CHAPTER 8 AIR QUALITY INVESTIGATION

8.1 Ambient Air Quality Monitoring

The air quality and meteorology investigation surrounding the Sohar mine area consist of SO_2, TSP, PM_{10}, dustfall, and meteorological investigation. The result of the investigation is summarized as below.

- The SO_2 concentrations at four monitoring points located downwind of the OMCO plant exceeded EEC SO_2 standard applied to OMCO plant (24-hour average concentration of 120µg/m^3) and exceeded SO_2 Japan's standard (1-hour average: 0.1ppm and 24-hour average: 0.04ppm) and WHO (24-hour average: 125µg/m^3) if compared with these standards. However, the concentrations were below the US standard (24-hour average: 0.14ppm).
- The TSP concentrations at monitoring points located downwind of OMCO's plant were higher than other points. The TSP concentrations at three points exceeded 24-hour average EU limit of 300µg/m^3 if compared with this standard.
- There are sensitive receptors, such as residences near points A-1 and A-2 where SO_2 concentrations exceeded the SO_2 standard. SO_2 emissions from OMCO's plant might affect to the resident people. However, based only on monitoring once in each summer and winter season, it is difficult to conclude whether the SO_2 emissions from OMCO's plant effects the resident people.
- The principal constituents of the particulate matter emitted from copper smelting are copper and iron oxides. Other heavy metals including arsenic, antimony, cadmium, lead, mercury and zinc are also present. The principal constituents of heavy metal in the collected dustfall samples at all monitoring points are copper and iron. Emitted particulate and fugitive dust from OMCO's plant are considered to be scattered over a large area.

8.2 Air Dispersion Modeling Analysis

The analyses were conducted to compare the predicted SO_2 concentrations with applicable ambient air quality standards for SO_2. The predicted results of ground-level SO_2 concentration show that SO_2 disperses westerly downwind area of OMCO plant. The predicted maximum concentration was 875 μ g/m^3 for 24-hour average and 121 μ g/m^3 for annual average. Both of maximum concentrations occur in the same area located approximately 3.5 km west of OMCO plant.

CHAPTER 9 INVESTIGATION ON EXPANSION PROGRAM FOR SMELTER AND REFINERY PLANT

It has been stated that plans for expanding the annual production of OMCO's smelter from 40,000 ton/year to 100,000 tons/year have been drafted. However, if the plant's production is increased, the concern exists that air pollution will be similarly increased. Therefore, the proposed expansion of the smelter and its potential impact on the environment were included in the Study.

During the actual Second field investigation, OMCO did not disclose any concrete data related to the expansion plan and a clear explanation of any proposed plans was not given. Therefore, the JICA Team concluded there is no feasible plan for expansion of the plant at this time.

CHAPTER 10 ENVIRONMENTAL IMPACT INVESTIGATION

The environmental impact investigation consisted of personal interviews with local residents based on an environmental questionnaire concerning air pollution, water pollution, effects on health, and damage from pollution. Interviews were conducted with 23 persons living within a radius of 23 km from the OMCO plant site.

Consequently, diseases, such as respiratory symptom, decrease of livestock, and some impact on plants and insects were observed.

CHAPTER 11 SOCIO-ECONOMIC INVESTIGATION

11.1 Socio-economic Investigation

Main industrial activities in Oman consist of the crude oil production, oil refining, natural gas production, construction, cement producing, and copper refining, etc. The largest component of Oman's economy is the oil industry, which accounted for almost 40% of the total GDP. On the other hand, agricultural production occupies only 4% of GDP because the amount of arable land occupies less than 2% of the whole land area of the nation.

As shown in Table 11.5, the total population of Oman is estimated 2,325,438 persons of which 1,729,312 persons are Omanis and 596,126 persons are foreign guest workers. The total number of employed people in1999 was 1,114,902 persons, which slightly decreased from 1,164,716 persons in 1998.

The number of persons and houses located within the area considered to be negatively impacted by the mining pollution were estimated. The total number of persons and houses within this area is estimated at 24,308 persons and 4,055 houses through the site investigation.

11.2 Results of Interview Investigation

To select the most viable countermeasures, benefits occurring from these countermeasures should be estimated and compared with their costs. The following benefits are considered to be obtained after taking proposed countermeasures;

a. Valuing damages from groundwater contaminated salt or air pollution,
b. Estimating the displacement cost saving,
c. Estimating the value of existence for Al Ons Nature Reserve and as a part of the national land.

The interview investigations for items a. and c. were conducted to obtain the basic data for estimating proposed countermeasures benefits. The result of the investigation is summarized as follows.

(Household and Damage Investigation)

- In Faraj A'Souq, Kheshishet, Misial A'sidr, Sagha, and Aarja, water is already salty.
- Symptoms such as hair falling off of goats are observed.
- Something a type of dust is deposited on the surface of dates because of salty water, therefore these dates can be used only for animal's food.
- Basins made from concrete, are easily cracked because of salty water.
- Trees in garden and farms have died.
- In Suhaylah, there is not any water problem, but air problem is serious. Some of the children and women are suffering from coughing, asthma or allergy.

- In Sagha, honeybees have disappeared. So honey has not been collected now.
- In Wadi al Owaynah there is a smoke smell depending on wind direction.
- There are no environmental negative effects caused by OMCO operation.
- Groundwater already includes salt, so most of households are buying water.

(Interview Investigation on Value of Existence)

- Almost all persons who visited Sohar mine area know the existing environmental negative effects.
- All persons who know the environmental problems in Sohar mine area insist on the importance of eliminating pollution.
- Some persons think it needs a lot of money for eliminating pollution.
- About one third of the interviewees said they are not using any land in Sohar mine area, but they may use it in the future.
- Some of persons think they do not use the land in Sohar mine area, but others may use it.
- Their willingness-to-pay for improving the environmental condition in Sohar mine area is considered to be reasonable.

CHAPTER 12 TECHNOLOGY TRANSFER

Technology transfer was implemented through cooperative efforts during study, including the practice of on-site training, the explanation of the analysis results with the counterparts, counterpart study and training in Japan and so on, according to the plan which was shown in the inception report of the study.

Some of the problems experienced in implementing the technology transfer element of the study included a shortage of technical experts within MCI and MMEW and the differences in the social environments between Oman and Japan. In the end, however, the anticipated object of the study was achieved sufficiently and the study was completed with the sincere attitude and efforts of Omani and Japanese study teams.

PART Ⅱ COUNTERMEASURES FOR THE GROUNDWATER CONTAMINATION

CHAPTER 13 ENVIRONMENTAL COUNTERMEASURES

Part I of this report presents the results of the investigation and documents the groundwater and soil contamination in the Sohar mine area caused by high salinity and heavy metals. Based on these results, mitigation countermeasures are urgently needed to address the upstream contamination sources and prevent the diffusion of contaminants to the downstream areas of Wadi Suq (Figure 13.1).
The environmental countermeasures along Wadi Suq are divided into two districts as shown in Figure 13.1, including district between the tailing dam and Subarea 1 and district between Subarea 1 and Subarea 5. Each district of the groundwater contamination countermeasures of the Wadi Suq, which is the main purpose of this Feasibility Study, is examined in the following sections of this report.

13.1 Countermeasures for the Water Quality in the Tailing Dam

Countermeasures addressing water contamination between the tailing dam and Trenches -1 and -2 in Subarea 1 have been proposed by OMCO. OMCO's contamination countermeasure plan was reviewed in this Study and re-examined including alternatives for the contamination countermeasures.

OMCO prepared a plan for ending the practice of recycling seepage collected in Trenches -1 and -2 and capping the tailing dam with a bitumen liner material as a method of preventing further infiltration of rainwater into the tailings. The purpose of this plan is to reduce or eliminate seepage coming from the dam, thereby mitigating the dam as a source of groundwater contamination.

1) Alternative-1 is installation of de-watering by pumps for extracting the groundwater in the tailings.
2) Alternative-2 addresses seepage from the tailing dam by cutting off infiltration and off-site surface water run-on by capping the tailings with a permanent engineered covering system. The covering system would be designed to reduce or eliminate the source of the seepage, which is rainfall and storm water running onto the tailings from off site.
   - Under Alternative-2A, the surface of the tailing dam would be capped with the permanent engineered composite cover system. A drainage channel would be constructed to link the tailing dam with tributaries to Wadi Bani Umar al Gharbi. Rainfall and surface water running onto the capped tailings would flow by gravity to the topographic low point in the tailing dam and would then by conveyed by the drainage channel north to Wadi Bani Umar al Gharbi.
   - Under Alternative-2B, the surface of the tailing dam would be capped with the permanent engineered composite cover system. No drainage channel would be constructed. Instead, rainfall and surface run on would collect on the liner surface at the topographic low point. The water would be allowed collect during the wet seasons and would evaporate during the dry seasons of the year. The impermeable layer of the cover system would prevent infiltration.
   - Under Alternative-2C, the tailings would be capped with a simple 50 cm soil cover placed directly over the tailings and armored with a 15 cm layer of loosely placed stones. A system of lateral

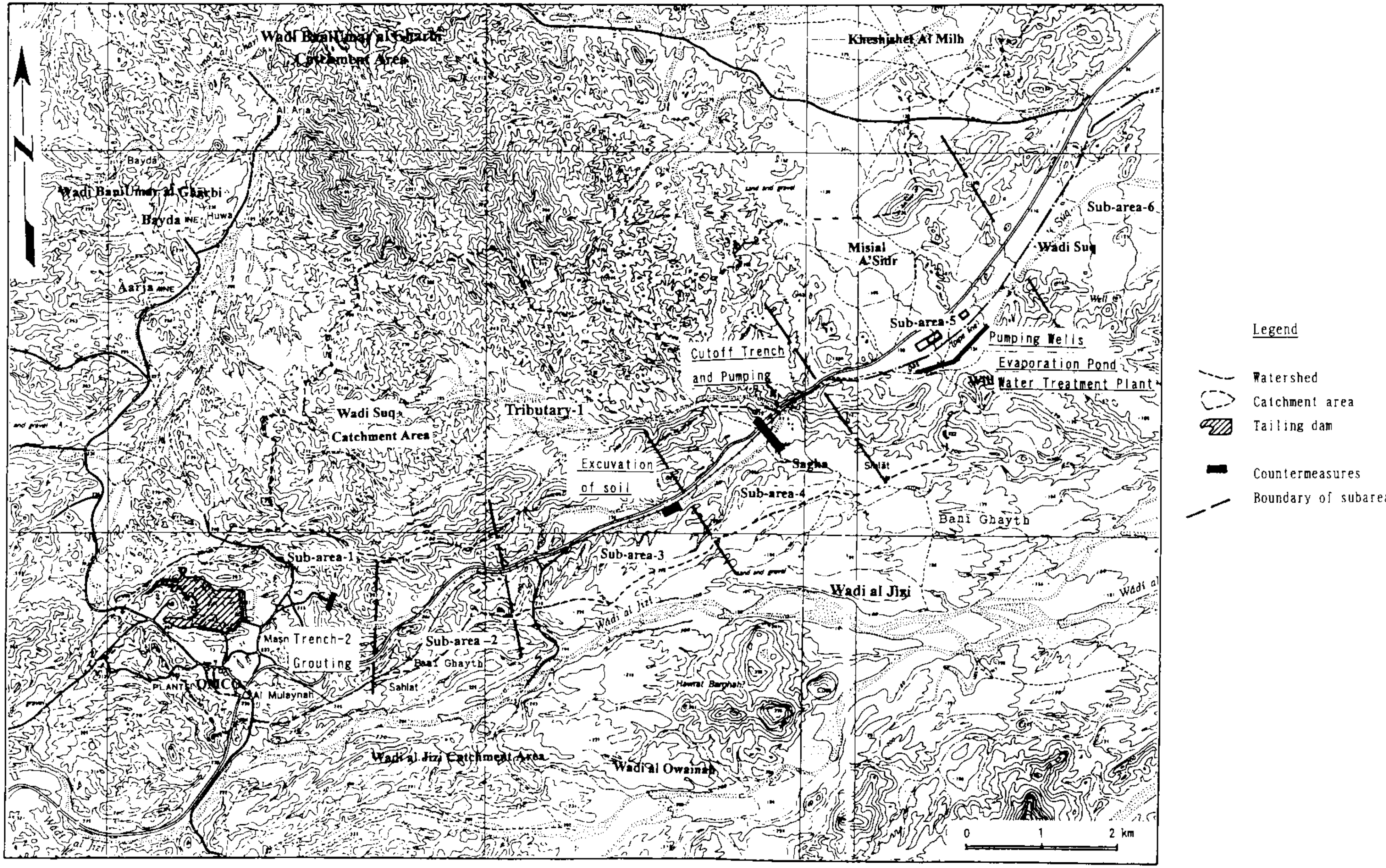


Figure 13.1 Location of Mine Pollution Countermeasures along Wadi Suq

drainage ditches and detention dams would be constructed to prevent rainfall from running onto the tailings impoundment from offsite. These drainage ditches would collect runoff from the hills to the west and north of the tailing dam and convey it to the north, as in Alternative-1.

Although five alternatives of the contamination countermeasures for the tailing dam were examined in this report, the construction work of countermeasures has already been commenced. Therefore, it is obliged to select OMCO's alternative.

From the viewpoint of implementability, it is necessary to re-examine the basic plan of countermeasures of the tailing dam, i.e. design slope (0.2%) of surface of the tailings is nearly impossible to achieve, deformation due to consolidation in the tailing dam may continue, etc. In addition, it is necessary to take care about the working conditions during removal of the tailings because of scattering of the fine-grained tailings.

13.2 Contamination Countermeasures along Wadi Suq

The location of the countermeasure alternatives along Wadi Suq consist of the Subareas 1, 3, 4, and 5 as shown in Figure 13.2. The countermeasure alternatives of the Subareas 1, 3, 4, 5 and water treatment of the contaminated groundwater consist of 7 alternatives, shown as below.

Countermeasure Alternatives	:	No. of Alternatives
・Subarea-1	:	Alternative-3
・Subarea -3	:	Alternative -4
・Subarea -4	:	Alternative -5A Alternative -5B
・Subarea -5	:	Alternative -6
・water treatment of the contaminated groundwater	:	Alternative -7A Alternative -7B

13.2.1 Contamination Countermeasures of the Subarea 1 (Alternative-3)

Trench-2 is installed by OMCO at the end of the Subarea 1. The curtain grout was not sufficient, so that the leakage of contaminated groundwater occurred through the weathered zone of bedrock. This is thought to be one of the reasons why the groundwater contamination is now extending to the downstream areas of Wadi Suq.

The contamination countermeasures are limited to the grout method (Alternatives-3) on the downstream side of trench-2. The construction period is about 7 months. Total cost for the grouting work at Trench-2 is estimated US$1,700,000.

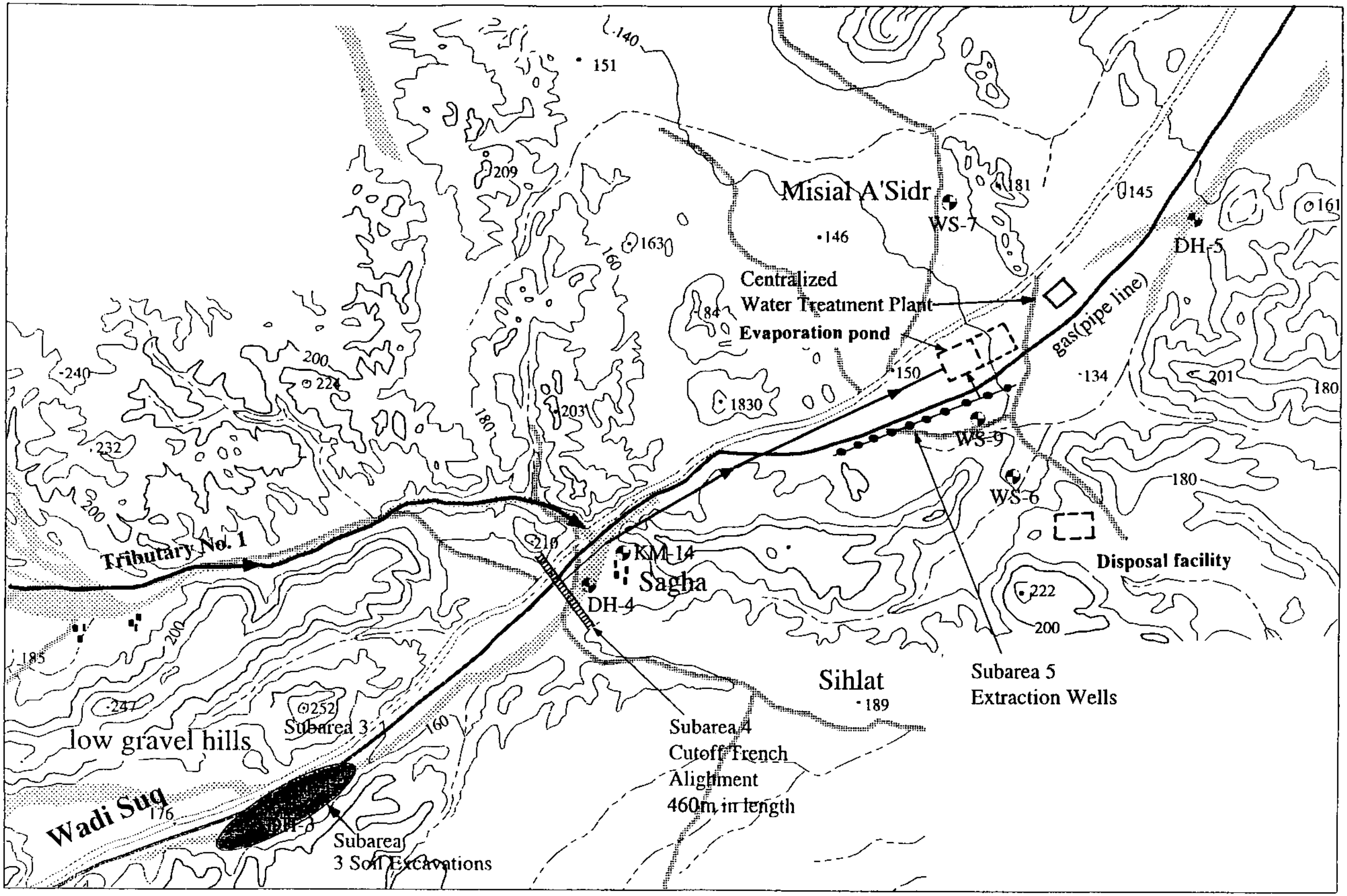


Figure 13.2 Contamination Countermeasures of Wadi Suq Subarea 3, 4 and 5

The content of the grouting work is shown as below.

1) Location of grouting : downstream side and both wings of the Trench-2
2) Drilling survey : 30 m/hole, 10 drill holes : Total depth 300 m
3) Specification of grouting work
- Width of grouting : 200 m
- Number of grouting line : 5 lines
- Number of grouting holes : 500 holes
- Total depth of grouting holes : 20 m/hole, 10,000 m
- Diameter of grouting holes : 60 mm, casing diameter : 152 mm
- Interval of each hole : 2 m interval
- Grouting depth : 10 ~ 20 m deep; Calcrete layers and basalt
4) Equipments
- Boring machines for survey : Rotary type : 2 sets
- Boring machines for grouting : Rotary type : ODEX method 2 sets
- Lugeon test : Packer type, pump

13.2.2 Contamination Countermeasures of the Subarea 3 (Alternative-4)

Subarea 3 consists of the approximately 2.5 km of the Wadi Suq main channel from the 6.2 km point to the drill hole DH-3. The principal concern in Subarea 3 consists of salt-laden soils resulting from prolonged leakage of seawater from pump station (PS-2) in the vicinity of drill hole DH-3. The contaminated soil at PS-2 is affected only by seawater without any heavy metals, so that it is different from the contamination derived from the tailing dam.

The contaminated soil at PS-2 will continue to affect to the groundwater downstream of Wadi Suq, if no countermeasure are implemented. Therefore, it is necessary to remove contaminated soil and to improve the groundwater quality.

Contamination countermeasures at PS-2 are limited to excavating the contaminated soil (Alternative-4). The contaminated soil is assumed to be approximately 35,000 m^3. The contaminated soil would be transported to seashore for use as fill material in the construction of seaport facilities, because the contaminated soil is polluted only by seawater. The excavated soils would be replaced with clean soils, approximately 25,000 m^3, supplied from surroundings. The construction period is about 4 months. Total cost for the excavating work at Subarea 3 is estimated US$ 1,100,000, shown as below.

The content of the excavating work is shown as below.
1) Location of excavating : Between DH-3 and PS-2
2) Specification of grouting work
- Length of excavating zone : 400 m

- Width of excavating zone : 10 - 70 m
- Depth of excavation : 0 - 30 m
- Total volume of excavation : 35,000 m^3
- Backfilling volume of clean soil : 25,000 m^3

3) Equipments

- Bulldozer	: D-8 class with ripper	: 3 units :
- Hydraulic excavator	: 2 m^3 class	: 3 units
- Dump truck	: 20 t class	: 10 units

13.2.3 Countermeasures in Subarea 4 (Alternatives-5A and 5B)

Subarea 4 consists of 3.5 km of the main channel of Wadi Suq from drill hole DH-3 to drill hole DH-4 near KM-14 at the small village of Sagha. No sources of groundwater pollution were identified within this subarea.

A natural constriction in the wadi channel occurs at KM 14. This natural constriction provides an excellent opportunity to intercept the subsurface flow either through a cutoff trench or a system of extraction wells. Intercepting groundwater at KM 14 provides an opportunity to treat or dispose of the water for the purpose of reducing the salt loadings at down gradient locations.

In case without any contamination countermeasures at KM 14, the contaminated groundwater including salinity and heavy metals will continue to flow down along Wadi Suq and reach to Falaj al Qabail and Sohar agricultural and residential area as well as extending the damage by the contaminated groundwater. Therefore, it is necessary to implement effective countermeasures as soon as possible.

Tributary No.1 joins with mainstream of Wadi Suq at KM 14 (Subarea 4). Although the groundwater along main stream of Wadi Suq is contaminated, the groundwater along Tributary No.1 is clean. Therefore, the location of contamination countermeasures at KM14 would be installed in the vicinity of DH-4 upstream of the confluence with Tributary No.1.

The countermeasure alternatives in the Subarea 4 consist of two alternatives, namely Alternative-5A (Pumping wells) and Alternative-5B (Cutoff trench).

(1) Alternative-5A

- A line of appropriately spaced groundwater extraction wells would be installed perpendicular to the flow direction in the vicinity of Drill Hole DH-4.
- This system of wells would capture saline groundwater upstream of the confluence of Wadi Suq and Tributary 1 in order to allow the relatively clean water from the tributary to continue to recharge the wadi aquifer down gradient of KM 14.

- The pumped contaminated groundwater will be conveyed to the water treatment plant.

(Content of the Pumping Well Work)

The content of the pumping well work is shown as below.

1) Location of pumping wells : DH-4

2) Specification of pumping well work
   - Width of pumping wells zone : 460 m
   - Number of pumping well : 22 wells (20 m interval)
   - Diameter of pumping wells : 12-1/4 inch
   - Length of pumping wells : Average 30 m
   - Diameter of screen : 8 inch (PVC)
   - Depth of screen : 4 ~ 30 m
   - Pumping volume : 150 m^3/day

3) Equipments
   - Percussion drilling rig : Air-form : 1 unit
   - Pump : 22 units
   - Water gauge : 22 units

The construction period is about 4 months. Total cost for installing the pumping system in Subarea 4 is estimated US$ 800,000, shown as below.

(2) Alternative-5B

Alternative-5B of the Subarea 4 is planning to extract the contaminated groundwater by cutoff trench at the Alternative-5A.

- A line of appropriately spaced groundwater extraction wells would be installed perpendicular to the flow direction in the vicinity of Drill Hole DH-4.
- The conceptual design of the proposed cutoff trench is illustrated in Figure 13.3.
- The depth of bedrock at the cutoff trench ranges from 5m to 14 m. The bedrock consists of weathered to strongly weathered basaltic pillow and massive lavas. The Wadi sediments mainly consist of consolidated diluvial deposits by calcrete and loose alluvial deposits in ascending order.
- Cutoff wall will be installed at the downstream side of the trench.
- Weathered and fracture developed bedrocks will be improved rock quality by curtain grout.
- During construction of the cutoff trench, measures would be taken to protect the natural gas pipeline and seawater pipeline buried in the Wadi sediments. Also, the highway would have to be temporarily rerouted during construction.
- This system of wells would capture saline groundwater upstream of the confluence of Wadi Suq and Tributary 1 in order to allow the relatively clean water from the tributary to continue to recharge the wadi aquifer down gradient of KM 14.

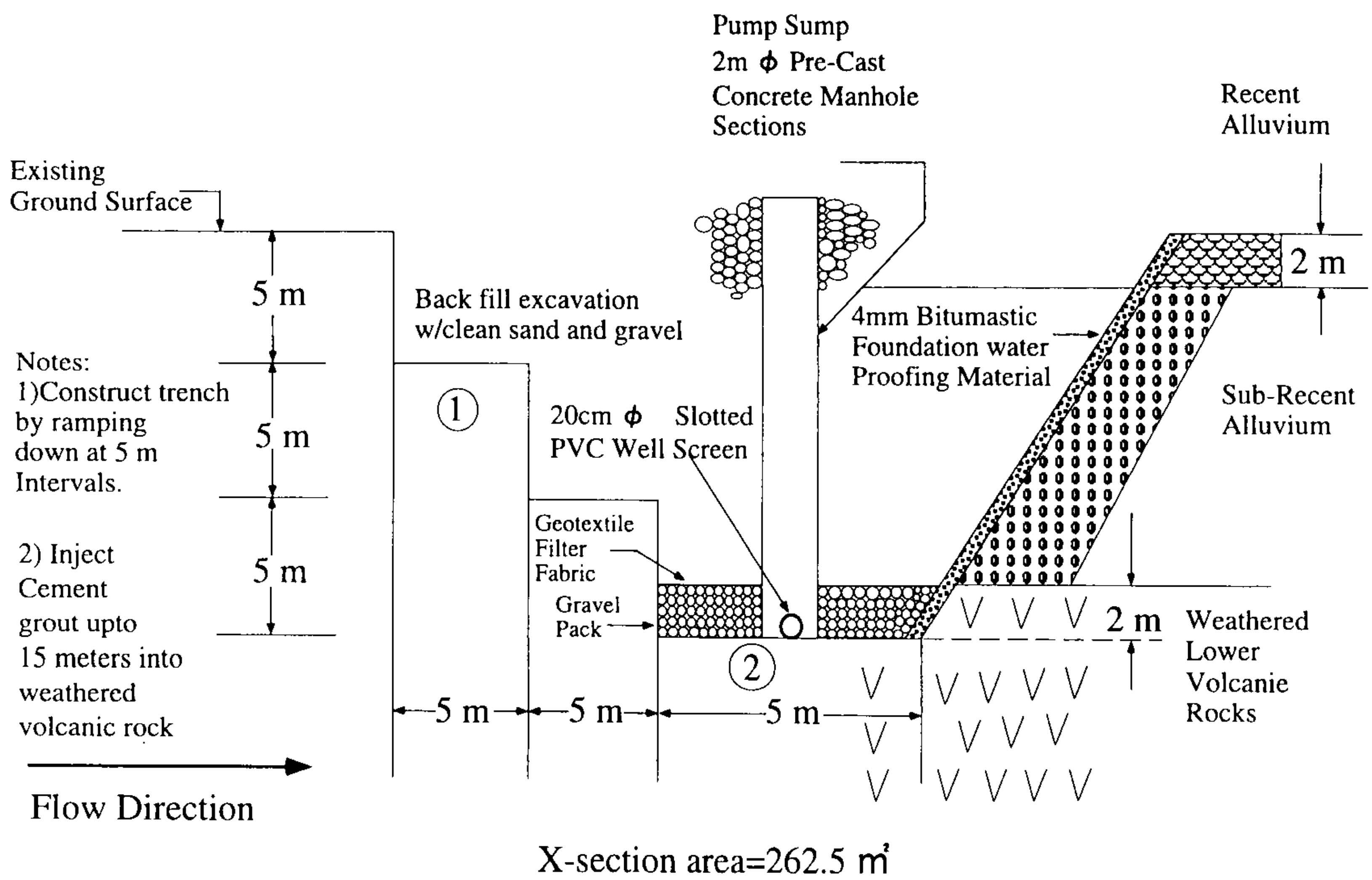


Figure 13.3 Subarea 4, Cutoff Trench Conceptional Design

- The pumped contaminated groundwater will be conveyed to the water treatment plant at Subarea 5.

a. Content of the Cutoff Trench Work

The content of the cutoff trench work is shown as below.

1) Location of cutoff trench : DH-4

2) Specification of cutoff trench work

- Length of cutoff trench : 460 m
- Width of cutoff trench : 10 ~ 15 m
- Width of bottom of cutoff trench : 5 m
- Excavating and replacing volume : 50,000 m^3
- Area of bottom of cutoff trench : 5,900 m^2
- Concrete volume of bottom of cutoff trench : 1,400 m^3
- Concrete volume for cutoff wall at downstream side : 4,350 m^3
- Length of joint at downstream side : 300 m
- Cutoff wall made by membrane at downstream side : 8,500 m^2
- Drainage system : 1 unit
- Well made by concrete : 1 unit (Diameter : 1 m)
- Pumping volume : 150 m^3/day
- Others : Temporary construction and replacement of road, electric line, gas pipeline, etc.

3) Equipments

- Bulldozer : D-8 class with ripper : 2 units :
- Hydraulic excavator : 2m^3 class : 4 units
- Dump truck : 10 t class : 5 units
- Pump (for construction) : 5 units
- Pump (for operation) : 1 unit
- Water gauge : 3 units
- Others

The construction period is about 11 months. Total cost for the cutoff trench work at Subarea 4 is estimated US$ 5,400,000, shown as below.

13.2.4 Countermeasures in Subarea 5

Subarea 5 consists of 4.0 km of the main wadi channel from KM14 at the village of Sagha to Drill Hole DH-5. This subarea includes the village of Misial A'Sidr. Groundwater in the main channel of Wadi Suq is contaminated with salt from upstream sources throughout Subarea 5. However, relatively fresh water exists along the periphery of Subarea 5. Also, relatively clean groundwater is found in Tributary 3 which runs parallel Subarea 5 on its northern periphery.

The contaminated groundwater from Subarea 4 flows down through topographical narrow valley to the Sabarea 5. Although most of the contaminated groundwater flowed into the Subarea 5 is thought to stay in the Subarea 5, the contaminated groundwater in Subarea 5 including salinity and heavy metals will continue to flow down along Wadi Suq and reach to Falaj al Qabail and Sohar agricultural and residential areas, if no countermeasures are implemented in Subarea 5.

Therefore, it is necessary to implement effective countermeasures at Subarea 5. However, these countermeasures will be terminated when the groundwater quality at Subarea 5 improves.

The specific actions proposed under Subarea 5 are described, as follows:

- A line of extraction wells similar to that in Subarea 4 would be installed parallel to the flow direction at the approximate midpoint of Subarea 5. The extraction system would be installed between the main highway and the natural gas pipeline.
- It is estimated that the line sink at this location would consist of 20 wells, average 40 m deep, in a line approximately 600 m in length along the wadi. For estimation purposes, it is assumed that the groundwater extraction rate will be approximately 200 m^3/d.
- The purpose of the groundwater extraction system would be to create a line sink to remove the potential source of pollution, and it is assumed that mitigating the highly saline water in the main channel will reduce the salt and dissolved solids loads that may be affecting the water quality at Misial A' Sidr and Tributary 3.
- Contaminated groundwater extracted from the extraction wells is pumped to the water treatment plant located in Subarea 5.

a. Content of the Pumping Well Work

1) Location of pumping wells : Upstream side of DH-5

2) Specification of pumping well work

- Width of pumping wells zone : 600 m
- Number of pumping well : 20 wells (30 m interval)
- Diameter of pumping wells : 12-1/4 inch
- Length of pumping wells : 40 m
- Diameter of screen : 8 inch (PVC)
- Depth of screen : 20 ~ 40 m
- Pumping volume : 200 m^3/day

3) Equipments

- Percussion drilling rig : Air-form : 1 unit
- Pump : 20 units
- Water gauge : 20 units

The construction period is about 4 months. Total cost for the pumping work at the Subarea 5 is estimated US$ 600,000.

13.2.5 Water Treatment Countermeasures for Contaminated Groundwater

The total pumping volume of the contaminated groundwater extracted from the Subarea 4 and 5 is estimated at 150 to 350 m^3/day, and pumped groundwater containing high salt and heavy metals should be treated water quality before discharge.

The countermeasure alternatives for the water treatment consist of two alternatives, namely Alternative-7A and Alternative-7B.

- Alternative-7A: Extraction by reverse osmosis (RO)
- Alternative-7B: Treatment totally by evaporation pond

Other technologies, including electrodialysis, ion exchange, and distillation are capable of removing anions, but are considered impractical for treating large volumes of water. The coagulating sedimentation method using lime for extracting heavy metals is not a suitable method for the contaminated groundwater, as indicated by the results of laboratory tests conducting during the site investigations. In addition, the absorption method, including tannin, etc. is too expensive for operation and is considered impractical.

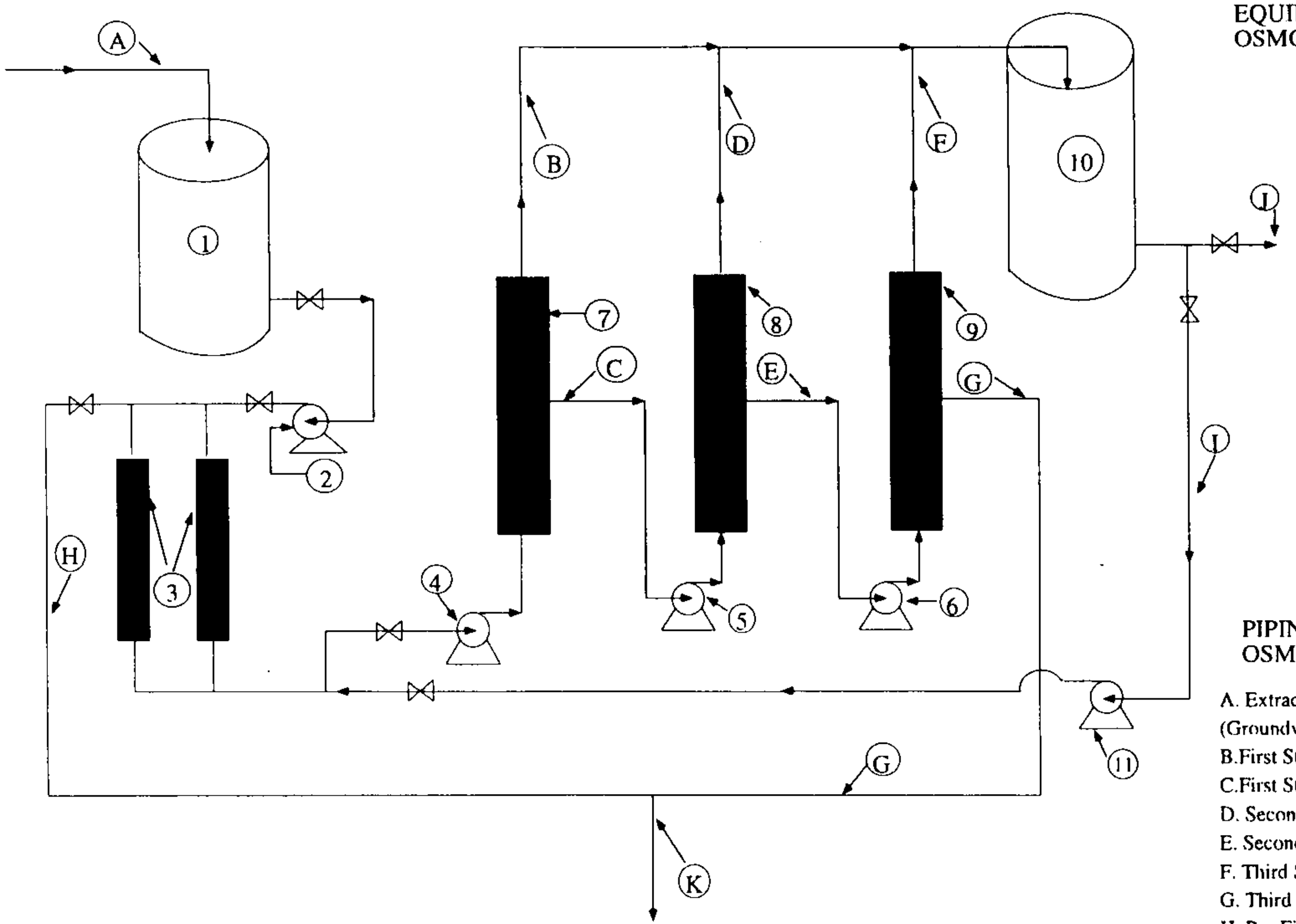
(1) Alternative-7A

The contaminated groundwater extracted from the extraction sites would be pumped to a treatment system designed to remove the salt and heavy metals. The treatment system would use a membrane separation technology known as reverse osmosis (RO). RO is the only water treatment technology capable of effectively removing anions, such as chloride and sulfate from water.

A schematic process flow diagram for the proposed RO treatment plant is presented in Figure 13.4. Based on conceptual design data, the RO treatment system would produce a permeate stream of relatively fresh water of 75 to 175 m^3/day, and the permeate stream would exhibit low salt and dissolved solids levels that would be suitable for domestic or agricultural uses. The extraction rate of each ion is shown in Table 13.1.

The permeate stream would either be re-injected into the wadi gravels downstream of KM 14 or provided to local residents for domestic or agricultural purposes.

After water treatment, rejected water of approximately 75 to 175 m^3/day containing high salt and heavy



EQUIPMENT LIST FOR
OSMOSIS TREATMENT SYSTEM

1. Raw Water Storage Tank
2. Pre-Filter Feed Pump
3. Dual Media Pre-Filters
4. First Stage High Pressure Stainless Steel Feed Pump
5. Second Stage High Pressure Stainless Steel Feed Pump
6. Third Stage High Pressure Stainless Steel Feed Pump
7.First Stage Reverse Osmosis Membrane Unit
8.Second Stagde Reverse Osmosis Membrane Unit
9. Third Stage Reverse Osmosis Membrane Unit
10. Permeate(Treated Water) Storage Tank
11. Pre-Filter Backwash Pump

PIPING LIST FOR REVERSE
OSMOSIS TREATMENT SYSTEM

A. Extraction System Discharge Piping (Groundwater from Extraction Wells or Trench)
B.First Stage Permeate Discharge Line
C.First Stage Concentrate Discharge Line
D. Second Stage Permeate Discharge Line
E. Second Stage Concentrate Discharge Line
F. Third Stage Permeate Discharge Line
G. Third Stage Concentrate Discharge Line
H. Pre-Filter Backwash Discharge Line
I. Pre-Filter Backwash Feed Line
J. Treated Water Distribution Line

Figure 13.4 Process Flow Design for Reverse Osmosis Treatment System

Table 13.1 Treatment Efficiency by RO Treatment

Parameters	Existing Concentration (mg/L)	Target concentration (mg/L)	Maximum allowable (mg/L)	RO treated Water quality (mg/L)	Treatment Efficiency (%)
Ca	813	200	500	35	95.7
Mg	811	200	500	35	95.7
Na	2,384	200	400	335	85.9
K	95	NA	NA	15	84.2
Fe*	0.272	0.3	1.0	0.01	96.3
Mn	0.18	0.1	0.5	0.01	94.4
As*	0.008	NA	0.01	0.003	62.5
Cu*	0.062	1.0	1.5	0.01	83.9
Cr*	0.21	NA	0.05	0.01	95.2
Pb*	0.3	NA	0.01	0.01	96.7
Ni*	0.033	NA	0.02	0.01	69.7
Zn*	0.082	3.0	5	0.01	87.8
SiO_2	100	NA	NA	10	90.0
HCO_3	167	NA	NA	25	85.0
Cl*	6,388	250	600	600	90.6
SO_4	584	250	400	30	94.9
NO_3	12	NA	50	5.0	58.3
F	0.5	NA	1.5	0.05	90.0
pH	7.15	6.5-8.0	9	6.5-7.0	NA
TDS	11,500	800	1,500	1,000	91.3

Notes : 1. Target concentrations are the same as Oman's best level of quality for drinking water to be achieved (Final Draft Omani Drinking Water Standard, 8/1998).

2. Maximum allowable concentrations are acceptable for use as drinking water if no other source is available (Final Draft Omani Standard, 8/1998).

3. RO treated water quality is predicted based on modeling results from HS Process Technologies in Denver, Colorado.

* = Data from JICA Feasibility Study from Drill Hole DH-4S. All other value are from KM-14 presented in the 1995 Ministry of Water Resources Report.

metals will be produced . The rejected water will be will sent to the evaporation ponds and evaporated there. Two evaporation ponds are located in the Subarea 5, and the ponds will be used alternatively for managing the treatment of residues.

The evaporated residue will be finally packed by plastic bags and stored at a disposal warehouse for the protection against the scattering and re-melting by weather. The warehouse is located on the hill without any damage by temporary current of the wadi, shown in Figure 13.6. Total Cl volume of removal by the water treatment system is estimated at 921 to 2,148 kg/day.

a. Content of Water Treatment System

The content of the water treatment system is shown as below.

1) Location of water treatment system : Subarea 5

2) Specification of water treatment system

- Volume of treatment water : 150 to 350 m^3/day
- Flow of water treatment plant : See Figure 13.4
- Area of facility : 0.5 ha

3) Specification of evaporation ponds

- Volume of treatment water : 75 to 175 m^3/day
- Numbert of ponds : 2 units
- Size of ponds : 100 m x 100 m x 2 sites
- Area of ponds : 10,000 m^2 x 2 sites
- Depth of ponds : 1 m (Height of embankment:1m) : Total 2m
- Volume of evaporation : 15,000 m^3 x 2 sites
- Sealing materials : Double HDPE membrane
- Weight of residue : 1.6 to 3.7 t/day

4) Drainage system

- Location of drainage : Re-injection at downstream of the water treatment plant

5) Disposal warehouse

- Weight of residue : 590 to 1,350 t/year ≒ 400 to 900 m^3/year
- Volume of residue : 4,000 to 9,000 m^3 (after 0 – 10 years)
  2,000 to 4,500 m^3 (after 10 – 20 years)
  1,000 to 2,250 m^3 (after 20 – 30 years)
- Size of facility : 40 m x 50 m x 5 m (height) x 1 to 2 units
  Volume : 10,000 m^3/unit

The construction period is about 9 months. Total cost is estimated at US$ 1,700,000 to 3,100,000.

(2) Alternative-7B

The Alternative-7B is treated all of pumped contaminated groundwater at the evaporation ponds. Total volume of treatment is same as 150 to 350 m^3/day, but no water treatment is performed. Therefore, the groundwater level will be drawn down.

The pumped contaminated groundwater will be sent to the evaporation ponds and evaporated, instead of being treated by RO. Two evaporation ponds are located in Subarea 5, and the ponds will be used alternatively for the treatment of residues.

The evaporated residue will be finally packed by plastic bags and stored at disposal warehouse for the protection against the scattering and re-melting by weather. The warehouse is located on the hill without any damage by temporary current of the wadi. Total Cl volume of removal by the water treatment system is estimated at 958 to 2,236 kg/day.

a. Content of Water Treatment

The content of the water treatment by the evaporation pond is shown as below.

1) Location of water treatment : Subarea 5

2) Specification of evaporation ponds
   - Volume of treatment water : 150 to 350 m^3/day
   - Numbert of ponds : 2 units
   - Size of ponds : 100 m x 100 m x 2 sites
   - Area of ponds : 10,000 m^2 x 2 sites
   - Depth of ponds : 1 m (Height of embankment:1m) : Total 2m
   - Volume of evaporation : 15,000 m^3 x 2 sites
   - Sealing materials : Double HDPE membrane
   - Weight of residue : 1.8 to 4.1 t/day

3) Disposal warehouse
   - Weight of residue : 660 to 1,500 t/year≒ 440 to 1,000 m^3/year
   - Volume of residue : 4,400 to 10,000 m^3 (after 0 ~ 10 years)
     2,200 to 5,000 m^3 (after 10 ~ 20 years)
     1,100 to 2,500 m^3 (after 20 ~ 30 years)
   - Size of facility : 40 m x 50 m x 5 m (height) x 1 to 2 units
     Volume : 10,000 m^3/unit

The construction period is about 8 months. Total cost for the evaporation ponds, etc. construction work is estimated US$ 700,000.

13.3 Simulation Results with Countermeasures along Wadi Suq

In case of implementation of capping in the tailing dam and cutoff at KM 14, it is shown that significant clean up occurred downstream of KM 14, and the clean up is very dramatic with the chloride concentration returning to below 600 mg/L within 30 years. Therefore, the clean up of the main branch of Wadi Suq upstream of KM 14 will require further remedial measures at Trench No. 2 to make this trench more effective (Figure 13.5).

13.4 Selection of the Preferred Assemblage of Alternatives

Based on the results of evaluating the alternatives, three assemblages of alternatives were selected based

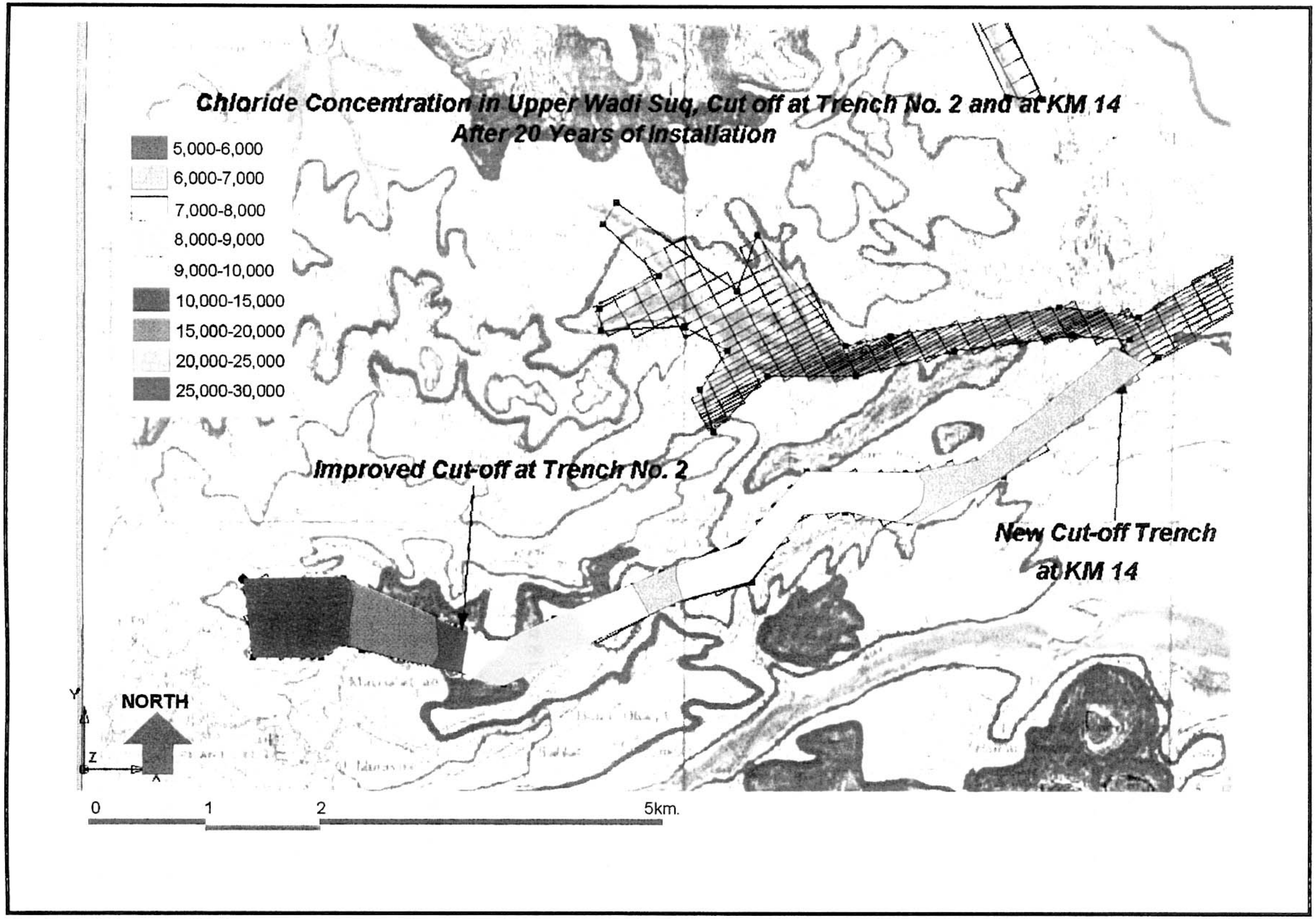


Figure 13.5 Estimated Chloride Concentration in Upper Wadi Suq, Cut off at Trench-2 and KM14 After 20 Years of Instollation

on the engineering judgment and cost evaluation, as 1) Countermeasures-A thought to be the best overall, 2) Countermeasures-B thought to be second best overall, and 3) Countermeasures-C technically thought to be the necessary minimum.

The Countermeasures-A (Figure 13.6) is thought to provide the best overall results consists of as follows.

1) Tailing dam	: Capping, drainage system	: By OMCO
2) Trench -1 and 2	: Pumping, evaporation pond	: By OMCO
3) Subarea-1	: Cutoff by Grouting	: Alternative-3
4) Subarea-3	: Extraction	: Alternative-4
5) Subarea-4	: Cutoff trench	: Alternative-5B
6) Subarea-5	: Pumping by wells	: Alternative-6
7) Water treatment facility	: RO treatment, etc.	: Alternative-7A

The period of the countermeasures along Wadi Suq is thought to be 25 to 30 years. The construction period is about 12 months. The total cost for the Countermeasures -A is estimated at US$ 11,900,000.

The Countermeasures-B (Figure 13.7) is thought to be second best overall consists of as follows.

1) Tailing dam	: Capping, drainage system	: By OMCO
2) Trench -1 and 2	: Pumping, evaporation pond	: By OMCO
3) Subarea-1	: Cutoff by Grouting	: Alternative-3
4) Subarea-3	: Extraction	: Alternative-4
5) Subarea-4	: Pumping wells	: Alternative-5A
6) Water treatment facility	: RO treatment, etc.	: Alternative-7A

The period of the countermeasures along Wadi Suq is thought to be 25 to 30 years. The construction period is about 12 months. The total cost for the Countermeasures -A is estimated at US$ 5,300,000.

The Countermeasures-C (Figure 13.8) is thought to be minimum necessary to improve water quality in Wadi Suq consists of as follows.

1) Tailing dam	: Capping, drainage system	: By OMCO
2) Trench -1 and 2	: Pumping, evaporation pond	: By OMCO
3) Subarea-4	: Pumping wells	: Alternative-5A
4) Water treatment facility	: RO treatment, etc.	: Alternative-7A

The period of the countermeasures along Wadi Suq is thought to be 25 to 30 years. However, groundwater quality between Subarea 2 and 4 is not expected to improve under Countermeasures -C. The construction period is about 12 months. The total cost for the Countermeasures -A is estimated at US$ 2,500,000.

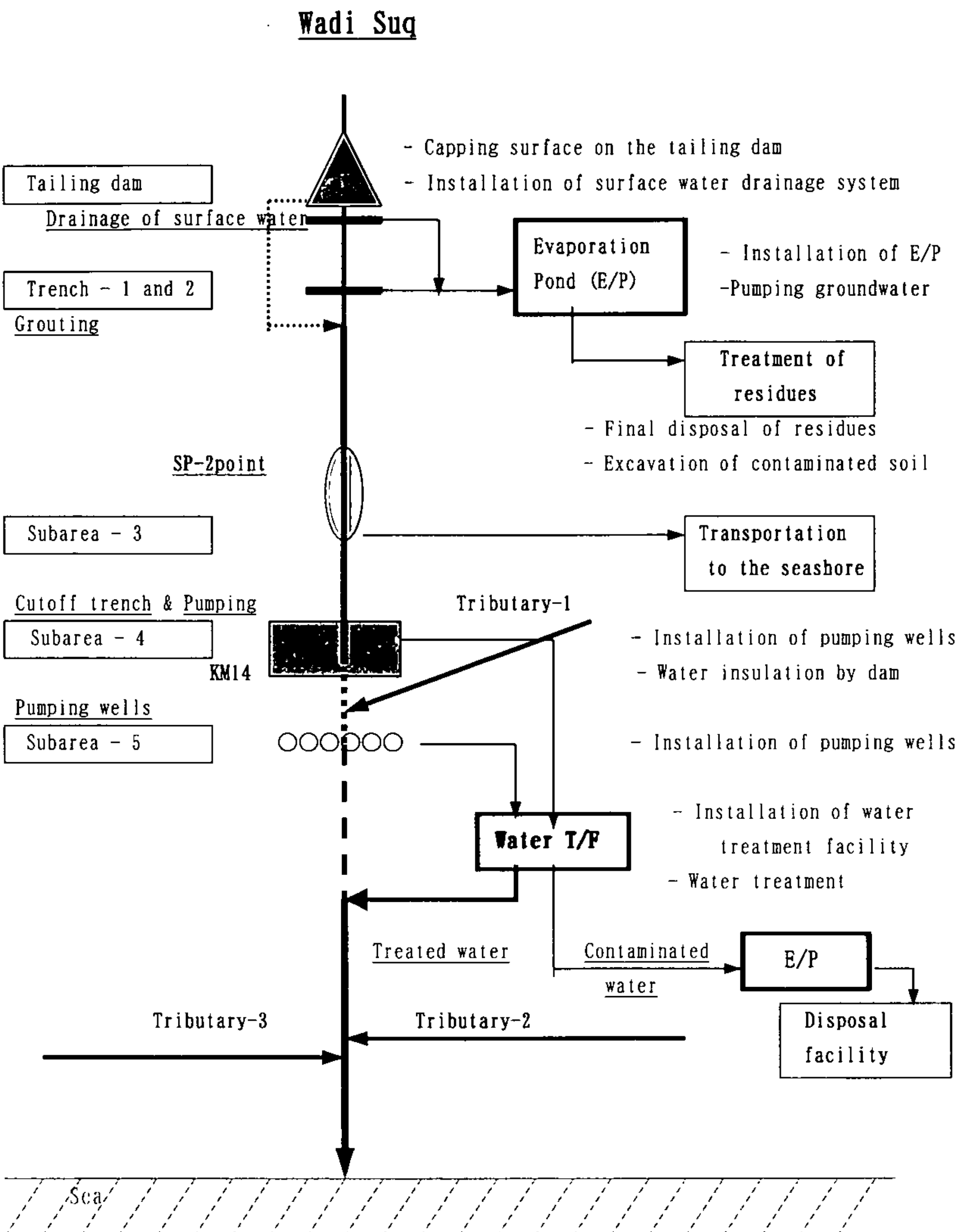


Figure 13.6 Flow of Mine Pollution Countermeasures-A in the Sohar Mine Area

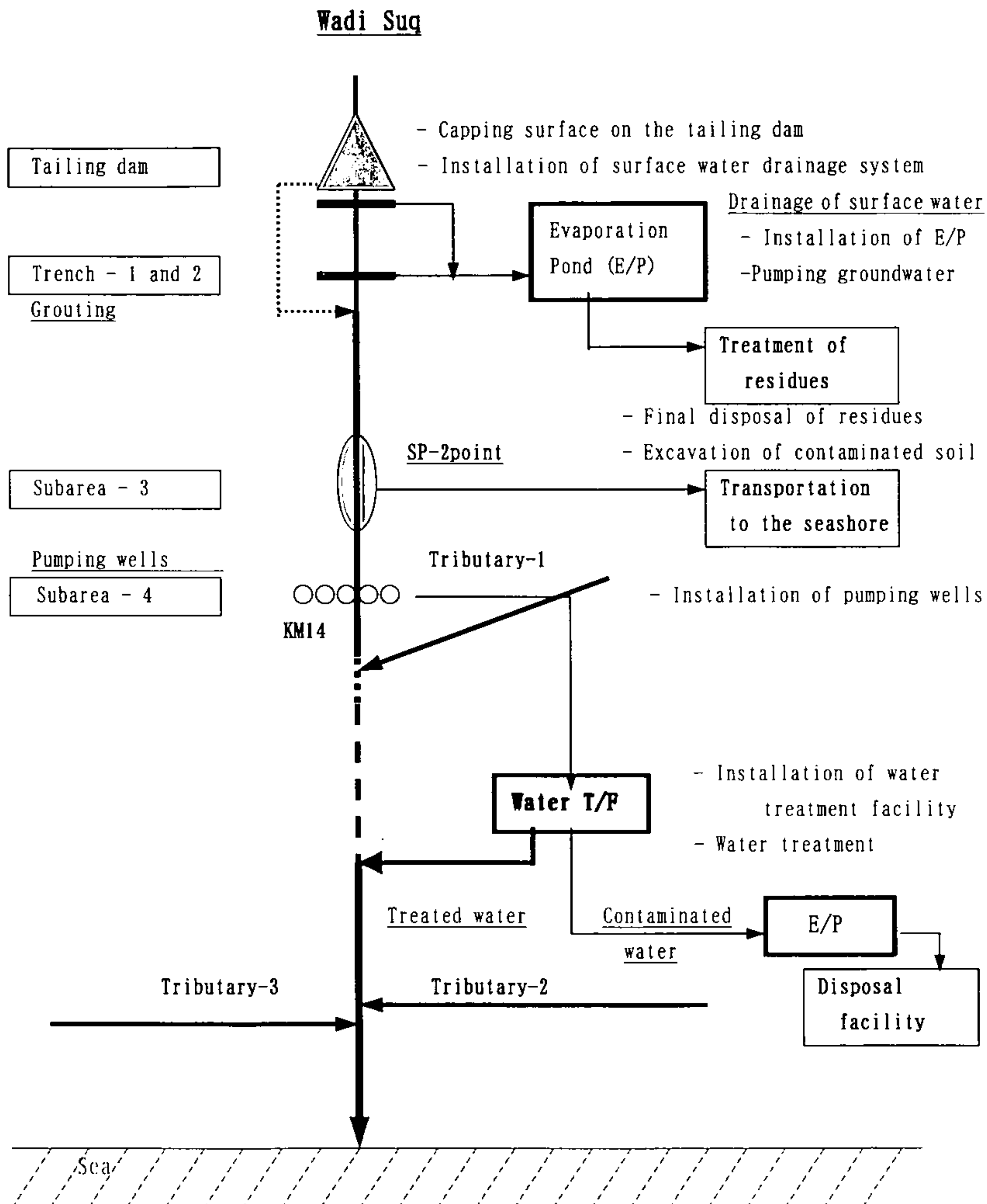


Figure 13.7 Flow of Mine Pollution Countermeasures-B in the Sohar Mine Area

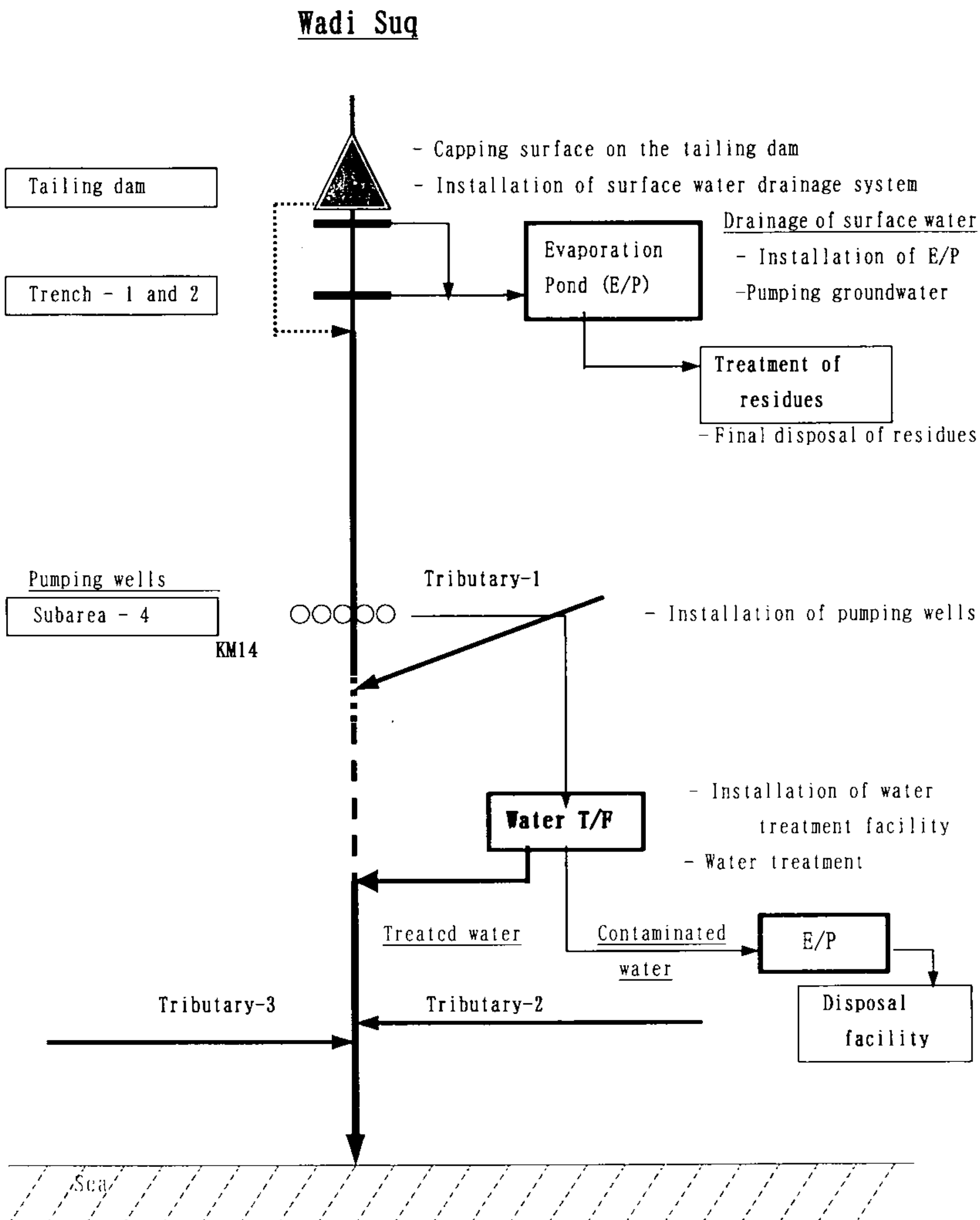


Figure 13.8 Flow of Mine Pollution Countermeasures-C in the Sohar Mine Area

CHAPTER 14 ECONOMIC ANALYSIS

The financial cost of the countermeasures was estimated at US$ 11,900,000. This financial cost was converted into an economic cost by subtracting various taxes (estimated to be 15 % of the financial cost). As a result, the economic cost was estimated at US$ 10,120,000. The yearly financial maintenance cost was estimated to be US$200,000, which was also converted into an economic cost of US$170,000 in the same way as the above.

In this project, the benefits were estimated in terms of use-value and non-use-value. Use-value benefits were estimated from the rise in the value of farm and orchard land, the increase in the number of goats raised in each household, and the savings from the cost of free drinking water supplied by OMCO to households in the area of groundwater contamination.

The willingness to pay for improving environmental conditions by countermeasures in order to avoid abandonment of the area was made to estimate the existence value of the area as assessed by residents and/or nations (only Omani persons with job), using the contingent valuation method (CVM).

Three economic indicators, namely, Internal Rate of Return, Net Present Value and Cost Benefit Ratio, were calculated using the yearly cost and benefit. For calculating values of net present value and cost benefit ratio, the social discount rate of 10 % was adopted here (Table 14.1).

Table 14.1 Values of Economic Indicators

(1) Alternative A

Indicators	Value
Internal Rate of Return	14.0 %
Net Present Value	US $ 4,030,820
Cost Benefit Ratio	3.19

(2) Alternative B

Indicators	Value
Internal Rate of Return	29.2 %
Net Present Value	US $ 10,558,666
Cost Benefit Ratio	6.68

(3) Alternative C

Indicators	Value
Internal Rate of Return	55.2 %
Net Present Value	US $ 13,104,121
Cost Benefit Ratio	10.89

In order to check the sensitivity of the value of IRR for the countermeasures-A by the changes of benefit and cost, the sensitivity analysis was performed. In this analysis, the following changes are examined; the case of 5%, 10%, and 15% decrease of the mean of willingness to pay, considering the difficulty of acceptance of the estimated

CHAPTER 15 COUNTERMEASURE PROJECT IMPLEMENTATION

15. 1 Procurement of Project Fund

15. 1. 1 Burden of Project Cost

In the case of the alternative-A, US$ 11,900,000 is required for the construction cost and US$ 200,000 for the maintenance cost per year for implementing the countermeasure projects. In the case of the alternative-C, the construction cost is US$ 2,500,000 and the maintenance cost per year is US$ 120,000. It is desired that the operating entity, that is, OMCO bear both construction cost and maintenance cost on the basis of "polluter-pays principle". However, considering the present financial difficulties of OMCO, it is almost impossible for OMCO to procure such a large amount of construction financing by itself. In addition, considering that OMCO has been undertaking, as a state-run enterprise, the copper refinery under the state policy, it would be unfair to place all of burden to only OMCO. Therefore, the government should burden for this project, which contributes to the improvement of regional environment.

Therefore, the government should burden for this project, which contributes to the improvement of regional environment. In specialty since the construction cost is necessary for a large amount of money, the government is requested for giving its help to OMCO as much as possible by granting subsidy, borrowing soft loans, etc. However, OMCO is desired to expend the yearly maintenance cost basically since the amount is not so large and its expenditure continues for a long time. In case that it is impossible by all means for OMCO to burden the yearly maintenance cost, OMCO would ask subsidy to the government through the Ministry of Commerce and Industry.

15. 1. 2 Procurement of Construction Cost

Since OMCO cannot procure the construction cost by it, the financial sources should be sought. Generally, the followings are considered to be financial sources:

a. Subsidy from the government
b. Loans from domestic banks
c. Grants or loans from foreign governments or international financial institutions

It is desirable that the government should pay construction cost. However, considering the severe financial situation of the government caused by resent stagnant export of oil and gas, the government itself cannot prepare all of the construction cost. However, since the export of oil and gas is taking a turn for the better at this moment, the assignment of the government subsidy is desired to examine. Other than subsidy, loans should be borrowed. In this case it is very important to examine the loan conditions such as the interest rate, repayment period, grace period, etc. In the below, the amortization of capital and interest is examined under the conditions listed in Table 15.1.

Table 15.1 Loan Conditions

Fond Sources	Project Type	Interest Rate	Repayment Year	Grace Period
Domestic Bank	General	8.0 %	5 year	0 year
International Financial Institutions	Standard	12.0 %	20 year	5 year
International Financial Institutions	Standard	3.0 %	25 year	7 year
International Financial Institutions	Environmental	2.5 %	25 year	7 year

15. 1. 3 Repayment Schedule

Table 15.2 summarized the repayment schedule on the condition of loan share of 100 %, 50 %, and 30 % to the total construction cost. In case of loan from domestic banks, yearly repayment becomes considerably high, even if borrowed money is not so large, because the repayment period is short (under 30 % borrowing, yearly repayment reaches to 790 thousands dollars at minimum). Therefore, it is necessary to negotiate on loan conditions for borrowing from domestic banks. It goes without saying that soft loans through the bilateral relationship are favorable. However, it is very difficult for a high-income country like Oman to borrow soft loans, therefore, to ask assistance to the international funding institutions like World Bank might be a better solution. In this case, repayment of capital and interest is sufficiently possible by assigning only 0.01 % of GDP to the projects (the Oman's GDP is 15.6 billion dollars in 1999). Table 15.2 shows the summery of repayment schedule.

15. 2 Technical Support

For the implementation of the countermeasure project, it is necessary to execute making of detailed implementation plans, detailed design works and the construction management and so on. In Oman, a domestic or an international consultant company carries out such works, which are hired by the Oman government or OMCO generally. After completion of the countermeasure project, operations and management of the water treatment facilities are very important. In this report, costs of the plans are calculated as by contract biases of a domestic or an international private company.

There is a good solution to use the technology support scheme by foreign countries as the means that cuts these expenses and moreover can receive technology transfer.

Table 15. 2 Repayment Schedule by Case

(Unit : US$)

Fund Sources (Loan share)	Total Repayment	Largest Repayment	Minimum Repayment	Final Year of Repayment
Domestic Banks				
Loan share: 100 %	25,240,000	2,944,800	2,374,000	2007
50 %	12,917,800	1,662,000	1,187,000	2007
30 %	12,568,000	1,108,000	791,000	2007
International Bank				
Loan share: 100 %	37,349,000	2,108,000	594,000	2026
50 %	18,675,000	1,009,000	297,000	2026
30 %	16,407,000	673,000	198,000	2026
International Financial Institutions				
Loan share: 100 %	30,155,000	817,000	356,000	2033
50 %	15,077,000	408,000	178,000	2033
30 %	14,009,000	272,000	119,000	2033
International Financial Institutions				
Loan share: 100 %	29,086,000	760,000	297,000	2033
50 %	14,543,000	380,000	148,000	2033
30 %	13,653,000	253,000	99,000	2033

PART Ⅲ RECOMMENDATIONS AND SUMMARIES

CHAPTER 16 COUNTERMEASURES FOR THE AIR POLLUTION

Main air pollutants emitted from OMCO's plant are SO_2 and particulate matter from the processes. The constituents of the particulate matter include Cu, Fe, Zn, As, Cd, Pb and Hg. Mitigation measures by emitting gases through tall stacks were traditionally applied to reduce ground-level air pollutant concentrations. Since this method does not address the problem of long-range transport and deposition of sulfur and merely disperses the pollutant, reliance on this strategy is no longer recommended. Therefore, the objective must be to reduce total emissions. Emission control technologies can be classified into solvent injection and flue gas desulfurization (FGD).

Flue gas desulfurization (FGD) system consists of major 5 sections, namely, flue gas ducting section, SO_2 removal section, limestone feed and handling section, gypsum handling section, and wastewater treatment facility.

The total installation cost of the wet limestone/gypsum scrubber FGD system into OMCO plant is estimated approximately US$ 20 million.

JICA Study Team executed air dispersion simulation for the case that OMCO installs the FGD system (90 % SO_2 removal option) in order to evaluate the effectiveness of the mitigation measure recommended by JICA Study Team. As results of the simulation, ambient air quality standard is not violated in the area over 20km x 20km surrounding OMCO plant, if 90% SO_2 removal FGD system is installed.

CHAPTER 17 ENVIRONMENTAL MONITORING SYSTEM

17.1 Recommendations for Water Quality Monitoring System

The current monitoring network is deemed adequate for conducting ongoing water quality evaluations to meet the following objectives:

- Continuing to monitor contaminant migration in Wadi Suq and Wadi Bani Umar al Gharbi
- Collecting water quality data to evaluate the effectiveness of countermeasures undertaken to control contaminant migration;
- Providing data needed to improve modeling of groundwater flow and contaminant transport;
- Collecting geochemical data needed to identify contaminant sources and design groundwater treatment systems.

This section describes the JICA Team's recommended water quality monitoring system, including the following recommendations:

- To streamline the collection of water quality data, the JICA Team recommends ongoing monitoring be conducted at 40 specific locations, including newly 25 JICA's monitoring wells and 4 monitoring points of surface water.
- Therefore, the JICA Team recommends replacing these 2 wells with new wells cased with 4-inch diameter PVC casing. In addition, it is recommended all the new JICA monitoring wells be equipped with data logging devices to continuously monitor the water levels at each of the 16 locations.
- In addition to eliminating some monitoring points, the JICA Team also recommends that the frequency of monitoring the selected points be reduced. Again, this recommendation is made to reduce costs. More importantly, however, the current weekly or monthly monitoring schedule is not needed for detecting water quality tends. Rather, it is recommended that the monitoring frequency for the selected wells be reduced to quarterly or biennial. Biennial monitoring is probably more than adequate for detecting significant trends in water quality in the Sohar Mining areas. A biennial sampling plan should, at a minimum, include collecting dry season and wet season samples.
- It is recommended that these same parameters be monitored at all locations during each sampling event, except as noted.
- To ensure the uniformity of monitoring activities conducted by the various interested parties, it is strongly recommended that standard operating procedures (SOPs) be established.
- Ensuring the quality of the collected data is a critical function of any water quality monitoring system. Therefore, it is important that a uniform quality assurance/quality control (QA/QC) procedure be followed during all field and laboratory activities. The required QA/QC protocols should be written into the SAP to ensure continuity.
- The SAP should establish strict and uniform record keeping protocols to ensure the integrity, accessibility, and usefulness of the data collected through the water quality monitoring program for

the Sohar mine area.

- Analyzing and interpreting water quality data is a complex subject requiring years of training and experience. For geochemists or engineers should perform this reason, analysis and interpretation of the groundwater monitoring results trained in the art and science of interpreting water quality data.

17.2 Recommendations for Air Quality Monitoring System

MMEW has established national ambient air quality monitoring stations in Oman, and OMCO has ten monitoring stations for ambient air quality within 10 km radius of the OMCO plant.

At present, MMEW and OMCO have independent monitoring system within Sohar mine area. To accomplish ultimate goal of air quality monitoring, MMEW and OMCO have to not only fulfill their own role and responsibility sufficiently, but also cooperate each other.

- Another national ambient air quality monitoring station would be necessary in order to monitor impact of stack emission from OMCO. Based on the study results, the JICA team recommends installation of another national ambient air quality monitoring station.
- The JICA team recommends installation of another national ambient air quality monitoring station as follows:
  1) Condition of emission: location of emission source, emission condition of air pollutants, meteorology.
  2) Condition of receptor: location of residential areas, location of sensitive receptors, presently recognized air quality deterioration.
  3) Condition of maintenance: accessibility, sustainability, and prevention of vandalism.
  4) Aarja, Rahab and Suhaylah or one of them are recommended as additional appropriate monitoring points.
- National ambient air quality monitoring should monitor all of these 6 parameters, including SO_2, PM_{10}, CO, NOx, ozone and lead. SO_2 monitoring is the first priority to monitor the impact from OMCO.
- Ambient air are automatically monitored and collected data are sent to MMEW head office by on-line system. Similar system of Sohar Industrial Estate should be adopted for the newly installed ambient air quality monitoring station in Sohar mine area.
- New local meteorological monitoring station is necessary to be installed not only to analyze on correlation with air quality monitoring data, but also to prediction of alert of day, to construct simulation model specified to target area, etc. The meteorological parameters consist of wind speed, wind direction, air temperature, solar radiation, relative humidity, air pressure, weather, and precipitation.
- Introduction of emission monitoring system is recommended because it can determine the actual emissions of a pollutant from a stack of OMCO.
- On the analysis of SO_2 monitoring in OMCO, JICA recommends to change existing conductometric

SO_2 monitor into UV fluorescent one same as MMEW.

- A smaller subset of monitoring stations should be selected for ongoing long term monitoring because the Study indicated that northeastern area of OMCO, which identified with windward of locally dominant wind, scarcely influenced by stack emission from OMCO. The reduction of monitoring station also contributes to reduce monitoring cost. We recommend OMCO execute air quality monitoring at the following 3 stations, namely Rahab (A-8), Suhaylah (A-2), and Magan.
- In future planning of monitoring system, both MMEW and OMCO should take into consideration mutual use of monitoring data.

CHAPTER 18 ENVIRONMENTAL MANAGEMENT SYSTEM

18.1 Recommendations for Water Quality Management System

The recommendations for water quality management system are shown as below.

- No change in Oman's current wastewater discharge and drinking water standards is recommended. The current Omani standards are consistent with world standards.
- A permanent liaison position be created within DGM to foster coordination and cooperation between MCI and MMEW is recommended.
- Investigating the potential risks to water quality and human health and performing a feasibility study for constructing a national system of hazardous waste disposal sites are recommended.
- It is necessary to have a nation-wide system in place for responding to emergencies involving releases of oil or other hazardous substances.

18.2 Recommendations for Air Quality Management System

The recommendations for air quality management system are shown as below.

- The JICA team reviewed existing air quality management system and activity of MMEW and OMCO as part of the Study. In order to improve existing system and to make it more appropriate and sufficient one, some recommendations to each body are described in the following sections;

  1) MMEW

     a. Establishment of National Ambient Air Quality Standards

     b. Strengthen National Ambient Air Quality Monitoring Network

     c. Improvement of National Emission Standards for Copper Smelter

     d. Development of Database System

     e. Establishment of Financial Support and Incentive System for Air Pollution Con

     f. Reinforcement of Administrative Staff

  2) OMCO

     a. Reinforcement of Administrative Staff

     b. Development of Database System

- In order to execute the recommendations, reinforcement of air quality management staff is necessary. Appropriate number of stuff in charge of air quality management should be assigned. It is also necessary to give training program to the staff.

CHAPTER 19 SUMMARIES

19.1 Conclusions

The conclusions of the Study are, as follows:

(Topography, geology, hydrologeology investigation)

- The topography of the Study area mainly consists of the moderate and low relief mountain, hilly land, fans and terraces, alluvial plain and coastal plane.
- Wadi Suq has a river length of 34 km with an average slope of 0.008 (1:125), 275 m in maximum elevation of the wadi, 71 km^2 as the catchment area, and of Wadi Suq, and the mountainous area of the basin occupies approximately 29 km^2. The downstream portion has a gentle slope and forms wide floodplain.
- Wdi Suq is topographically divided into seven subareas, including Subarea 1 to 7.
- The geology of the Study area consist of the Samail Nappe, which is composed of the Ophiolite and Batinah Olistostromes of the Pre-Tertiary, Tertiary Deposits in the eastern part of the area, and Quaternary Deposits.
- The Quaternary Deposits consist of terrace deposits in diluvium, wadi sediments and screes. The Alluvial Terrace Deposits generally is almost consolidated by calcrete, and the permeability is relatively low.
- The dominant directions of faults are northeast to southwest and northwest to southeast. A narrow graven structure from 1 km to 1.5 km wide runs along Wadi al Jizi in an east-northeast to west-southwest direction.

(Geochemical investigation)

- High concentration zones of Cd, Pb, Cu, Fe, Zn, and SO_4, which are caused by the smelter and tailings dam, were found by soil investigation and locally dispersed beyond 3 km.
- Leakage of contaminated groundwater in a northwest direction from the tailing dam was confirmed and its impact has reached downstream to Bayda village.
- Leakage of seawater occurred out of pumping station PS-2, and there exists a high chloride concentration zone approximately 400 m in length.

(Geophysical survey)

- In the tailing dam, the specific resistivity basement appears as an almost horizontal line about 30 m under the ground surface with a layer of low specific resistivity spreading horizontally.
- In the middle reach of Wadi Suq exist 50 to 100 m under ground surface, and it is deeper than upper reach of the wadi.
- In the upper and middle reaches, the depth of the basement is distributed almost horizontally from 5 to 10 m below the wadi ground surface.
- In the middle and lower reaches, the basements exist at a slightly deeper depth of about 20 m. However, their form is almost flat on the whole.

(Drilling investigation)

- There exists an aquifer with very shallow groundwater level of –4m upstream of Sagha village. The shallowness of the aquifer in this area is caused by a natural constriction in the topography that results in a damming effect on the groundwater.

- Deep groundwater in DH-4, DH-5 and DH-8 is slightly confined. Compact calcreted sand and gravel beds may act as confining beds.
- Permeability coefficients obtained by the field pumping tests ranged from 10^{-3} to 10^{-6} cm/sec. Permeability is lower in calcreted sand and gravel beds.
- Elevated concentrations of Cd and Pb were observed in seepage out of the tailing dam and slightly higher concentrations were observed in downstream areas until DH-5 and in mine water out of Aarja and Bayda mines. Other areas presented low concentration not exceeding Omani drinking water standards.
- Cl concentration ranged from 45 to 34,578 mg/L with the high concentrations obtained from seepage out of the tailing dam, including its downstream area near DH-5 and northwestern part of the tailing dam.
- All chemical constituents in the shallow and deep groundwater exhibited marked attenuation with distance from the sources. The concentrations generally decreased with distance downstream until approximately the area of borehole DH-5 is reached in Wadi Suq. The entire area form the tailing dam downstream to Sagha village is considered contaminated.
- There exist water quality differences between the deep layer groundwater and that of shallow layer.
- Peak concentrations of Cd, Cr, Pb and Cu are observed at DH-5, while peak concentrations in Mn and Fe were observed at DH-6. The presence of weak natural mineralization in area around DH-5 and -6 seems to be causing elevated concentrations of metals in this area.
- SO_4 concentrations exhibit attenuation with distance downstream from the source and a peak was observed at DH-7 borehole. This sulfate peak may be the result of natural sulfate minerals in the area of DH-7.
- A high concentration peak of Cl was detected at DH-5. This chloride peak could be caused by leakage out of the seawater pipeline.

(Pollutant source investigation)

- High salinity groundwater is flowing out from the tailing dam, and the tailings from the surface to the tailing dam are scattered by wind.
- Wastes were dumped in dumping areas, located in Lasail, Lasail West, Aarja, and Bayda mines.
- Abandoned open pits of Lasail West and Aarja mines are filled by mine water.
- Off-gas is directly discharged out of the main stack after simple dust collection without desulfurization.
- Waste liquid out of tank house is neutralized by hydrated lime after liberating electrolysis to decopper, and finally transported by tank truck to the evaporation ponds.
- Tailings contain a great amount of sulfur, which might produce a lot of acidic water. But it is believed the surplus lime in tailings; calcreted beds and basement rock might act as buffering agents to prevent the onset of acid drainage.
- Wastes of both Lasail and Aarja mines have high sulfur contents ranging between 10 and 13 %. Some of these wastes might produce acidic water with leached heavy metals in the future as oxidation progresses further.

- Aarja mine water contains high concentration of Hg, Na, Ca and Cl is different from shallow layer groundwater in the surrounding area. On the other hand, Lasail West mine water presents slightly low pH, but has some correlation with the groundwater in the surrounding area.

(Environmental (water quality) investigation)

- pH values are almost neutral.
- Electric Conductivity presented a high value of 7.66 S/m at the tailings impoundment and decreased with distance downstream along Wadi Suq.
- Cd, As, Pb, Cu, Zn, and SO_4 presented higher values at the tailings impoundment, northwest of the tailing dam, and mine water of Aarja and Lasail West.
- Cl presented high concentration at the tailings impoundment, extending to the northwest, and downstream along Wadi Suq.
- Extent of water contamination impact in Sohar mine area is summarized, as follows:
    - Cd, Pb, Cu, SO_4 and Cl as pollutants originate from the tailings dam and are observed downwards along Wadi Suq. The extent of water contamination is limited from the tailing dam to the KM-14 point of Sagha Village along Wadi Suq.
    - A high concentration zone of Cl in the area downstream of Wadi Suq could be influenced by old seawater based on the results of radioactive dating by tritium. The age of this water was estimated at 27 year and contains Cl contamination from before mine development.
    - Contaminated groundwater is leaking toward the northwest out of the tailing dam and is impacting Wadi Bani Umar al Gharbi.
- The groundwater modeling of Wadi Suq was performed using Groundwater Modeling System (GMS) v3.0.
- Steady state simulation results of the Wadi Suq model presented excellent comparison with measured groundwater levels.
- Calculated simulation results of contaminated groundwater showed excellent correlation with measured concentrations obtained by monitoring. In the future, however, further study will be made.

(Air quality investigation)

- The 1-hour average SO_2 concentrations varied from 0.001ppm (3 $\mu g/m^3$) to 0.835 ppm (2,404 $\mu g/m^3$).
- The 24-hour average TSP concentrations varied from 49 $\mu g/m^3$ to 332 $\mu g/m^3$.
- The 24-hour average PM_{10} concentrations varied from 33 $\mu g/m^3$ to 205 $\mu g/m^3$.
- Measured dustfall masses varied from 0.42 t/km^2/30days to 2.90 t/km^2/30days.
- 24-hour average SO_2 ranged from 19 to 225 $\mu g/m^3$, and exceeded the EEC standard at 2 points.
- The predicted result of ground level concentrations in air showed relatively excellent comparison with measured concentrations. The predicted SO_2 concentration of the ground level for 24-hour is 120 $\mu g/m^3$ as diluted value on west side of the OMCO smelter.

(Investigation on expansion program for smelter and refinery plant)

- It has been stated that plans for expanding the annual production of OMCO's smelter ranging from 40,000 to 100,000 t/year have been drafted. The JICA Team concluded there is no feasible plan for expansion of the plant at this time.

(Environmental impact investigation)

- Environmental impact investigation was performed by personal interview with local residents, health and medical facilities based on an environmental questionnaire. Consequently, diseases, such as respiratory symptom, decrease of livestock, and some impact on plants and insects were observed.

(Socio-economic survey)

- Population in Sohar prefecture is estimated to be 104,169 persons. Agriculture and fishery are active but industrialization has progressed rapidly in recent years.
- There are 8 communities around Sohar mine with 119 families and 870 residents.
- Areas around mine have suffered from salinization of groundwater and offensive odor etc.
- The results of the interview investigation are, as follows:
  - About half of the interviewee do not the situation of Sohar mine area.
  - Almost all persons who visited Sohar mine area know the existing environmental negative effects.
  - Some of persons think they do not use the land in Sohar mine area, but others may use it.
  - Their willingness-to-pay for improving the environmental condition in Sohar mine area is considered to be reasonable.

(Technical transfer)

- Technology transfer was implemented through cooperative efforts during study, including the practice of on-site training, the explanation of the analysis results with the counterparts, counterpart study and training in Japan and so on.
- Some of the problems experienced in implementing the technology transfer element of the study included a shortage of technical experts within MCI and MMEW and the differences in the social environments between Oman and Japan, but the anticipated object of the study was achieved sufficiently and the study was completed with the sincere attitude and efforts of Omani and Japanese study teams.

(Environmental countermeasures)

- The environmental countermeasures in the Sohar mine area consist of the tailing dam and along Wadi Suq.
- The countermeasures between the tailing dam and Trenches -1 and -2 in Subarea 1 are examined by OMCO. A part of construction of evaporation pond is commenced. The tailing dam will be capped with a bitumen liner material, and the contaminated groundwater at Trenches-1 and 2 will is pumped to and treated at the evaporation pond.
- The contamination countermeasures in Subarea 1, 3, 4, and 5 along Wadi Suq were examined and evaluated.
- The contaminated soil in Subarea 3 is necessary to be extracted by excavation, and the excavated zone should be replaced clean soil. The contaminated soil would be transported to seashore for use as fill material in the construction of seaport facilities.
- The countermeasure alternatives at KM 14 in the Subarea 4 consist of two alternatives, including cutoff trench and pumping wells. During construction of countermeasures at the Subarea 4, measures would be taken to protect the natural gas pipeline and seawater pipeline buried in the wadi gravel, and the highway would have to be temporarily rerouted during construction.

- The countermeasure in the Subarea 5 consists of the pumping wells.
- The contaminated groundwater extracted from the Subarea 4 and/or 5 would be transported and treated at the water treatment facility.
- The contaminated groundwater will be removed the salt and heavy metals in the water treatment system. The treatment system would use a membrane separation technology known as reverse osmosis (RO). The permeate stream would be suitable for domestic or agricultural uses. The permeate stream would either be re-injected into the wadi gravels downstream of KM 14, or provided to local residents for domestic or agricultural purposes.
- The condensed water will send to the evaporation ponds and evaporated at there, and finally will be stocked at warehouse after packed.
- Three assemblages of alternatives were selected based on the engineering judgment and cost evaluation, as 1) Countermeasures-A as thought to be the best overall, 2) Countermeasures-B as thought to be second best overall, and 3) Countermeasures-C as technically thought to be necessary minimum.
- The total cost for the Countermeasures-A are estimated at US$ 11,900,000. The total cost for the Countermeasures-B are estimated at US$ 5,300,000. The total cost for the Countermeasures-C are estimated at US$ 2,500,000. The construction period is 12 months.

(Economic analysis)

- The economic cost of the Countermeasures-A was estimated at US$ 10,120,000, and the yearly financial maintenance cost was estimated at US$ 170,000.
- The value of land would fall since the quality of the dates deteriorates as contamination increases. If the implementation of countermeasures can make the groundwater clean, the fall in land values will be stopped, and may even rise. The benefit for land is calculated at 59,700 R.O./year.
- The number of goats, etc. has dropped drastically. If countermeasures will be taken, the number of goats, etc. will increase. The estimated benefit is 37,500 R.O./year.
- If the countermeasures will be implemented, the cost-saving benefit for supplying with free drinking water by OMCO is calculated at 11,984 R.O./year.
- The estimated mean of willingness to pay was 7 R.O./year for Muscat city and 8 R.O./year for Sohar city. Using the estimated mean of willingness to pay, the total amounts of willingness to pay in Muscat were estimated at 800,000 to 1,000,000 R.O./year. That of Sohar was estimated at 350,000 to 450,000 R.O./year.
- As a result of the economic analysis, IRR is 14.0 %, the present net value is considerably large, and the cost benefit ratio is indicated to be greater than 3.0. Therefore, the recommended countermeasures can be judged to be sufficiently feasible.
- Other benefits, including improvement of existing orchard land, growing of trees in the “Al Ons Nature Reserve”, returning of honeybees to the mine area, increasing of tourists, etc. will be obtained after the countermeasures will be implemented.

(Countermeasure project implementation)

- The government should burden for this project, which contributes to the improvement of regional environment. In specialty since the construction cost is necessary for a large amount of money, the government is requested for giving its help to OMCO as much as possible by granting subsidy, borrowing soft loans, etc.

- Although it is desirable that the government should pay construction cost, the assignment of the government subsidy is desired to examine. It is necessary to negotiate on loan conditions for borrowing from domestic banks. In this case, repayment of capital and interest is sufficiently possible by assigning only 0.01 % of GDP to the projects.
- For the implementation of the countermeasure project, it is necessary to execute making of detailed implementation plans, detailed design works and the construction management and so on. After completion of the countermeasure project, operations and management of the water treatment facilities are very important. There is a good solution to use the technology support scheme by foreign countries as the means that cuts these expenses and moreover can receive technology transfer.

19.2 Recommendations

The recommendations of the Study are, as follows:

(Countermeasures for the air pollution)

- Wet limestone/gypsum scrubber Flue gas desulfurization (FGD) system is recommended to reduce SO_2 emissions from OMCO. SO_2 removal is approximately 90 % or more.
- If 90 % SO_2 removal FGD system is installed in the OMCO plant, the ambient air quality standard is not violated in the area over 20 km x 20 km surrounding OMCO plant.
- The total installation cost of the wet limestone/gypsum scrubber FGD system into OMCO plant is estimated approximately US$ 20,000,000.

(Environmental monitoring system)

- On the monitoring system in the Sohar mine area, total 40 monitoring locations including the existing monitoring places and JICA Team's 25 new monitoring wells are recommended.
- On the monitoring work, establishing of the standard operating procedures (SOPs) for the water sampling and treatment in the field, chemical analysis in the laboratory, data-analysis technique are recommended.
- Another national ambient air quality monitoring station would be necessary in order to monitor impact of stack emission from OMCO.

(Environmental management system)

- The JICA Team recommends no changes in Oman's current wastewater discharge and drinking water standards. The current Omani standards are consistent with world standards.
- The JICA Team recommends that a permanent liaison position be created within DGM to foster coordination and cooperation between MCI and MMEW.
- The government of Oman has not yet established national ambient air quality standards. US EPA ambient air quality standards (NAAQS) are tentatively used as a substitute for ambient air quality standards of Oman.
- Although MMEW presently only reviews these monitoring data/reports and keep them by filing, development of database system of the data/reports gathered in MMEW will certainly contribute to

air quality management policy planning.

- OMCO should develop database system, as the database system is helpful to understand ambient air quality monitoring condition and trend around OMCO area, and effective to make and review air quality management plan.