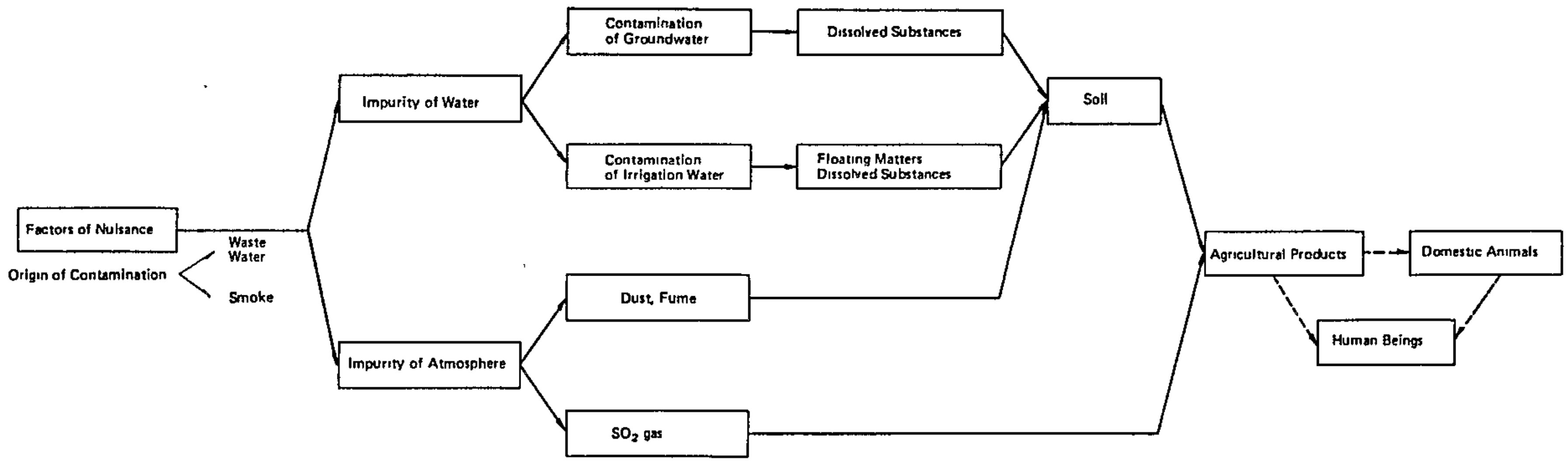


FIGURE 7 – 2 FLOW CHART FOR PROCESS OF EFFECT TO AGRICULTURAL PRODUCTS

iii) $FeSO_4$ will become acid by the following hydrolytic reaction; $FeSO_4 + 2H_2O \rightarrow Fe(OH)_2 + H_2SO_4$. Sulfuric acid is produced through the reaction.

The reaction numbered ii) will take place as follows if further oxygene is added, and the acidity becomes weak.

$$2FeSO_4 + H_2SO_4 + O_2 \rightarrow Fe(SO_4)_3 + 2H_2O.$$

<u>In case of oxidation of chalcopyrite</u>

Mined chalcopyrite chemically reacts as follows when exposed to air. $CuFeS_2 + 4O_2 \rightarrow CuSO_4 + FeSO_4$.

If, along with FeS_2, there exist water and Fe^{+++} by the oxidation of FeS_2, they result in producing some acidic water through the progress of the following reaction.

$$16Fe^{+++} + CuFeS_2 + 8H_2O \rightarrow CU + 17Fe^{++}\ 2SO_4^{--} + 16H^{+}$$

<u>In case of oxidation of zincblende</u>

Mined zincblende will become $ZnSO_4$ when exposed to the oxygen in the air in the following process; $ZnS + 2O_2 \quad ZnSO_4$. If there exist Fe^{+++} and water, the following reaction takes place to produce acidic water.

$$ZnS + 8Fe^{+++} + 4H_2O \rightarrow Zn^{++} + SO_4^{--} + 8H^{+} + 8Fe^{++}$$

<u>In case of oxidation of galena</u>

In spite of the evidence that no Pb mineral was confirmed under the microscope, the quantitative chemical analysis detected 0.01 percent of Pb. If the content of Pb means the existence of galena, then the mined galena reacts as follows through exposure to air. $PbS + SO_2 \rightarrow PbSO_4$. As the result, some acidic water is produced if there exist F^{+++} and water, and the reaction mentioned below progresses.

$$PbS + 8Fe^{+++} + 4H_2O \rightarrow Pb^{++} + SO_4^{--} + 8H^{+} + 8Fe^{++}.$$

2) Occurrence of Acid and Dissolution of Heavy Metals

As mentioned above, when the ores in Lasail mine are being mined, sulfide minerals such as pyrite and chalcopyrite are oxidized in the air, and the oxidation rapidly progresses in the existence of groundwater and water used for rock drills. Through the oxidation, acid and soluble salts are produced and the water becomes acidic having low value of pH. These reactions of oxidation dissolve many kinds of heavy metals into water. The results of these reactions are clearly confirmed through the analyses of water samples MS-3-100 and DP-2. Conclusively, it may be presumed that the underground waste water of Lasail mine is acidic in quality, having pH of less than 4, and containing much of Fe and Cu and small or very small values of Pb, Zn, As, and Cd.

b) Process of Generation of Environmental Degradation by the Underground Waste Water

If the underground waste water flows out in the following conditions, the soils and water in the downstream for the agriculture development of Sohar will be contaminated by some metal elements and will injure agricultural crops.

i) Under the condition that the elimination of copper by the reaction $Cu^{++} + Fe \rightarrow Fe^{++}$ Cu is insufficient.

ii) Under the condition that the neutralization of acid is insufficient.

iii) Under the condition that the method of disposal of precipitates which are created in the course of neutralization, is not appropriate in view of the location of Wadi Jizzi relative to morphology and geology of the area.

iv) Under the condition that precipitates or acidic water mentioned in i) to iii) flow out into the Wadi Jizzi together with surface water and groundwater by rainfall.

v) Under the condition that the pH and grades of concentration of heavy metals become more than permissible values because of the muddiness of surface water and groundwater in the Wadi Jizzi contaminated by the condition mentioned in item iv) and this impedes the growth of agricultural crops.

In other words, water under the conditions of item iv) flows into the area of Sohar Agriculture Development without diffusion and dilution by a great quantity of water, resulting in irrigation water pollution and soil contamination.

7.2.2. Waste Water from the Dressing Plant

a) Forecast on Water Quality

The quality of the waste water from the dressing plant is presumed to be salty by the effects of metal contents such as pyrite (mainly), magnetite, hematite, chalcopyrite and zincblende, other metals and non-metals, and ions of heavy metals due to the fact that the ore-dressing employs a method of floatation using sea water.

The major pollutants caused by ore-dressing are salts and metallic minerals contained in tailings.

Salts contained in water for dressing are expected to amount to 30,000 tons[1/] per year in quantity in the case that the daily

1/ Quantity of sea water used and content of salt; (crude ore 3,000 t/day) x (300 day/year) x (quantity of sea water used 2t/crude ore t) x (repeatedly used water 50%) x (concentration of salt in sea water 33 - 38%) = 29,700 - 34,200 t/year.

quantity of ore supply to the dressing plant is 3,000 tons.

Floatation is meant to separate the concentrates of copper from tailings. Consequently, it is estimated that 1,000 t/day of Fe, less than one ton of Zn, less than 100 kg of Pb, and a very small quantities of As and Cd will be discharged.

b) Generation of Pollutants by Waste Water from Ore Dressing

Waste water used in floatation in Lasail mine flows into the area of Sohar Agricultural Development and will contaminate soils. The agricultural products will be injured if the following conditions arise.

i) Conditions in which the concentration of salt in waste water is kept just as the sea water (33 - 38%) and waste water joins the stream in the Wadi Jizzi as surface water or groundwater.

ii) Condition in which the concentration of salt in waste water become high due to the natural evaporation of water in the settling pond of tailings and waste water joins the stream of the Wadi Jizzi as mentioned above.

iii) Condition in which minerals contained in tailings flow out in waste water without being separated and join the stream of the Wadi Jizzi as mentioned above.

iv) Condition in which salts and minerals contained in surface water or in groundwater in the Wadi Jizzi contaminate the irrigation water and the soils in the similar way to the waste water from the mine. In this case both the water will become muddy under the conditions mentioned in the item i) to iii).

7.2.3. Smoke from the Smelter

Sohar Copper Project employs the method of dry smelting with electric furnace and the converter and, thus smoke is emitted (refer to Appendix M-3).

a) Estimation of Harmful Materials contained in Smoke

Smoke emitted from the processing plant contains nitrogen, steam, oxygen, gases of sulfureous acid, dust, and fume.

Combustion of sulfide minerals is carried out in the electric furnace or converter and generates SO_2.

A study of the contents of ores in the mine revealed that the grade of concentration of SO_2 in the gas was estimated to be more than 10 percent and thus SO_2 seemed to be the main elements of the gas which causes the environmental pollution.

Minute substances which are thrown in the electric furnace or converter will be emitted as dust mixed in smoke; however, materials which are harmful to agricultural crops will not be included in the dust.

Some contents in the sulfide minerals will be volatilized in the electric furnace or converter by heat and condensed as fume outside. Fume probably includes some oxides of heavy metals like Pb, Zn, As and sulfuric acid as well. The pollutants, thus, generated in smoke from smelter are SO_2 gas and fume.

b) Mechanism of Smoke Pollution

Conditions that generate smoke pollution to the agricultural crops of the Project Area are as follows: SO_2 gas and fume that are diffused in the air through the chimney of the smelter reach the Area floating in the air over the distance of 30 km and changing chemically as well as physically. Then, the floating materials fall down on the ground surface in the circulation movement of air and by gravity. As a result, the agricultural products will be contaminated more seriously than permissible extent. The condition mentioned here is provided by the east wind.

7.2.4. Waste Water in the Process of Slag Production

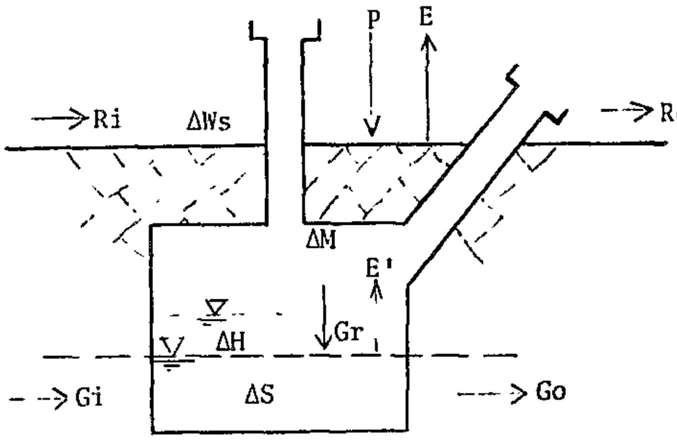
In the course of smelting of copper in Sohar plant, slag is produced by wet-method. Slag itself has no relation with the pollutants; however, if the sea water is used in the process, the quantity of waste salts created in the whole processing plant will be increased. For this reason, the process is considered to be a factor that generates environmental pollution.

7.2.5. Possibility of Environmental Pollution after the Exhaustion of Ores in Lasail Mine

After the exhaustion of ores and the close of the mine, two types of environmental pollution will be presumed. One is the natural drainage of closed underground and another is some pollution caused by the behavior of precipitates containing elements of heavy metals accumulated during the mine operation.

a) Possibility of the Natural Drainage of Closed Underground

No possibility of water leakage from the closed underground is considered. Therefore, it can be concluded that no attention is required for the pollution of this kind. The basis of this conclusion is as follows. Consideration is given to the change in quantity of water which is stored in the closed underground.



P:	Precipitation
E:	Quantity of evaporation from the ground outside
E':	Quantity of evaporation in underground
Ri, Ro:	Inflow of surface water, outflow of surface water, respectively
Gi, Go:	Inflow of groundwater, outflow of groundwater, respectively
Gr:	Replenishment of groundwater
S:	Variation of stored water
H:	Variation of groundwater level
M:	Variation of dampness of soil in unsaturated zone
Ws:	Variation of standing water on the surface
:	Variation of water content in zone where groundwater level is variable

The relations between the inflow and outflow of water, variation of stored water, and recharge of groundwater are shown in the equation below:

$$P = (Ro - Ri) + E\ (Go - Gi) + \Delta S, \quad \Delta S = \Delta Ws + \Delta M + \mu \Delta H$$

$$Gr = (Go - Gi) + \mu \Delta H$$

Assuming that Ri ≑ Ro ≑ 0, Gi ≑ Go ≑ 0, P ≑ 130 mm (mean of a year), E = 0 (the whole rain water infiltrates immediately into abandoned caves through the fissures of the rock), and E' ≑ 0 (it is saturated in the underground) then, P = ΔS = Gr = 130 mm (per year) is obtained, and the whole rain water would be kept in the underground.

In this case, the total volume of the abandoned caves underground is estimated at 2,000,000 m^3. Assuming that the whole rain water infiltrated in the underground is 33,000 m^3/year (area of basin: 500m x 500m x 130mm), it would take about 60 years for the abandoned caves to be filled up to the entrance with stored water. As a matter of fact, those factors of $E >> 0 \therefore P >> Gr$, $E' > 0 \therefore Gr > \Delta S$ are assumed, the abandoned undergrounds in Lasail mine are expected not to be submerged up to their entrances.

b) Behaviour of the Precipitates by Neutralization which Accumulate during the Operation

The precipitates produced during the course of neutralization of the waste water in the underground accumulated mostly in the disposal ponds ② and ③ in February, 1982, and some accumulated in the tributaries (1) and (2) flowing out of the ponds in the rain.

Although the precipitates are chemically stable against water, the quantitative chemical analysis of sample DP-2 (pond) clarified that the precipitates include Fe of about 10 percent and Cu, Zn in the level of 1/100 percent and they themselves are harmful to animals and plants directly or indirectly.

Furthermore, the specific features and forms of the precipitates are directly affected by the characteristics of the waste water, the change in forms, and the extent of eliminating Cu and of neutralization, etc., and the example by the disposal pond DP-2 shows that the neutralization in these ponds will produce the precipitates with much heavy metal content.

The precipitates produced during the plant operation accumulated in dry condition in the remains of disposal ponds or surroundings after the draining from the underground is halted.

It is assumed that such dried precipitates sometimes move to the lower reaches, being involved in the surface water in the rainy seasons.

7.2.6. Expected Environmental Degradation by Mine Industry after Closing of Its Operation

The Copper processing Plant is scheduled to be operated with ores supplied from the mines of Lasail, Bayda and Aarja. The future policy, however, has not been yet determined whether the operation of the plant will continue obtaining the ore supply from the other mines or will halt its operation, when the current sources of ore supply are exhausted.

However, it can be considered that the different types of the environmental pollution may be generated after the close of the plant. The pollutants in this case will be heavy metals and salts in tailings sedimented during its operation.

The surface of the tailing ponds after halting the operation will be dried up and the rain water flows down in small streams on the surface of dried tailing ponds and washes the tailings into the streams.

7.2.7. Brief Descriptions of the Mechanism of Generation of Environmental Degradation by Mining

a) Waste Water

In view of the locational relationship, the mechanism of the environmental pollution by any kinds of waste water was analyzed in two ways as follows;

i) Movement of pollutants from the origin to the point D_2

In this stage, direct effects to the agricultural crops of the proposed Project will not be identified.

Pollutants will be moved by muddy water running from the original source to the point D_2 in which the surface water by rainfall will be kept under the ground, and also the movement will contaminate sands and gravels in that course.

ii) Movement of pollutants from the point D_2 to the lower reaches

The pollutants reaching the point D_2 move further down to the lower reaches with water running the agricultural production areas in a considerable concentration exceeding the permissible level, and the soil pollution will be over the critical point. In this case, the environmental degradation will badly affect the agricultural crops.

b) Smoke

Moving direction of SO_2 gas, dust, and fume is changeable by the seasonal changes in air current. Also the extent of diffusion is changeable by the weather conditions such as wind velocity, temperature, and rainfall.

Pollution can be observed where pollutants produced in the smelters drift in the air by the east wind to the Project Area and fall down under certain weather conditions. In this case, the pollution to the agricultural crops will be triggered when the pollutant concentration or accumulation in the soils exceeds the permissible level.

7.3. Agricultural Products and Pollution by Mining

Pollution to the agricultural crops by those pollutants of acidic or saline water containing heavy metals, and SO_2 gases or fume containing heavy metals will be generated when the pollutant concentration or accumulation exceeds the permissble level and are directly in contact with plants or soils, and in this case, the resistivity of the plants to the pollutants has a close relation with the vulnerability of the plant to the pollution.

Pollutants drifting through water or atomospheric current will contaminate the plants when they contact the soils or are absorbed thereto through the air current.

7.3.1. Soil Contamination

The soil contamination in the Project Area caused by water containing pollutants can be defined as an extraordinary change of the soils after the start of operation of Sohar Copper Project, as compared with the normal state of pH values and heavy metal contents in the soils.

With respect to the soil contamination and the crop damages, two cases are observed: one is the case that impede the plants' growth and the other is the case where polluted plants themselves turn to harmful.

a) Soils Contamination caused by Heavy Metals in Waste Water of the Mine

Heavy metals which are injurious to the plants and included in the ores of Lasail mine are presumed to be Cu, Zn, and Pb.

Among them copper is accumulated in the plant roots and works against other elements necessary to the growth of plants. Zn and Pb act upon the protoplasm and lead plants to death.

Cd and As are the heavy metals which are injurious if they are contained in food staffs or feeds. However, the contents of Cd and As in ores or waste water are lower than the Clark number which shows the grade of existence of elements in the earthcrust. Also, it may not be considered that the elements are highly accumulated only in the Project Area.

The same is true of Fe. In conclusion, it can be said that the heavy metal elements which injure the crops are Cu, Pb, and Zn.

b) Soil Contamination resulting from Acidic Water of the Underground

The underground waste water in Lasail mine is discharged after neutralization. There will be no problem in discharging the water to the downstream, if the waste water can be well controlled. However, failure in the control will cause the soil pollution by acidic water containing Cu^{++}, Fe^{++}, Fe^{+++}, Pb, Zn, As, and Cd.

An example of the mechanism of the acidic water pollution is shown below: namely, the soil is acidified, and Fe and Al contents in the soil are dissolved in the water and the crops show the exceeding value of Fe by absorbing the polluted water. It is considered that the pH of the soil which may impede acidic pollution is less than 4.5.

c) Soil Contamination caused by Minerals Contained in Waste Water from Dressing Plant

Major metallic minerals included in waste water from the dressing plant are $Fe\ SO_4$, $CuFeS_2$, and ZnS (PbS is perhaps included).

These minerals contained in the waste water flow down and produce some acid on the way to the farmland soils or after reaching the soils. Such waste water dissolves heavy metals and contaminates the soils by acidic materials containing Cu, Zn, and Pb. Injuries will occur in the same way as (a) and (b).

d) Injury of Soil Contamination by Salts included in Waste Water from Dressing Plant

The saline pollution mechanism is that the salinity taken into by plants will disturb their metabolism, decline the carbon assimilation, cause some other malfunctioning to restrict the nutrient intake through roots, and finally cause a death.

The Cl content in polluted soil moisture is different among the different kinds of crops and the degree of saline injury is proportional to the number of days of saline exposure and rapidly progresses with an increase in salinity concentration.

e) Soil Contamination caused by Alkaline Water from Dressing Plant

The waste water from the dressing plant is mostly of alkali. It is said that when the soils are alkalized, Fe, Mn, Zn, and Cu in the soils become insoluble, resulting in ill-balanced absorption of nutrients.

The pH of the soils which produces alkaline injury will be more than 8.0.

7.3.2. Air Pollution

SO_2 gas or fume might touch or be absorbed by the plants. Toxicity of SO_2 gas is comparatively strong in comparison with other air pollutants. The crops vulnerable to the SO_2 gas suffer an acute injury on leaves soon after exposed to the gas with concentration of about 1.0 ppm. Alfalfa is a typical example of the crops affected by SO_2.

SO_2 changes into SO_3 in the air and further into sulfuric-acid mist.

The sulfuric-acid mist, though less toxic than SO_2, is considered to break the muscular tissues and hinder the action of ferment as acidic effects.

Fume containing oxides of heavy metals as Pb, Zn, and As have direct acidic effects on crops when it is absorbed to crops or it causes the soil contamination by floating on the ground surface.

7.4. Countermeasure against Mining Pollution

Based on the data obtained from the analyses of ores, rocks, sands and gravels, and waste water of Lasail mine, the quality and characteristics of waste water and smoke were forecasted. Also the process of occurrence of pollution was assumed and the specific features of contamination were examined.

As a result, the pollutants were confirmed as acidic water, heavy metals included in acidic water, alkaline water, any kinds of minerals in tailings, salts and gas, and fume.

7.4.1. Fundamental Problems

Fundamental problems in undertaking countermeasures against pollution by mine comprise two factors. One is to carry out the successful chemical and physical treatments of waste water and smoke, and the other is to establish an organization responsible for supervising the above treatments and results obtained therefrom.

A successful operation of the agricultural development project free from the mine pollution will require for the copper industry to take appropriate countermeasures for pollution as well as to establish a check system for effective execution of these measures. On top of the above, the efficient and powerful administrative guidance based on the said check results will be essential for establishing the most effective and successful pollution control system.

According to the law enacted on February 8, 1982, concerning the conservation of environment and the prevention of pollution, the obligation of entrepreneurs of Copper Project was defined clearly. It is strongly expected that the relevant by-laws and regulations concerned will be enacted in future so that the duties and obligations of the entrepreneurs can be clearly specified.

A fundamental idea of the pollution control for air and water, which is discussed below is that the control methods should strictly meet the requirements of the drainage and emission standards.

7.4.2. Water Pollution Control

The waste water to be controlled is of many kinds such as the waste water from the mine (acidic water, any kinds of heavy metals), the water from the dressing plant (alkaline water, salts, any kinds of metallic minerals), and the water to be emitted through slag of the smelters. The ore dressing, even after the closure of the plants, will emit the waste water flowing out from the tailing dam when raining.

a) Control of the Waste Water from the Mine

For the waste water containing much Cu ions, an eliminating process of Cu should be added through $Cu^{++} + Fe \rightarrow Cu + Fe^{++}$ and the acidic waste water produced there should be neutralized to deposit the precipitates of heavy metals such as Fe, Cu, Zn and Pb, etc. in the forms of hydroxides, which are deposited in physically stable conditions so as not to flow out even in the rain.

The process that will be taken in the disposal pond (2),i.e., $Cu^{++} + Fe \rightarrow Cu + Fe^{++}$ is effective to eliminate Cu out of the waste water.

As learnt from the results of analyses of water sample DP-2 taken from sands and gravels in the tributary (1), the precipitates were considered to overflow the concrete walls constructed at the side of lower reaches when the heavy rainfall took place on February 11, 1982. The rainfall on that day was 107 mm. It is, therefore, necessary to construct the pond having a sufficient capacity not to cause an overflow even in such a heavy rainfall.

b) Control of the Waste Water from Dressing

There are two ways of controlling the waste water from the dressing.

i) The waste water is naturally evaporated from the tailing ponds, and all kinds of minerals and salts are separated, and then these materials accumulate in the ponds.

ii) Waste water from the tailing ponds is guided to the disposal ponds to make natural sedimentation of minerals of any kinds and to separate these minerals. And the waste water can be discharged into the sea through pipes. In the both ways shown in i) and ii), the tailing ponds are required to be structured free from leakage of the waste water.

In the case of i), the area of tailing ponds should be so estimated to meet the requirements for the quantities of evaporation per day and the stored waste water.

In the case of ii), all kinds of minerals separated in the disposal ponds are again conveyed to the tailing ponds by pump.

c) Control of the Waste Water flowing out from the Manufacturing of the Smelter Slag

i) by dry method
ii) by groundwater in the wadi
iii) by conveying the waste water to the tailings ponds to be mixed with the waste water from the dressing

7.4.3. Smoke Control

a) Control of SO_2 Gas

The concentration of SO_2 gas emitted from the converter is assumed to be more than 10 percent, and the devices to remove SO_2 should be provided between the converter and chimney. The economical lime-gypsum method(a double method is necessary)is considered the most suitable to the Project. Suspension liquid of limestone powder or slaked lime absorbs SO_2 gas strongly and produces gypsum from lime sulfite.

$$CaCo_3 + SO_2 + H_2O \quad Ca\,(HSO_3)_2 + CO_2$$
$$Ca(HSO_3)_2 + O_2 \rightarrow CaSO_4$$

Lime sulfite and gypsum are both insoluble, and in the case that economical recovery of gypsum can be hardly expected, it will be possible to dispose them at a specially designated place.

b) Control of Dust and Fume

Electric dust collector should be equipped along with the Ballon Flue, because fine dust must be prevented from spreading out.

Since dust and fume emitted from the converter will adsorb gypsum through the devices for eliminating SO_2, it is not necessary to equip a dust collector in the system of the converter side in the case of the lime-gypsum method.

There are several types of electric dust collectors with respect to differences in their mechanism, and it is necessary to select an adequate type in considering the characteristics of dust and fume and specific features of gas as well as the conditions of the temperature and humidity.

7.5. Monitoring the Environmental Degradation by Mine Pollution

7.5.1. Fundamental Matters of Pollution Control

As the fundamental items of the control measures for the environmental pollution caused by chemical and physical emission of pollutants from mining, it is considered necessary to provide systematic activities for protecting the Area from environmental pollution.

Pollutants emitted by mining will continue to move throughout the whole period of operation of the Copper Project, and as the time goes by, the pollutants will gradually be condensed in between the Copper Project and the Agricultural Development Projet areas.

It will be too late to establish the necessary counter-measures for environmental pollution once the contamination in certain spot is observed. Consequently, a continuous investigation in the time series changes in the pollution at a spot will be essentially required, and for a timely countermeasure of pollution control, necessary actions have to be taken well in advance.

A monitoring system of the environmental degradation should be established for the purpose of successful pollution control.

Effective monitoring systems can be specified into three.

a) Measurement and observation (survey at the spot of measurement) should be made to know the environmental conditions and its changes.

b) Through the evaluation and analysis of the environmental data, forecast of various environmental change should be made. A warning must be given according to the rules previously specified (appraisal of survey results, analysis, and warning).

c) Positive actions should be taken for protecting the environment from worsening (countermeasures).

Three kinds of monitoring system will be available as follows.

i) The copper industry entrepreneurs, who themselves serve as monitors, shall conduct a close observation and make report on the monitoring results and proper countermeasures to the authorities concerned so as to give necessary information to the organization or agency concerned with the agricultural development program.

ii) Monitoring shall be made by those concerned with the agricultural development project or any other third parties, and the monitors shall make report on the monitoring results and the proper countermeasures to the authorities concerned so as to give necessary information or warning to the copper industry.

iii) The administrative authorities will carry out monitoring and give guidance in the environmental control to the copper industry according to the monitoring results.

7.5.2. Monitoring

a) Water Quality

i) Collection of water samples and observation at the wells

Observation wells should be provided in the wadi basin to collect water samples once a week or so. At the same time, such measurements should be taken as groundwater level, velocity and quantity.

Figure 7-3 shows the proposed locations of the observation wells located between the origin of the pollutants of the mine and Point D_2. (a survey well for the groundwater course is necessary in the lower reaches of the point D_2).

ii) Items of the water quality analyses

Water samples	Items of analyses			
	pH	EC	Heavy metals	P.A.W.R.
⊗ 1 ∿ 9				
⊗ 1-1 ∿ 1-6				
⊗ 2-1 ∿ 2-2				

Heavy metals

Basic items: Cu, Pb, Zn, Fe, As, Cd.

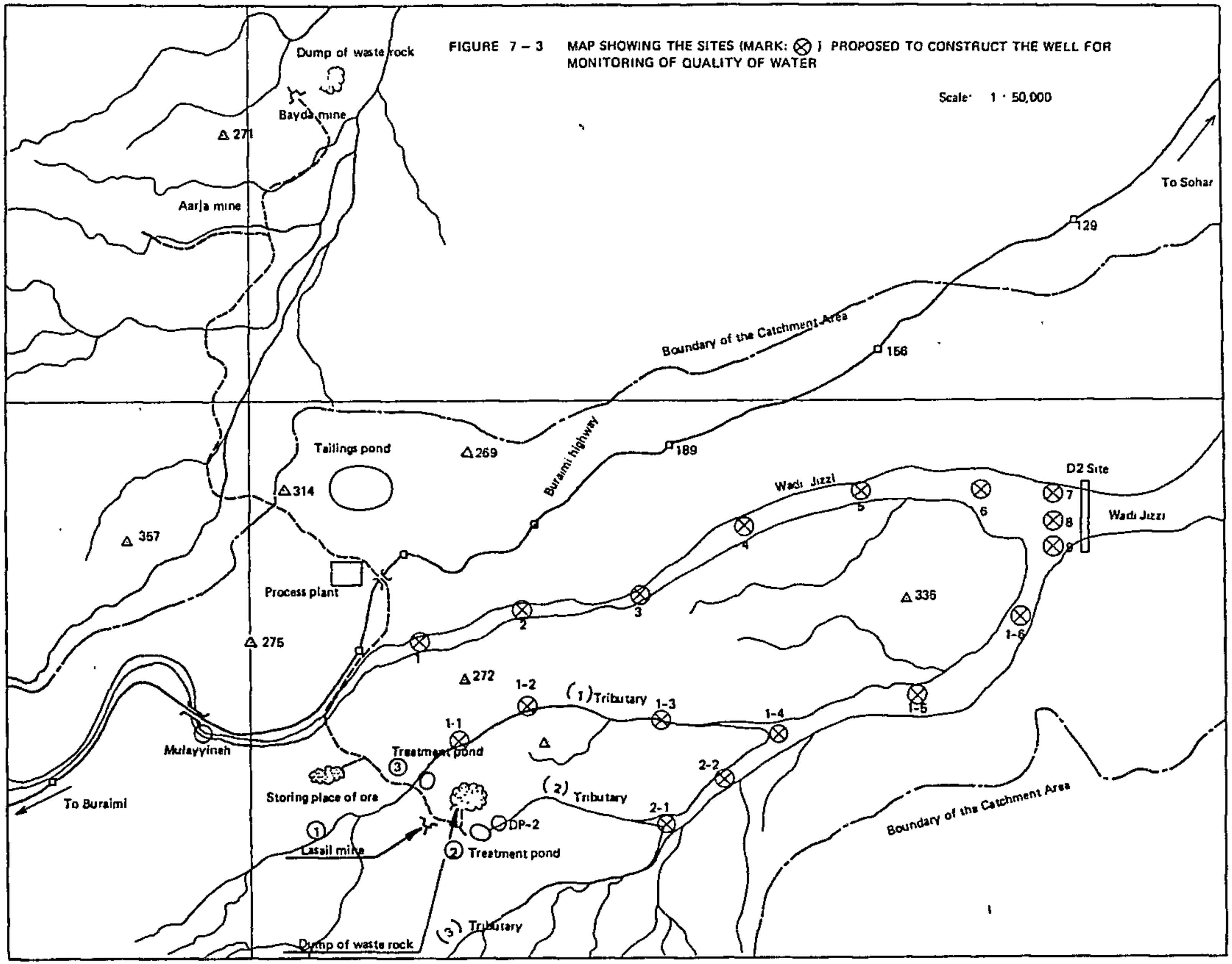
Special items: Mn, Cr, Hg in addition to the above.

Analysis item specified by P.A.W.R. (Public Authority for Water Resources)

Basic items: Ca^{++}, Mg^{++}, Na^{++}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4, NO_3^{-}.

Special items: Items analyzed by P.A.W.R. in addition to the basic items (refer to Appendix M-4)

FIGURE 7 – 3 MAP SHOWING THE SITES (MARK: ⊗) PROPOSED TO CONSTRUCT THE WELL FOR MONITORING OF QUALITY OF WATER



b) Monitoring Air Pollution

i) Air sampling points (Points of observation)

One or two observation points each will be located in the vicinity of the smelters and in the proposed agricultural development area and some others in the area between the above two areas. The definite observation points between the smelters and the farms will be determined according to the results of the weather observation to be conducted in Sohar. Since the pollutants move along with the atmospheric current in horizontal or vertical directions, weather observation should preceded the location determination of the points.

ii) Analysis items

Granular substance; falling dust (dust, fume)

Gaseous substance; oxidized sulfur (SO_2)

iii) Measurement

Measurement will be taken by either of the following three methods; instantly continuous method, integration method, and intermittent method. However, it is necessary to consider the seasonal changes in the wind direction, temperature, rainfalls for the selection of the method.

7.6. Future Problems

The possibility of the environmental pollution to the Agricultural Development Project in Sohar by the copper industry was studied and the fundamental countermeasures were pointed out.

It is desirable to establish the concrete countermeasures based on a further detailed study of various problems. In order to carry out the plant, it is necessary to make investigation for the analyses of water courses of groundwater along the main stream of the Wadi Jizzi and the weather conditions of the Area.

7.6.1. Waste Water Quality Check and Establishment of Water Quality Monitoring System

Routine works of check and control of the quality and feature of waste water emitted from the underground and dressing plants should be made by the entrepreneurs of the Sohar Copper industry to protect the proposed Project Area from the environmental pollution.

Monitoring of the water quality is necessary to compare the results of the checking of waste water mentioned above and the changing movement of the pollutants has to be forecast.

An effective measuring system for the pollutants should be established to meet the Project requirements under the close cooperation of the water quality control monitors assigned by the authorities concerned with those assigned by the copper industry. Data analysis, evaluation of the results and forecast upon those data and information are indispensable for successful monitoring. It is natural that the basic items of the waste water checking should be identical to those of monitoring.

The checking items are as follows:

Items	Waste water from underground	Waste water From dressing	Monitoring
Wasting hours of water and Quantity	o	o	-
Quality of waste water or groundwater	o	o	o
Quantity of surface water or groundwater	-	-	o

7.6.2. Survey on the Flow of Groundwater in the Downstream of the Point D_2 along the Main Wadi Stream

The specific features of the pollutants reaching the point D_2 in the main stream play an important role in the analysis of the possibility of the soil contamination in the proposed farms.

Geology of the bed of the Wadi Jizzi is composed of the Quaternary alternations of sands and graves and permeabile or impermeable silt layers, and the groundwater flow ways in the aquifer are complicated.

It is assumed that in the aquifer there are a main flow way and several branches, which sometimes separate from and join each other.

After reaching the point D_2, the pollutants are involved in the flow and sometimes diluted or concentrated.

In order to predict the relation of flows and the movements of the pollutants, specific features of flow ways of groundwater and quantity of discharge and locations of wells for agriculture are necessary to be clarified for references. Consequently, observation wells to analyze the flow ways and quantity of groundwater are necessary. These wells can be utilized as observation wells in monitoring as well.

7.6.3. Meteorological Surveys

Environmental pollution caused by SO_2 gas, dust, and fume emitted from the smelter is influenced by the meteorological conditions.

There may be no possibility of occurrence of pollution in the proposed farm lands, if the east wind bringing pollutants does not blow. Also, the same thing can be said of the case where the pollutant concentration is below the permissible level when SO_2 gas, dust, or fume in the smoke is scattered through the air current and is absorbed in the crops.

It is said that the direction of the wind is northwest in winter and southwest in summer and the wind velocity is 45 - 90 km/day. However, these can not serve as precise and detailed data.

Prediction of the occurrence of environmental pollution in the Area will be made based on the data of the characteristics of smoke emitted from the smelters and the strong air current. Consequently, detailed meteorological investigation in the Area of Sohar is essential, and the monitoring on the smelters' smoke should be planned on the basis of the meteorological data.

7.6.4. Monitoring and Preparation of Standard of Warning

A warning of the environmental degradation by the waste water from the mines will be effectively given after the characteristics of the all waste water emitted from the mines can be completely analyzed, the groundwater flow course in the downstream of the point D_2 is clarified and the systematic monitoring networks are available in the Area.

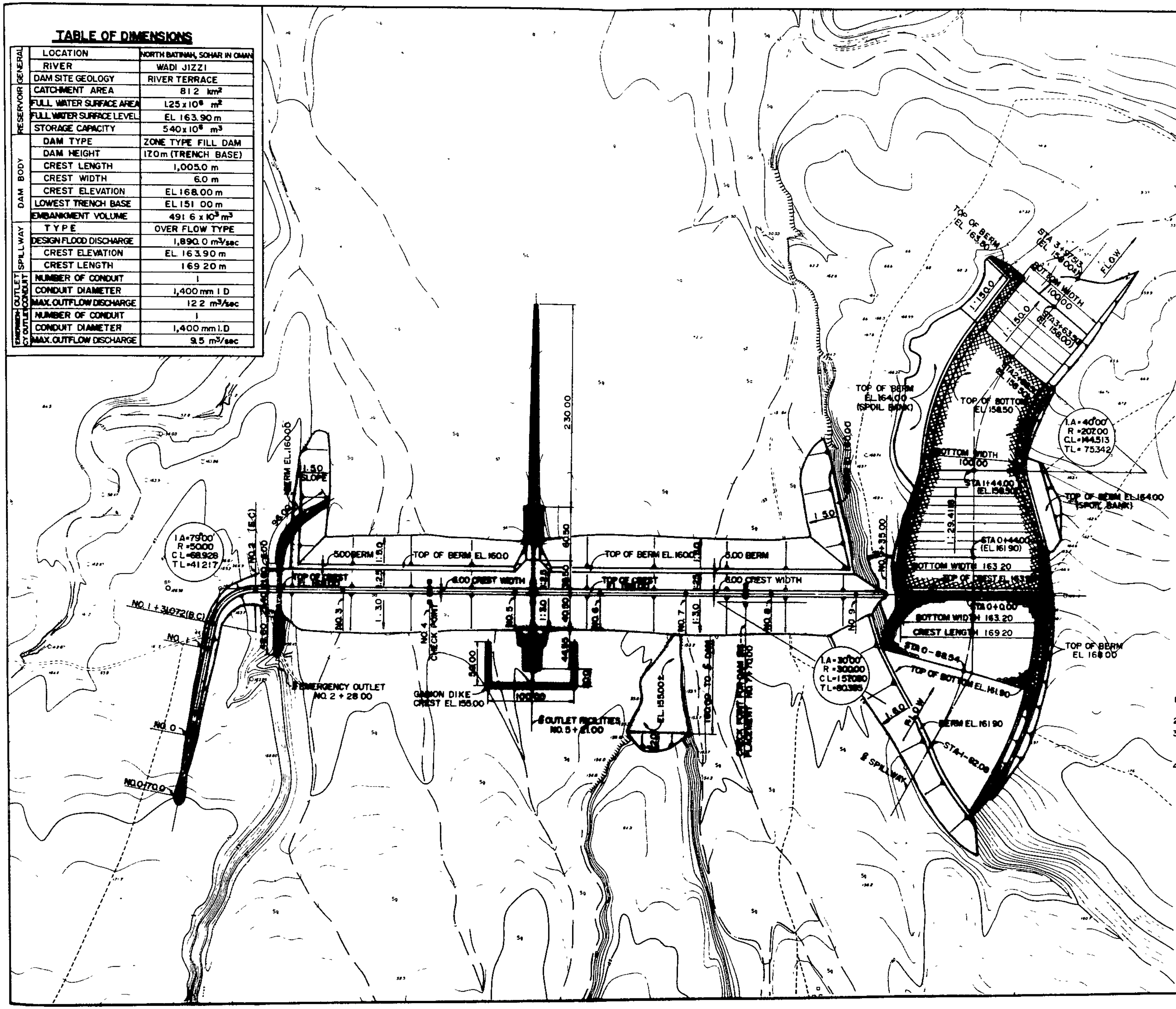
It is necessary to prepare the standards for warning on the pollution by their kinds, characteristics, and nature of pollutants.

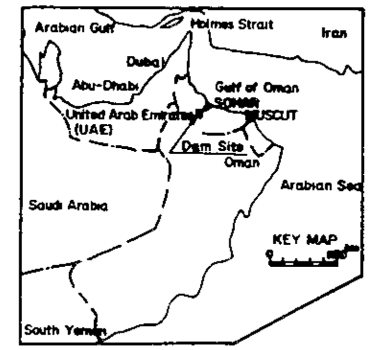
The same can be said of the case of air pollution as well. The standards should be closely related to the regulations which are scheduled to be put in force in accordance with the law of environmental conservation and prevention of pollution.

LIST OF DRAWINGS

TABLE OF DIMENSIONS

GENERAL	LOCATION	NORTH BATINAH, SOHAR IN OMAN
	RIVER	WADI JIZZI
	DAM SITE GEOLOGY	RIVER TERRACE
RESERVOIR	CATCHMENT AREA	812 km²
	FULL WATER SURFACE AREA	1.25 x 10⁶ m²
	FULL WATER SURFACE LEVEL	EL 163.90 m
	STORAGE CAPACITY	5.40 x 10⁶ m³
DAM BODY	DAM TYPE	ZONE TYPE FILL DAM
	DAM HEIGHT	17.0 m (TRENCH BASE)
	CREST LENGTH	1,005.0 m
	CREST WIDTH	6.0 m
	CREST ELEVATION	EL 168.00 m
	LOWEST TRENCH BASE	EL 151.00 m
	EMBANKMENT VOLUME	491.6 x 10³ m³
SPILLWAY	TYPE	OVER FLOW TYPE
	DESIGN FLOOD DISCHARGE	1,890.0 m³/sec
	CREST ELEVATION	EL. 163.90 m
	CREST LENGTH	169.20 m
OUTLET CONDUIT	NUMBER OF CONDUIT	1
	CONDUIT DIAMETER	1,400 mm I.D
	MAX. OUTFLOW DISCHARGE	12.2 m³/sec
EMERGENCY OUTLET CONDUIT	NUMBER OF CONDUIT	1
	CONDUIT DIAMETER	1,400 mm I.D
	MAX. OUTFLOW DISCHARGE	9.5 m³/sec





NOTES :—

1. ALL STATIONS AND ELEVATIONS ARE GIVEN IN METERS
2. ALL DIMENSIONS ARE GIVEN IN METERS.
3. DAM CREST ELEVATIONS ARE SHOWN WITHOUT EXTRA BANK AND MAX. EXTRA BANK IS 0.3m IN RIVER-BED PORTION
4. WORK THIS DRAWING WITH D-1002 TO D-1008.

SCALE 0 — 150m

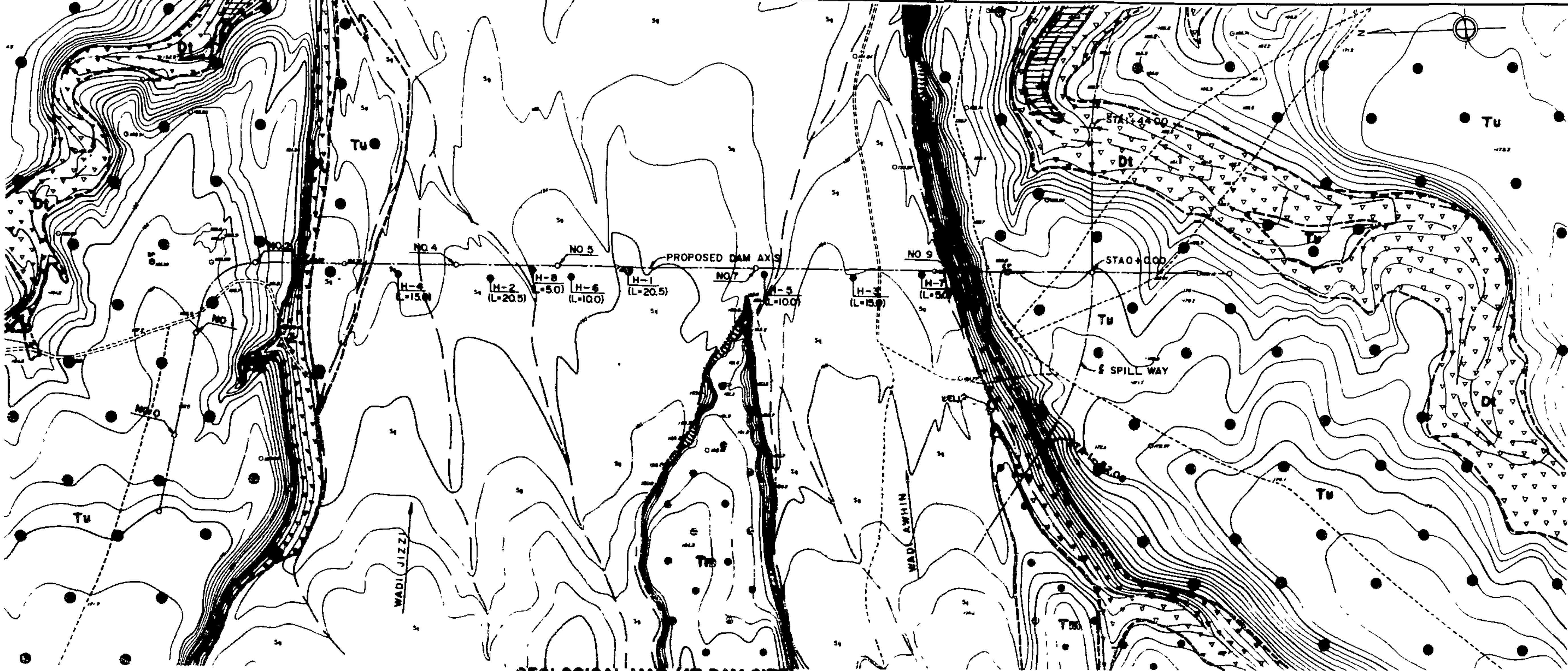
SULTANATE OF OMAN
MINISTRY OF AGRICULTURE AND FISHERIES
DIRECTORATE GENERAL OF WATER RESOURCES AND IRRIGATION

WADI JIZZI
AGRICULTURAL DEVELOPMENT PROJECT

GENERAL PLAN

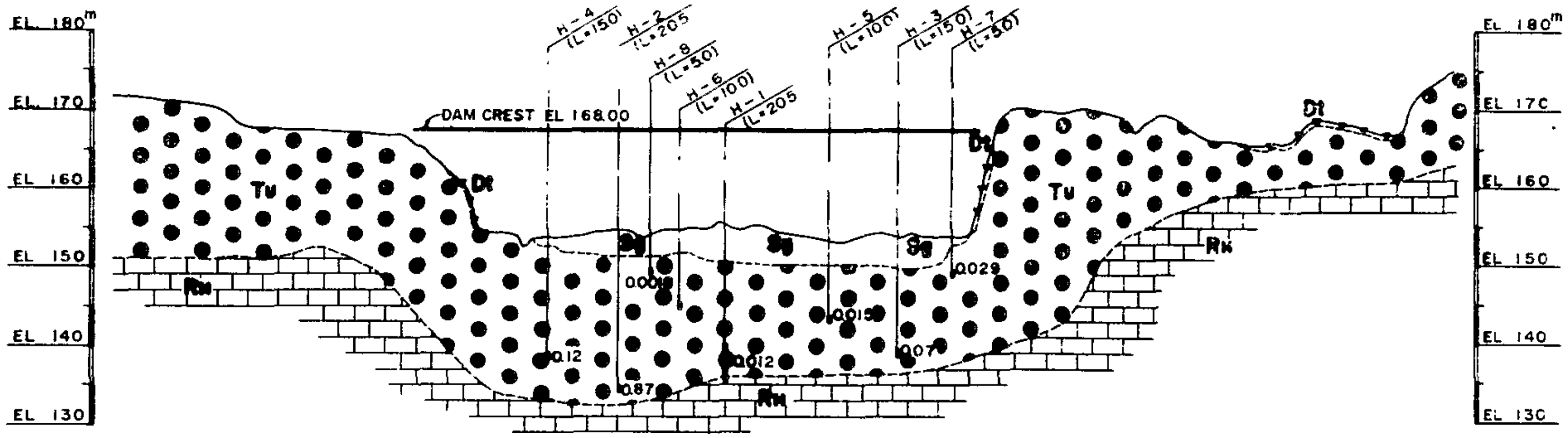
DATE	NOV. 1982	DWG NO.	WJP- D- 1001

JAPAN INTERNATIONAL COOPERATION AGENCY



GEOLOGICAL MAP (AT DAM SITE)

SCALE 0 150m



GEOLOGICAL PROFILE (ALONG DAM AXIS)

HORIZONTAL SCALE 0 300m

LEGEND

- Sg — RECENT WADI DEPOSIT
- Dt — TALUS DEPOSIT (GRAVEL WITH SILT)
- Dt — TALUS DEPOSIT (SILT, SAND)
- Tm — MIDDLE TERRACE DEPOSIT
- Tu — UPPER TERRACE DEPOSIT
- Rn — HAWASINA GROUP
- GEOLOGICAL BOUNDARY
- H-7 (L=50) — BORE HOLE POINT > DRILLED DEPTH
- H-7 (L=50) 0029 — PERMEABILITY TESTING POINT AND COEFFICIENT OF PERMEABILITY IN cm/sec

NOTES —

1 ALL STATIONS AND ELEVATIONS ARE SHOWN IN METERS
2 ALL DIMENSIONS ARE SHOWN IN METERS
3 DETAIL GEOLOGICAL DESCRIPTIONS REFER TO APPENDIX D

SULTANATE OF OMAN
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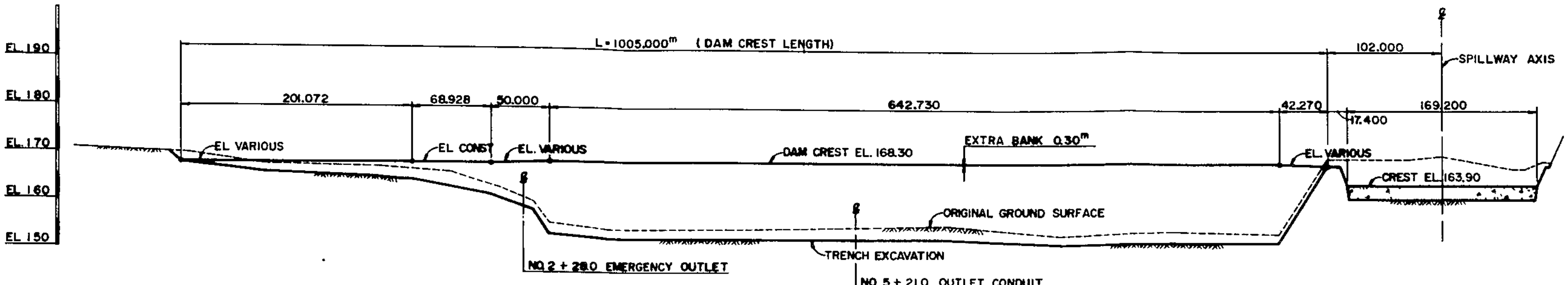
DIRECTORATE GENERAL OF WATER RESOURCES AND IRRIGATION

WADI JIZZI AGRICULTURAL DEVELOPMENT PROJECT

GEOLOGICAL MAP (PLAN AND PROFILE)

DATE	NOV 1982	DWG NO	WJP D-1002

JAPAN INTERNATIONAL COOPERATION AGENCY



NOTE ALL DIMENSIONS ARE GIVEN IN METERS.

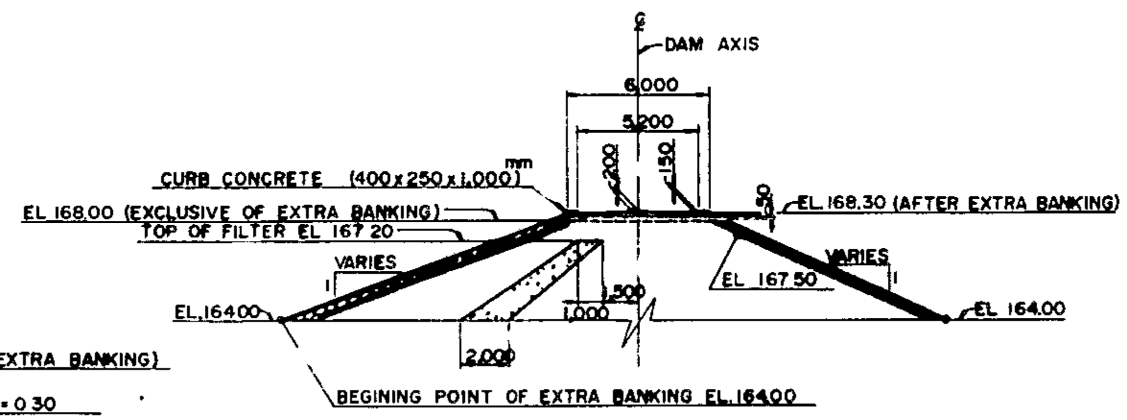
DAM CREST ELEVATION		168.000	168.040	168.080	168.100	168.100	168.100	168.100	168.140	168.250
TRENCH EXCAVATION ELEVATION		168.000	168.000	165.000	[illegible]	[illegible]	162.920	[illegible]	[illegible]	[illegible]
GROUND ELEVATION	171.800	170.000	167.700	167.200	[illegible]	[illegible]	166.000	[illegible]	[illegible]	160.000
TOTAL DISTANCE	10.000	0.000	70.000	170.000	191.072	[illegible]	[illegible]	270.000	[illegible]	307.000
DISTANCE	0.000	10.000	70.000	100.000	21.072	10.000	34.46[illegible]	34.46[illegible]	10.000	27.000
STATION	[illegible]	[illegible]	NO. 0	NO. 1	+21.072	[illegible] (B.C.)	+65.536 (I.P.)	NO. 2 (E.C.)	+10.000	+37.000

DAM CREST ELEVATION	168.300	168.300	168.300	168.300	168.300	168.300	168.300	[illegible]	[illegible]
TRENCH EXCAVATION ELEVATION	153.000	152.000	152.000	152.000	152.000	151.000	151.500	[illegible]	[illegible]
GROUND ELEVATION	158.510	153.980	154.090	154.710	155.020	153.030	153.950	[illegible]	[illegible]
TOTAL DISTANCE	[illegible]	370.000	470.000	570.000	670.000	770.000	870.000	[illegible]	970.000
DISTANCE	13.000	50.000	100.000	100.000	100.000	100.000	100.000	92.730	7.270
STATION	+50.000	NO. 3	NO 4	NO. 5	NO. 6	NO 7	NO 8	+92.730	NO. 9

DAM CREST ELEVATION	168.000	163.900	163.900	163.900	163.900	163.900
TRENCH EXCAVATION ELEVATION	[illegible]	162.900	160.900	160.900	160.900	162.900
GROUND ELEVATION	169.500	170.070	169.650	170.100	167.700	168.550
TOTAL DISTANCE	[illegible]	1022.400	1070.000	1107.000	1170.000	1191.600
DISTANCE	35.000	17.400	47.600	37.000	63.000	21.600
STATION	+35.000	+52.400	NO. 10	+37.000	NO 11	+21.600

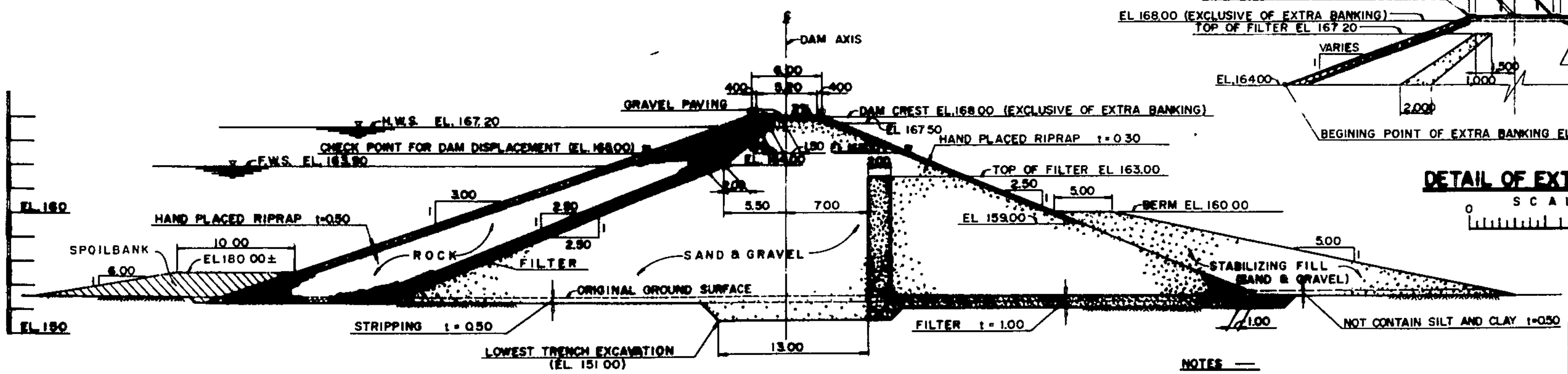
LONGITUDINAL PROFILE

HORIZONTAL SCALE 0 150m



DETAIL OF EXTRA BANK

SCALE 0 10m



TYPICAL SECTION

SCALE 0 10 14m

NOTES —

1. ALL STATIONS AND ELEVATIONS ARE GIVEN IN METERS.
2. ALL DIMENSIONS ARE GIVEN IN METERS.
3. MAXIMUM EXTRA BANK IS 30cm IN RIVER—BED PORTION
4. TRENCH EXCAVATION IS 2.0m THICK ON AN AVERAGE.

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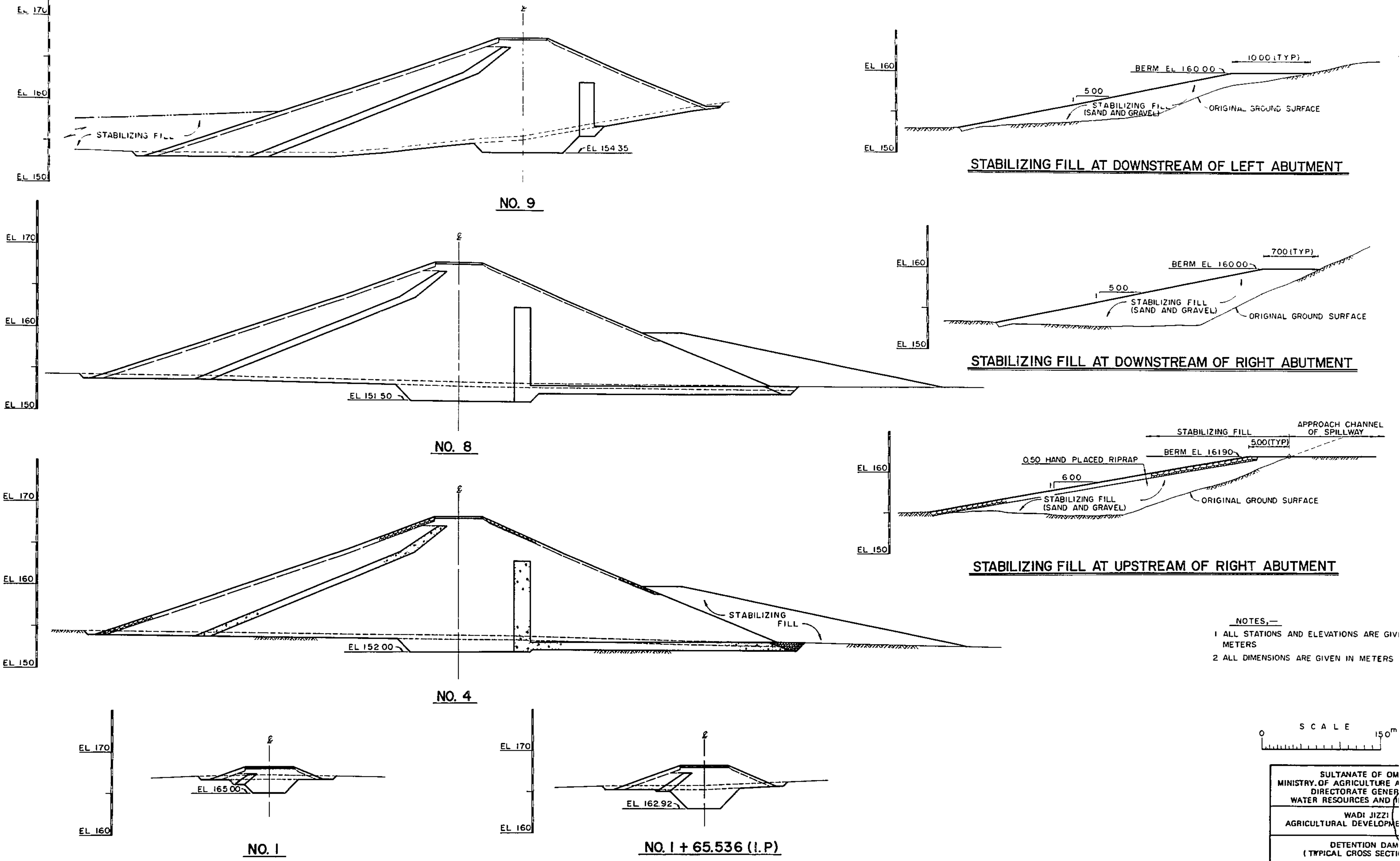
WADI JIZZI AGRICULTURAL DEVELOPMENT PROJECT			
DETENTION DAM (TYPICAL SECTION AND PROFILE)			
DATE	NOV 1982	DWG.NO.	WJP-D-1003
JAPAN INTERNATIONAL COOPERATION AGENCY			



NOTES,—

1 ALL STATIONS AND ELEVATIONS ARE GIVI
METERS

2 ALL DIMENSIONS ARE GIVEN IN METERS

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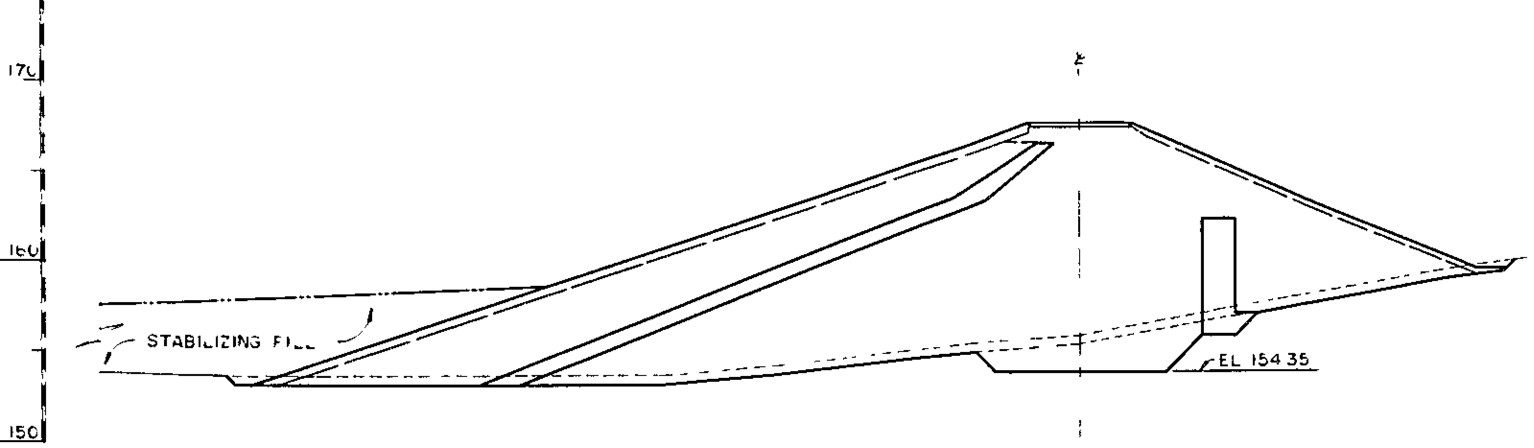

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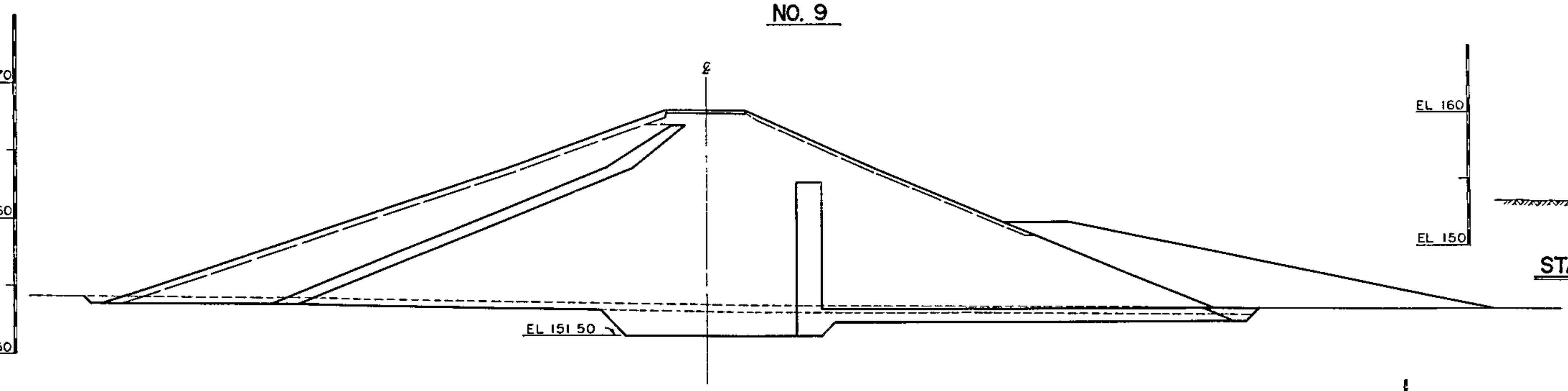

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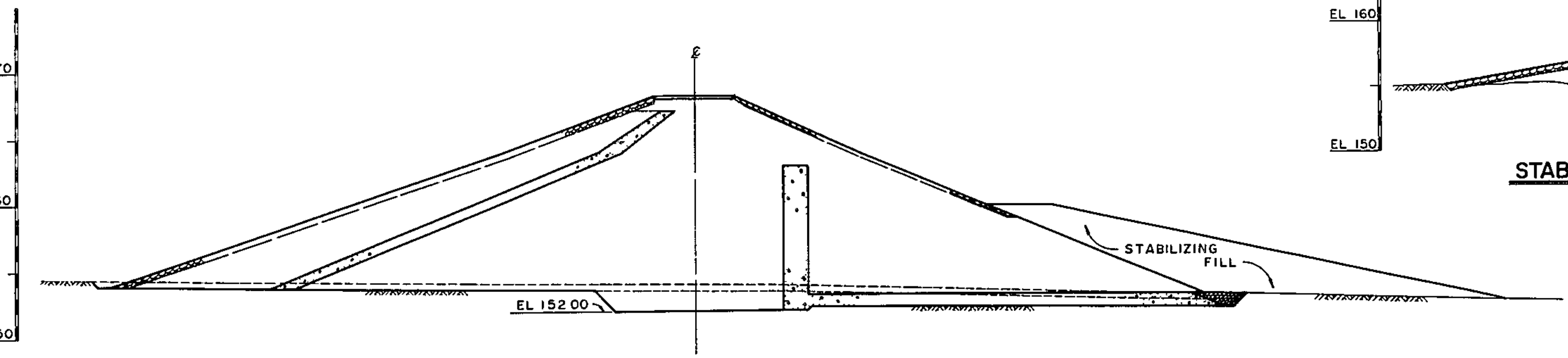

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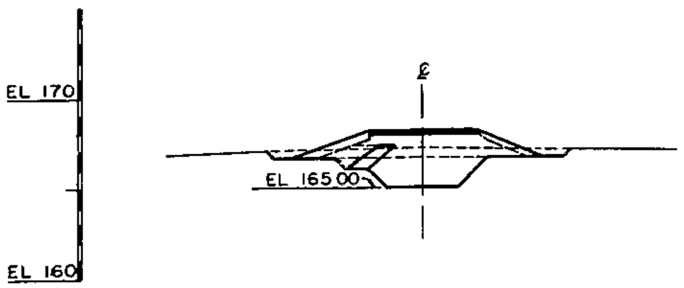
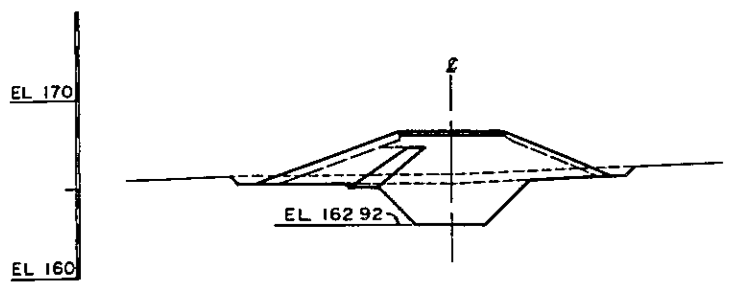
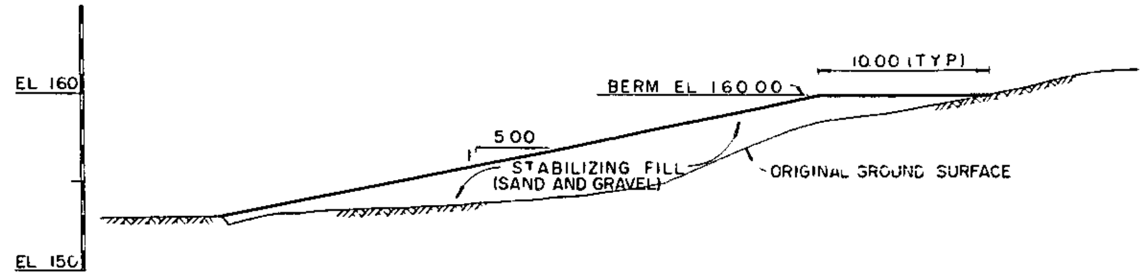


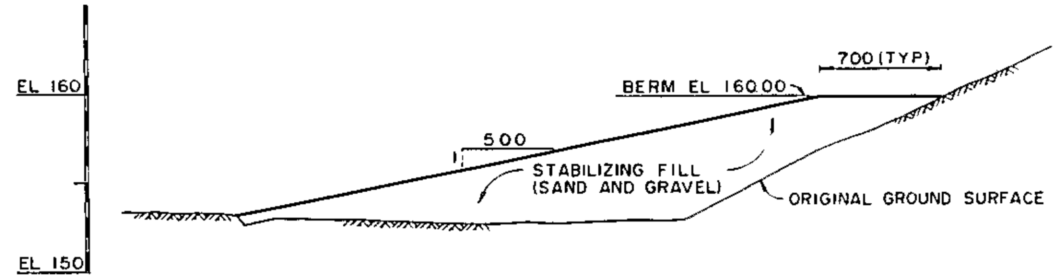
NO. 1



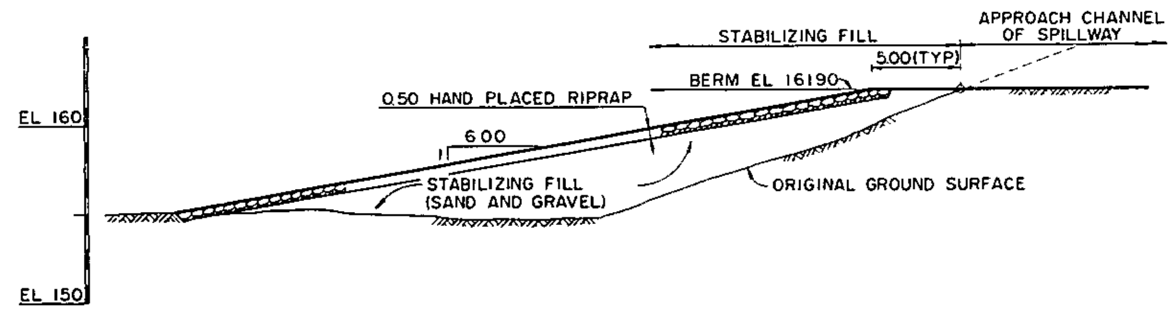
NO. 1 + 65.536 (I.P)



STABILIZING FILL AT DOWNSTREAM OF LEFT ABUTMENT



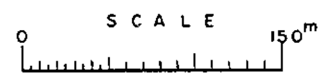
STABILIZING FILL AT DOWNSTREAM OF RIGHT ABUTMENT



STABILIZING FILL AT UPSTREAM OF RIGHT ABUTMENT

NOTES,—

1 ALL STATIONS AND ELEVATIONS ARE GIVEN IN METERS
2 ALL DIMENSIONS ARE GIVEN IN METERS



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WADI JIZZI AGRICULTURAL DEVELOPMENT PROJECT			
DETENTION DAM (TYPICAL CROSS SECTION)			
DATE	NOV 1982	DWG NO	WJP D-1004
JAPAN INTERNATIONAL COOPERATION AGENCY			