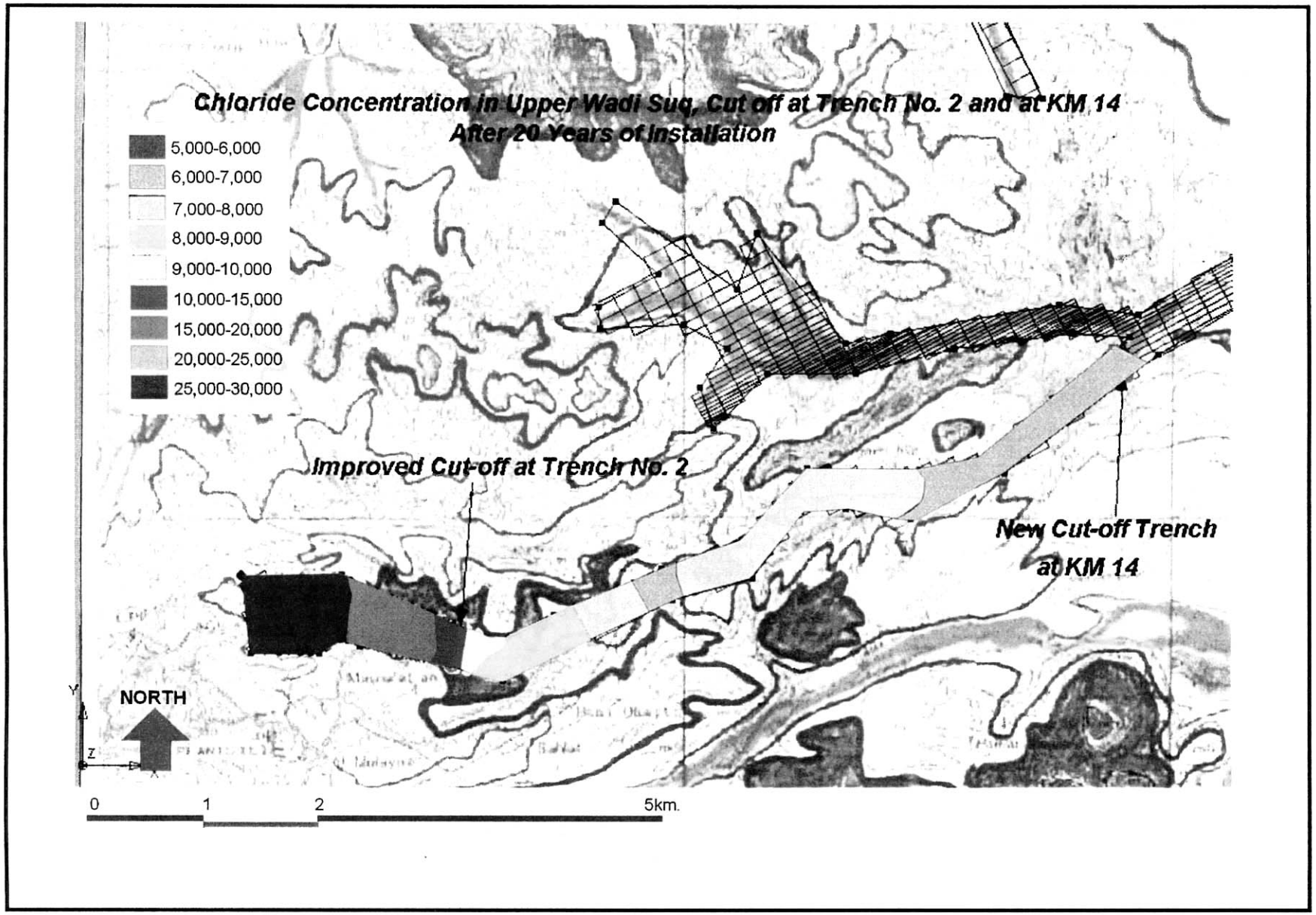

Figure 13.16 Estimated Chloride Concentration in Upper Wadi Suq, Cut off at Trench-2 and KM14 After 20 Years of Instollation

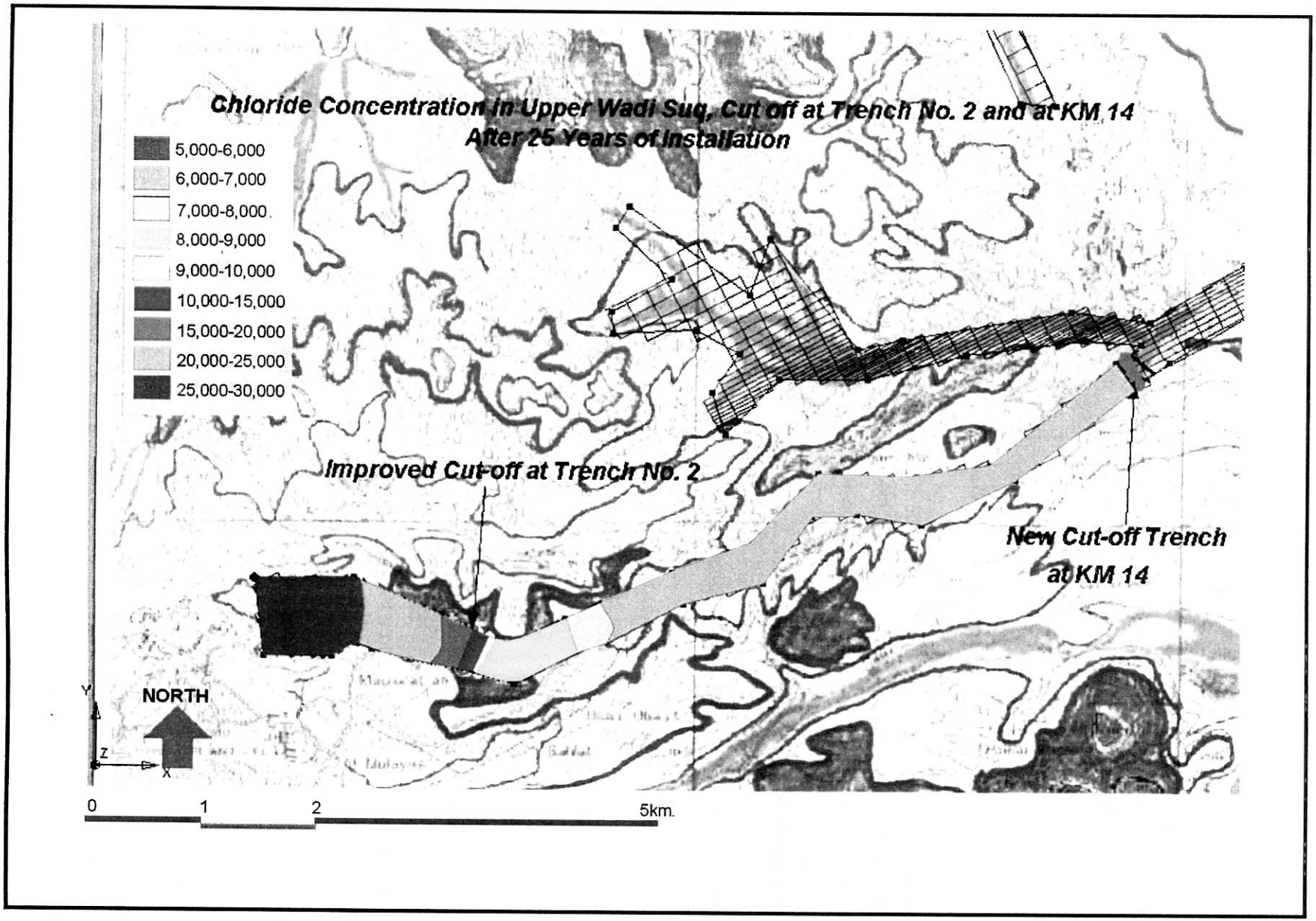

Figure 13.17 Estimated Chloride Concentration in Upper Wadi Suq, Cut off at Trench-2 and KM14 After 25 Years of Instollation

13.4 Selection of the Preferred Assemblage of Alternatives

Based on the results of evaluating the alternatives with respect to their cost, long-term effectiveness, and implementability, the most effective countermeasures are shown in Table 13.10 (1) to (2). Three assemblages of alternatives were selected based 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 details are described as follows.

13.4.1 Countermeasures-A as Thought to be the Best Overall

The Countermeasures-A was thought to provide the best overall results and was selected for the contamination countermeasures along Wadi Suq. The content of the Countermeasures-A and schematic flow are shown in Table 13.11 and Figure 13.18, respectively.

(1) Result of Selection

The Countermeasures -A 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 contamination countermeasures for the tailings dam have already been commenced according OMCO's plan.

The leakage of contaminated groundwater occurred through the weathered zone of bedrock at Trench-2 at the Subarea 1. The leakage will be stopped by efficient grouting at Trench -2 and groundwater quality will be improved. In addition, surface water from the tailing dam after completion of construction of capping will be re-injected downstream of Trench-2 and will proceed to improve water quality.

In Subarea 3, approximately 35,000 m^3 of contaminated soil is found within the wadi and is considered another contamination source. The extraction by excavation of contaminated soil will contribute to improvement in the water quality of Wadi Suq.

Table 13.11 Wadi Suq Alternatives for Effectiveness, Implementability, and Cost (1)

Alternative / Method	Effectiveness	Implementability	Cost
Subarea 1 Alternatives			
Alterative-3 : 1. Cutoff Grouting at Trench-2	Contaminated groundwater will be cut off at Trench-2 by grouting. This alternative would completely stop the leakage of pollution to areas downstream.	This alternative could be implemented using readily available materials and equipment.	The capital cost of this alternative is much higher than Alternative 2. The O&M costs of this alternative are not necessary.
Subarea 3 Alternatives			
Alterative- 4 : 1. Excavation of soil at SP-2	This alternative effectively removes the only identified source of groundwater pollution in Subarea 3. Excavation and disposal at seashore is expected to be highly effective.	This alternative is readily implenmentable using conventional excavation technology and equipment.	Transportation fee between site and seashore is approximately 20km, and relatively high.
Subarea 4 Alternatives			
Alterative- 5A : 1. Pumping wells at DH-4 2. Pumping water to Evaporation pond	Pumping would be highly effective in reducing the salt load in Wadi Suq.	Installation of the extraction wells is readily implementable.	The cost for the water wells is much lower than that of cutoff trnch.
Altemative- 5B : 1. Cutoff Trench at DH-4 2. Pumping water to Evaporation pond	The efficiency of the cutoff trench might be much improvement over extraction wells.	The permits and approvals needed to temporarily re-rout the highway and excavate around the existing natural gas lines ore severe obstacles to implementing Alternative 2, including both.	The capital costs for the cutoff trench under this alternative are very high compared with installing a system of extraction wells.

Table 13.11 Wadi Suq Alternatives for Effectiveness, Implementability, and Cost (2)

Alternative / Method	Effectiveness	Implementability	Cost
Subarea 5 Alternatives			
Alternative- 6 : 1. Pumping wells at DH-6 2. Pumping to Water treatment plant	Pumping are expected to be highly effective in reducing the salt lord in Wadi Suq.	Installation of the extraction wells is readily implementable.	The cost for the water wells is much lower than that of cutoff trnch.
Alternative- 7A : 1. Water treatment plant 2. Evaporation pond 3. Dumping waste	The treated water will be ensured water quality less than agricultural standards. The treated water will be re-injected into the aquifers. The extraction system would be effective in containing and preventing the spread of contamination to unaffected for less affected areas.	RO treatment technology is the only practical treatment technology available for reducing the salt content of water. Implementation will require workers with specialized training to operate the treatment system.	The capital and long-term O&M costs for RO treatment are high. The present worth of this alternative is low compared with other alternatives with little significant difference in effectiveness. However, the cost of refurbishing the seawater pipeline needs to be evaluated.
Alternative- 7B : 1.Evaporation pond	All of the contaminated water is dried up at the evaporation pond.	This alternative is readily implementable.	The present worth of this alternarive is low compared with other alternatives with little significant difference in effectiveness.

Table 13.12 Countermeasures -A Thought to be the Best Overall

Subarea	Proposed Countermeasures
1. Tailing dam	(Capping) - Recirculation of the seepage from the collection trenches would be stopped; - The tailings would be recontoured and capped according to OMCO's design; (Surface water) - Storm runoff from the tailings area would be routed to Wadi Suq below Trench-2.
2. Subarea 1	(Evaporation pond) - The evaporation pond being constructed according to OMCO's plan would be completed; - Seepage from Trench-1 and -2 would be collected and disposed of in the evaporation pond; - Solid wastes generated by the evaporation of contaminated seepage would be disposed of in a secured disposal facility; (Cutoff at Trench -2) - The cutoff would be tightened by grouting in downstream of Trench -2; - Storm drain in Subarea -1 would be routed to the evaporation pond.
3. Subarea 3	(Contaminated soil by sea-water) - Salt contaminated soil at SP-2 would be excavated and transported to the sea coast for use as fill material in construction of port facilities. Excavated soil would be replaced with clean wadi sand and gravel.
4. Subarea 4	(Cutoff trench and dewatering) - A groundwater cutoff wall and extraction trench would be installed in the vicinity of DH-4 upstream of the confluence with Tributary 1; - Extracted groundwater would be pumped to a central water treatment plant located downstream of KM14 (Subarea 5).
5. Subarea 5	(Dewatering by wells) - Groundwater extraction wells would be installed to remove salt contaminated water and control the flow gradient within the Subarea; - Extracted groundwater from Subareas 4 and 5 would be pumped to the central water treatment plant. Refer to the water treatment options presented below.
6.Water treatment options	(Water treatment plant) - Extracted groundwater would be treated by reverse osmosis (RO) and either be provided to local residents or used to recharge the wadi. The RO concentrate stream would be disposed by on-site evaporation in a lined evaporation pond. - Solid wastes generated by the evaporation of the concentrate would be placed in drums and disposed of in a secured disposal facility. - Treated water can be reinjected into the aquifer at Subarea 5.

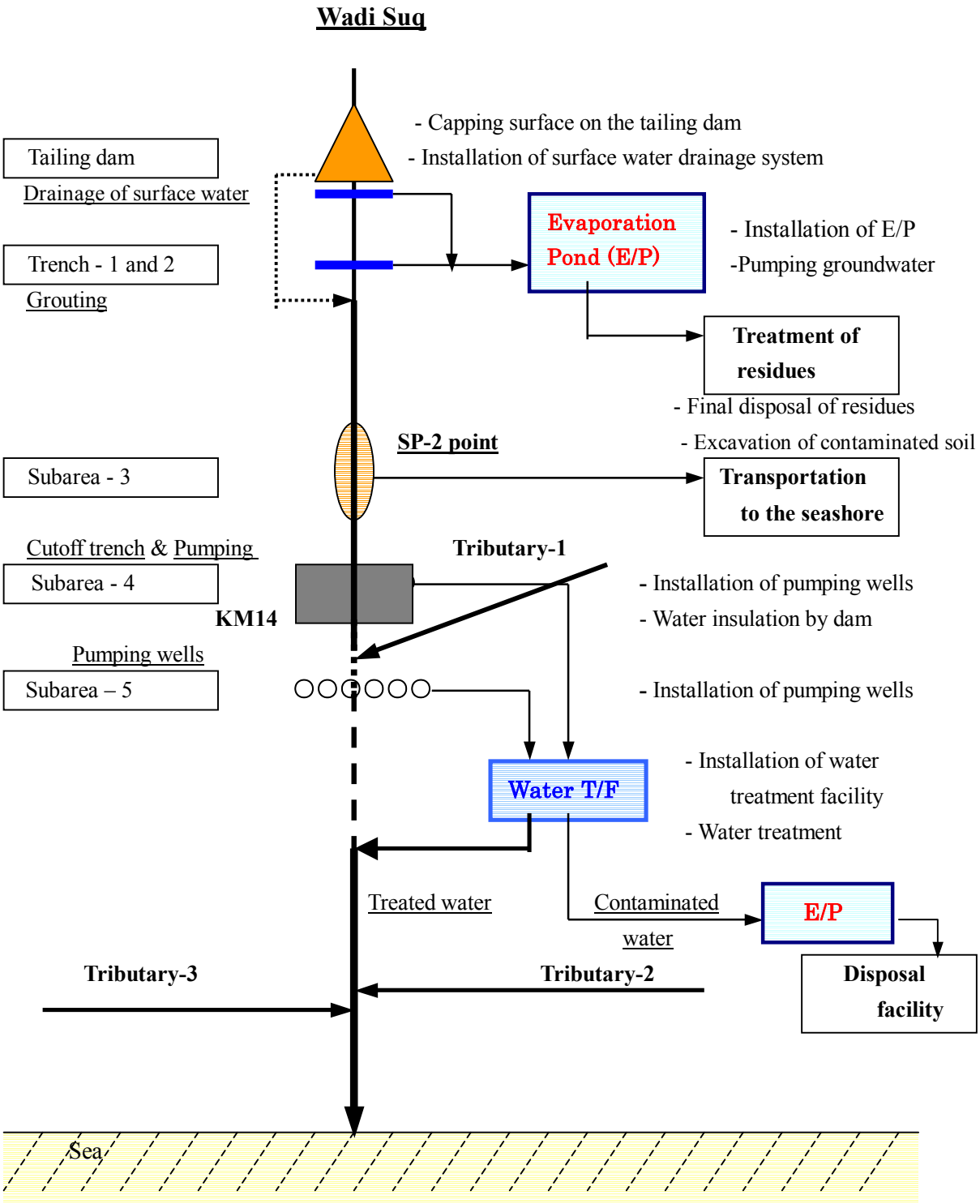

Figure 13.18 Flow of Mine Pollution Countermeasures-A in the Sohar Mine Area

In the Subarea 4, contaminated groundwater has reached from upstream and remains in this subarea due to topographical conditions. The cutoff of contaminated groundwater at Subarea 4 is the most important countermeasure along Wadi Suq. The leakage at the bottom and side of the trench will be protected by effective curtain grout, and the trench will cut all of the contaminated groundwater off. The groundwater collected by the trench will be pumped out of the aquifer.

In the Subarea 5, the contaminated groundwater exists locally and flows downward. It is necessary to pump up contaminated groundwater for improvement of the water quality in the downstream areas of Wadi Suq.

The pumping volume of the contaminated groundwater at the Subarea 4 and 5 is estimated at 350 m^3/day. As the contaminated groundwater contains noxious heavy metals, it is impossible to dispose directly to the sea. Therefore, water treatment is necessary. Extracted groundwater would be treated by reverse osmosis (RO) and treated water can be re-injected downstream of Subarea 5. The evaporation pond will treat reject water produced by the RO treatment system. Solid wastes generated by the evaporation of the concentrate would be stocked at secured disposal warehouse.

The period of the countermeasures along Wadi Suq is thought to be 25 to 30 years.

(2) Work Schedule

The work schedule of the construction work of the Countermeasures-A is shown in Table 13.13. The construction period is about 12 months.

(3) Cost Estimation

The total cost for the Countermeasures-A is estimated at US$ 11,900,000 shown as below.

1)	Grouting cost at Trench-2	US$ 1,700,000
2)	Soil excavation cost	US$ 1,100,000
3)	Cutoff trenching construction cost	US$ 5,400,000
4)	Pumping wells cost at Subarea 5	US$ 600,000
5)	Water treatment plant construction cost	US$ 1,500,000
6)	Evaporation ponds construction cost	US$ 700,000
7)	Disposal warehouse construction cost	US$ 900,000
	Total	US$ 11,900,000

(Cost includes overhead expense, contingencies and miscellaneous expenses.)

Table 13.13 Work schedule of the Water Treatment Facility Construction Work of Countermeasures -A

Work items (month)	1	2	3	4	5	6	7	8	9	10	11	12
1. Preparation, mobilization	━											
2. Subarea-1 Grouting		━	━	━	━	━	━	━				
3. Subarea -3 Excavation of soil		━	━	━	━							
4. Subarea -4 Cutoff trench		━	━	━	━	━	━	━	━	━	━	
5. Subarea -5 Pumping wells							━	━	━	━		
6. Subarea -5 Water treatment		━	━	━	━	━	━	━	━	━		
7. Subarea -5 Evaporation ponds				━	━	━	━	━	━	━		
8. Disposal warehouse				━	━	━	━	━	━	━	━	
9. Demobilization												━

13.4.2 Countermeasures-B Thought to be Second Best Overall

The Countermeasures -B is thought to be second best overall and are selected for the contamination countermeasures along Wadi Suq. The content of the Countermeasures-B and schematic flow are shown in Table 13.14 and Figure 13.19, respectively.

(1) Result of Selection

The Countermeasures -B 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

Table 13.14 Countermeasures-B Thought to be Second Best Overall

Subarea	Proposed Countermeasures
1. Tailing dam ～Subarea 1	(Capping) - Recirculation of the seepage from the collection trenches would be stopped. - The tailings would be recontoured and capped according to OMCO's design. (Surface water) - Storm runoff from the tailings area would be routed to Wadi Suq below Trench-2. (Evaporation pond) - The evaporation pond being constructed according to OMCO's plan would be completed. - Seepage from Trench -1 and -2 would be collected and disposed of in the evaporation pond. - Solid wastes generated by the evaporation of contaminated seepage would be disposed of in a secured disposal facility.
2. Subarea 1	(Cutoff at Trench -2) - The cutoff would be tightened by grouting in downstream of Trench-2. - Storm drain in Subarea -1 would be routed to the evaporation pond.
3. Subarea 3	(Contaminated soil by sea-water) - Salt contaminated soil at SP-2 would be excavated and transported to the sea coast for use as fill material in construction of port facilities. Excavated soil would be replaced with clean wadi sand and gravel.
4. Subarea 4	(Pumping wells and dewatering) - A groundwater pumping wells would be installed in the vicinity of DH-4 upstream of the confluence with Tributary-1. - Extracted groundwater would be pumped to a central water treatment plant located downstream of KM-14 (Subarea 5).
5.Water treatment plant, evaporation pond, disposal facility	(Water treatment plant) - Extracted groundwater would be treated by reverse osmosis (RO) and either be provided to local residents or used to recharge the wadi. The RO concentrate stream would be disposed by on-site evaporation in a lined evaporation pond. - Treated water can be reinjected into the aquifer at Subarea 5. (Evaporation pond) - Condensed contaminated water is dried up at the evaporation pond. - Solid wastes generated by the evaporation of the concentrate would be placed in backs and disposed of in a secured disposal facility. (Disposal facility) - Suitable location of the disposal facility is on the terrace.

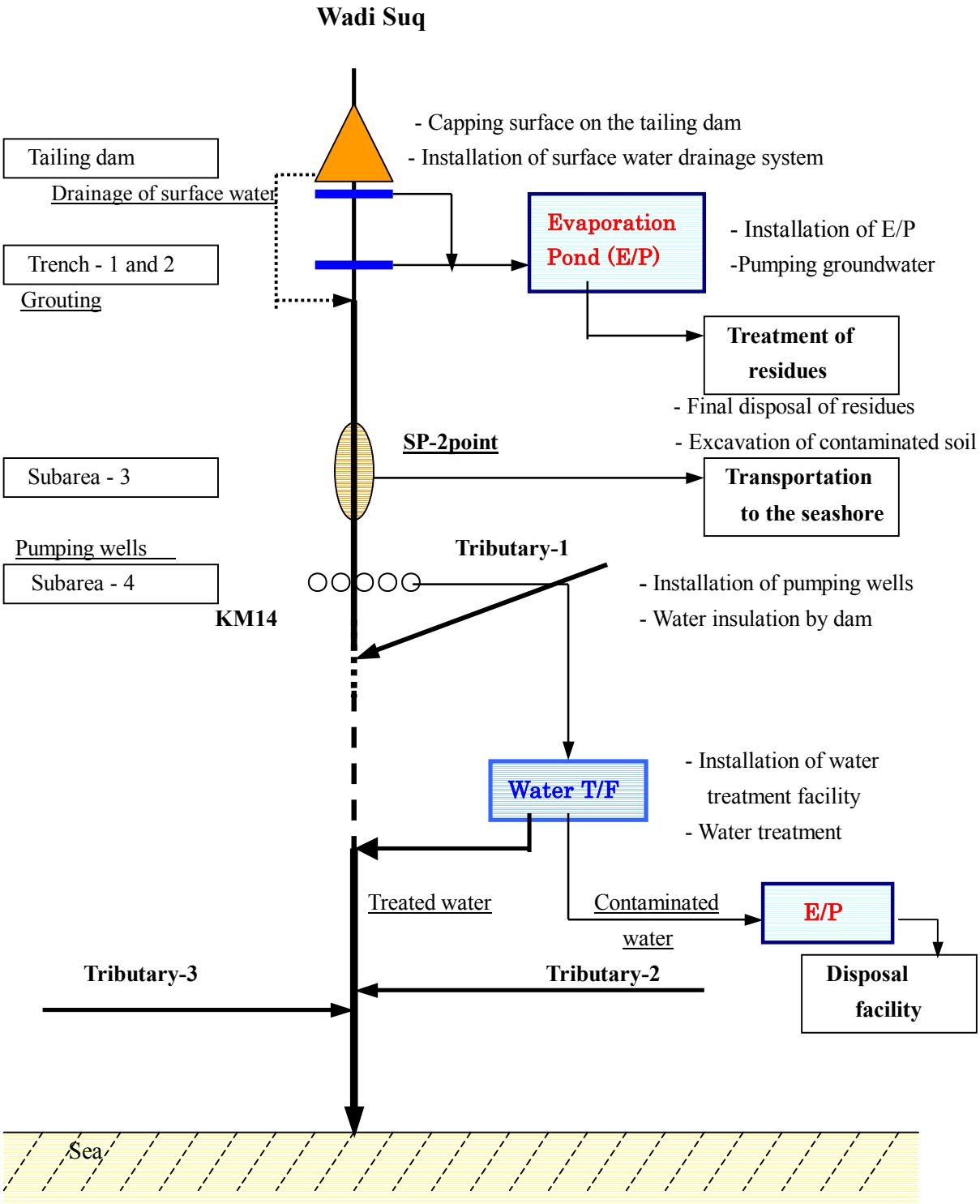

Figure 13.19 Flow of Mine Pollution Countermeasures-B in the Sohar Mine Area

6) Water treatment facility : RO treatment, etc. : Alternative-7A

The contamination countermeasures for the tailing dam have already been commenced according OMCO's plan.

The leakage of contaminated groundwater occurred through the weathered zone of bedrock at Trench-2 at the Subarea 1. The leakage will be stopped by efficient grouting at Trench –2 and will be improved water quality of groundwater. In addition, surface water from the tailing dam after completion of construction of capping will be re-injected at the downstream of Trench-2 and will proceed to improve water quality.

In Subarea 3, approximately 35,000 m^3 of contaminated soil is found within the wadi and is considered another contamination source. The extraction by excavation of contaminated soil will contribute to improvement in the water quality of Wadi Suq..

In the Subarea 4, the contaminated groundwater has reached from upstream and remains in the subarea due to topographical conditions. The cutoff of contaminated groundwater at Subarea 4 is the most important countermeasure along Wadi Suq. Almost all of contaminated groundwater will be cut off by pumping wells and pumped up.

The pumping volume of the contaminated groundwater at the Subarea 4 and 5 is estimated at 150 m^3/day. As the contaminated groundwater contains noxious heavy metals, it is impossible to dispose directly to the sea. Therefore, the water treatment is necessary. Extracted groundwater would be treated by reverse osmosis (RO) and treated water can be re-injected downstream of Subarea 5. The evaporation pond will treat water rejected from the RO treatment system. Solid wastes generated by the evaporation of the concentrate would be stored at a secured disposal warehouse.

The period of the countermeasures along Wadi Suq is thought to be 25 to 30 years.

(2) Work Sckedule

The work schedule of the construction work of the Countermeasures-B is shown in Table 13.15. The construction period is about 12 months.

Table 13.15 Work schedule of the Water Treatment Facility Construction Work of Countermeasures-B

Work items (month)	1	2	3	4	5	6	7	8	9	10	11	12
1. Preparation, mobilization	▬											
2. Subarea-1 Grouting		▬	▬	▬	▬	▬	▬	▬				
3. Subarea -3 Excavation of soil		▬	▬	▬	▬							
4. Subarea -4 Pumping wells		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	
5. Subarea -5 Water treatment		▬	▬	▬	▬	▬	▬	▬	▬	▬		
6. Subarea -5 Evaporation ponds				▬	▬	▬	▬	▬	▬	▬		
7. Disposal warehouse				▬	▬	▬	▬	▬	▬	▬	▬	
8. Demobilization												▬

(3) Cost Estimation

The total cost for the Countermeasures -B is estimated at US$ 5,300,000 shown as below.

1)	Grouting cost at Trench-2	US$	1,700,000
2)	Soil excavation cost	US$	1,100,000
3)	Pumping wells cost at Subarea 5	US$	800,000
4)	Water treatment plant construction cost	US$	1,000,000
5)	Evaporation ponds construction cost	US$	400,000
6)	Disposal warehouse construction cost	US$	300,000
	Total	US$	5,300,000

(Cost includes overhead expense, contingencies and miscellaneous expenses.)

13.4.3 Countermeasures-C Technically Thought to be Necessary Minimum

The Countermeasures-C are thought to be minimum necessary to improve water quality in Wadi Suq and are selected for the contamination countermeasures along Wadi Suq. The content of the Countermeasures-C and schematic flow are shown in Table 13.15 and Figure 13.20, respectively.

Table 13.16 Countermeasures -C Technically Thought to be Necessary Minimum

Subarea	Proposed Countermeasures
1. Tailing dam	(Capping) - Recirculation of the seepage from the collection trenches would be stopped - The tailings would be recontoured and capped according to OMCO's design (Surface water) - Storm runoff from the tailings area would be routed to Wadi Suq below Trench -2.
2. Subarea 4	(Cutoff trench and dewatering) - A groundwater cutoff wall and extraction trench would be installed in the vicinity of DH-4 upstream of the confluence with Tributary-1 - Extracted groundwater would be pumped to a central water treatment plant located downstream of KM-14 (Subarea 5).
5.Water treatment plant, evaporation pond, disposal facility	(Water treatment plant) - Extracted groundwater would be treated by reverse osmosis (RO) and either be provided to local residents or used to recharge the wadi. The RO concentrate stream would be disposed by on-site evaporation in a lined evaporation pond. - Treated water can be reinjected into the aquifer at Subarea 5. (Evaporation pond) - Condensed contaminated water is dried up at the evaporation pond. - Solid wastes generated by the evaporation of the concentrate would be placed in backs and disposed of in a secured disposal facility. (Disposal facility) - Suitable location of the disposal facility is on the terrace.

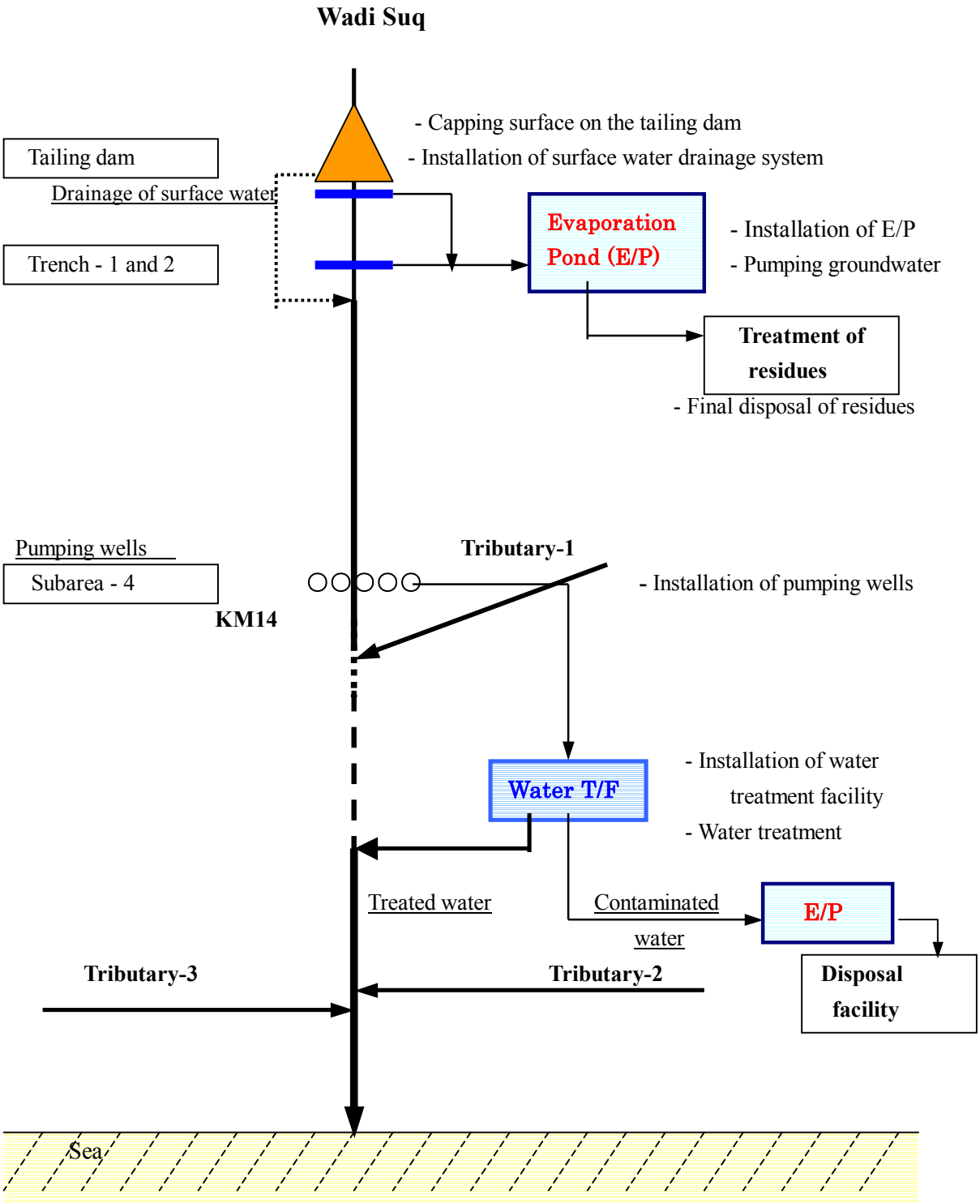

Figure 13.20 Flow of Mine Pollution Countermeasures-C in the Sohar Mine Area

(1) Result of Selection

The Countermeasures-C 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 contamination countermeasures for the tailing dam has already been commenced according OMCO's plan.

In the Subarea 4, the contaminated groundwater had reached from upstream and is topographically staying in this Subarea. The cutoff of contaminated groundwater at Subarea 4 is the most important countermeasure along Wadi Suq. Almost all of the contaminated groundwater will be cut off by pumping wells and pumped up.

The pumping volume of the contaminated groundwater at the Subarea 4 is estimated at 150 m^3/day. As the contaminated groundwater contains noxious heavy metals, it is impossible to dispose directly to the sea. Therefore, water treatment is necessary. Extracted groundwater would be treated by reverse osmosis (RO) and treated water can be re-injected downstream of Subarea 5. The evaporation pond will treat rejected water produced by the RO treatment system. Solid wastes generated by the evaporation of the concentrate would be stored at a secured disposal warehouse.

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.

(2) Work Schedule

The work schedule of the construction work of the Countermeasures -C is shown in Table 13.17. The construction period is about 12 months.

Table 13.17 Work schedule of the Water Treatment Facility Construction Work of Countermeasures -C

Work items (month)	1	2	3	4	5	6	7	8	9	10	11	12
1. Preparation, mobilization	━											
2. Subarea -4 Pumping wells		━	━	━	━	━	━	━	━	━	━	
3. Subarea -5 Water treatment		━	━	━	━	━	━	━	━	━		
4. Subarea -5 Evaporation ponds				━	━	━	━	━	━	━		
5. Disposal warehouse				━	━	━	━	━	━	━	━	
6. Demobilization												━

(3) Cost Estimation

The total cost for the Countermeasures -C is estimated at US$ 2,500,000 shown as below.

1)	Pumping wells cost at Subarea 5	US$	800,000
2)	Water treatment plant construction cost	US$	1,000,000
3)	Evaporation ponds construction cost	US$	400,000
4)	Disposal warehouse construction cost	US$	300,000
	Total	US$	2,500,000

(Cost includes overhead expense, contingencies and miscellaneous expenses.)

13.5 Cost Estimation

The cost of each assemblage alternatives of the contamination countermeasures is shown as below.

Countermeasures	:	Capital cost	Operation cost (year)
1) Countermeasures -A	:	US$ 11,900,000	US$ 200,000
2) Countermeasures -B	:	US$ 5,300,000	US$ 120,000
3) Countermeasures -C	:	US$ 2,500,000	US$ 120,000

The cost data presented in Tables 13.18 to 13.20 are presented in terms of 2001 US dollars. The net present value of the alternatives represents the amount of 2001 dollars that would need to be set aside today at current interest rates to ensure adequate funds are available to fund the capital construction costs, as well as the future O&M and equipment replacement costs. The present value analysis assumes a discount rate of 5 %; or, in other words, the time value of money is assumed to be 5 %/year. The net present value of the alternatives provides a means of evaluating the costs of various alternatives by comparing a single dollar value, even when the costs are distributed over different time periods and for many years in the future.

The cost data presented in Tables 13.18 to 13.20 assume the O&M activities are carried on for 20 years.

Table 13.18 Cost for Countermeasures -A as Thought to be the Best Overall

- CAPITAL COST -

Subarea	Location	Content	Estimated Capital Cost (US$)	
			Cost	Total
Subarea 1	Trench-2	Grouting at Trench-2	1,700,000	1,700,000
Subarea 3	SP-2	Excavation of soil	1,100,000	1,100,000
Subarea 4	Sagha	Cutoff trench	5,400,000	5,400,000
Subarea 5	Lower stream	Pumping wells	600,000	600,000
Subarea 5	Lower stream	Water treatment facilities	1,500,000	3,100,000
		Evaporation pond	700,000	
		Disposal facility	900,000	
Total				11,900,000

- OPERATION AND MAINTENANCE COST -

Subarea	Location	Content	2002 to 2021 (US$/year)	Total NPV (US$)
Subarea 4	Sagha	Pumping wells	50,000	650,000
Subarea 5	Lower stream	Pumping wells	40,000	520,000
Subarea 5	Lower stream	Water treatment facilities	60,000	1,430,000
		Evaporation pond	40,000	
		Disposal facility	10,000	
Total			200,000	2,600,000

Table 13.19 Cost for Countermeasures -B Thought to be Second best Overall

- CAPITAL COST -

Subarea	Location	Content	Estimated Capital Cost (US$)	
			Cost	Total
Subarea 1	Trench-2	Grouting at Trench-2	1,700,000	1,700,000
Subarea 3	SP-2	Excavation of soil	1,100,000	1,100,000
Subarea 4	Sagha	Pumping wells	800,000	800,000
Subarea 5	Lower stream	Water treatment facilities	1,000,000	1,700,000
		Evaporation pond	400,000	
		Disposal facility	300,000	
Total				5,300,000

- OPERATION AND MAINTENANCE COST -

Subarea	Location	Content	2002 to 2021 (US$/year)	Total NPV (US$)
Subarea 4	Sagha	Pumping wells	50,000	650,000
Subarea 5	Lower stream	Water treatment facilities	40,000	910,000
		Evaporation pond	20,000	
		Disposal facility	10,000	
Total			120,000	1,560,000

Table 13.20 Cost for Countermeasures -C Technically Thought to be Necessary Minimum

- CAPITAL COST -

Subarea	Location	Content	Estimated Capital Cost (US$)	
			Cost	Total
Subarea 4	Sagha	Pumping wells	800,000	800,000
Subarea 5	Lower stream	Water treatment facilities	1,000,000	1,700,000
		Evaporation pond	400,000	
		Disposal facility	300,000	
Total				2,500,000

- OPERATION AND MAINTENANCE COST -

Subarea	Location	Content	2002 to 2021 (US$/year)	Total NPV (US$)
Subarea 4	Sagha	Pumping wells	50,000	650,000
Subarea 5	Lower stream	Water treatment facilities	40,000	910,000
		Evaporation pond	20,000	
		Disposal facility	10,000	
Total			120,000	1,560,000