Table 8.3-5 Assumed unit prices of inverters (DC 24 V, AC 230 V)

Part no.	Capacity (VA)	Unit price in April 2000 (US$/VA)	Unit price in 2005 (US$/VA)	Remarks
49910	200	0.19	**0.14**	0.75
49912	500	0.11	**0.08**	0.75
49914	2000	0.14	**0.10**	0.75
49916	3000	0.14	**0.10**	0.75
50901	3300	0.67	**0.47**	0.63
51016	1500	0.45	**0.31**	0.66
51008	2400	0.38	**0.27**	0.65

○Batteries

Unit prices of batteries are varied as shown below. The shaded assumption of a battery for stand-alone system was used.

Table 8.3-6 Assumed unit prices of batteries

Type	Part no.	Voltage (V)	Capacity (Ah)	Unit price in April 2000 (US$/Ah)	Unit price in 2005 (US$/Ah)	Remarks
Dry	42192	12	48	1.45	1.05	0.67
	42191	12	72	1.55	1.09	0.72
	42193	12	85	1.37	0.96	0.64
	42189	12	105	1.24	0.86	0.63
	42198	12	255	1.18	0.82	0.67
	42202	6	220	1.26	0.88	0.72
Wet	40426	6	250	0.48	0.34	0.72
	40427	12	130	0.54	**0.38**	0.72
	40428	6	400	0.77	0.54	0.72
	40446	6	682	1.11	0.78	0.69
	40446	6	854	1.11	0.78	0.69
	40465	6	1025	1.12	0.78	0.69

Notes) 1. Ah is V-based.
2. Part no. 40426 is for stand-alone use.
3. Part no. 40446 is guaranteed to have 10 years of useful life.

○Breakdown of installation cost

As for the installation costs of the individual and mini-centralized PV systems, assumption of unit price was made based on the actual procurement cost of this project in local market and the following table.

Table 8.3-5 Assumed unit prices of inverters (DC 24 V, AC 230 V)

Part no.	Capacity (VA)	Unit price in April 2000 (US$/VA)	Unit price in 2005 (US$/VA)	Remarks
49910	200	0.19	0.14	0.75
49912	500	0.11	0.08	0.75
49914	2000	0.14	0.10	0.75
49916	3000	0.14	0.10	0.75
50901	3300	0.67	0.47	0.63
51016	1500	0.45	0.31	0.66
51008	2400	0.38	0.27	0.65

○Batteries

Unit prices of batteries are varied as shown below. The shaded assumption of a battery for stand-alone system was used.

Table 8.3-6 Assumed unit prices of batteries

Type	Part no.	Voltage (V)	Capacity (Ah)	Unit price in April 2000 (US$/Ah)	Unit price in 2005 (US$/Ah)	Remarks
Dry	42192	12	48	1.45	1.05	0.67
	42191	12	72	1.55	1.09	0.72
	42193	12	85	1.37	0.96	0.64
	42189	12	105	1.24	0.86	0.63
	42198	12	255	1.18	0.82	0.67
	42202	6	220	1.26	0.88	0.72
Wet	40426	6	250	0.48	0.34	0.72
	40427	12	130	0.54	0.38	0.72
	40428	6	400	0.77	0.54	0.72
	40446	6	682	1.11	0.78	0.69
	40446	6	854	1.11	0.78	0.69
	40465	6	1025	1.12	0.78	0.69

Notes) 1. Ah is V-based.

2. Part no. 40426 is for stand-alone use.

3. Part no. 40446 is guaranteed to have 10 years of useful life.

○Breakdown of installation cost

As for the installation costs of the individual and mini-centralized PV systems, assumption of unit price was made based on the actual procurement cost of this project in local market and the following table.

Table 8.3-7 Assumed cost breakdown of individual systems installation (US$)

Capacity (W)	60	120	240	360	480
Array structure	10	16	30	42	75
Bolts, etc.	3	4	5	6	10
Concrete	9	9	9	9	18
Cable	27	30	34	38	49
Battery	3	3	3	3	3
Assembly	13	14	14	15	16
Wiring	1	1	2	2	2
Miscellaneous	0	0	0	0	4
Total	66	77	97	114	178

Table 8.3-8 Assumed cost breakdown of mini-centralized systems installation (US$)

Capacity (W)	960	2,040	3,000
Array structure	150	300	449
Bolts, etc.	21	42	63
Concrete	55	110	164
Cable	458	914	1372
Battery	2	18	35
Assembly	30	48	63
Wiring	2	4	6
Underground cable	42	84	127
Miscellaneous	0	0	1
Total	759	1,520	2,279

c. Conditions for calculation of generating cost

Generating costs of respective PV systems were calculated according to the following conditions:

1) Interest rate: Interest rate of long-term loan (6.5%) to the Ministry of Electricity from Arab Development Bank

2) Rate of inflation: Not considered.
(For reference, case of 3% was considered.)

3) Useful life of system: Based on PV module life of 20 years.
(For reference, case of 30 years was considered.)

4) Other particulars

- Administrative expense of operation and maintenance: 1% of installation cost.
- Administrative expense of the Ministry of Electricity: 1% of installation cost.
- Distribution loss : 8%

d. Assumption of power demands

On the actual data of operation obtained by the various demonstrated systems, power demands were estimated for various kinds of electric appliances, which is expected to use. As a result, the capacity factor of individual PV systems was estimated to be about 6% in yearly average for the nighttime. The capacity factor of individual PV systems for daytime was estimated to be about 7%; use of TV improved it a little. As for the mini-centralized PV systems, power generated is expected to use for pumping in daytime, which amounts to about 3%. Thus the annual capacity factor is estimated to improve up to 9%.

$$\text{Capacity factor} = \frac{\text{Power generated by the system}}{\text{Rated output (W)} \times 24\text{(hr)} \times \text{Operating days (day)}} \times 100\ (\%)$$

e. Results of calculation of generating costs for PV systems

Costs of individual and mini-centralized PV systems, which were calculated on the above-mentioned assumptions, are shown in the table below. Batteries have large factors on operation of PV systems. Hence the following cases were assumed:

- Case of conventional overseas batteries for PV system : useful life : 5 years.
- Case of overseas seal type batteries with guaranteed useful life : 10 years
- Case of improved batteries made in Syria

As for mini-centralized PV systems, the following two cases were assumed:

- Average line length from PV system station to respective houses : 30 m.
- Average line length : 60 m.

Table 8.3-9 Cost of individual PV system

1)Battery : only for PV, Life=5 Years

	60W	120W	240W	360W	480W	Remarks
Module (US$)	136	262	523	785	1,046	
Controller (US$)	17	34	67	101	135	
Inverter (US$)	0	0	0	0	0	
Battery (US$)	17	35	70	105	139	
Transportation (US$)	9	17	34	51	68	
Material cost (US$)	50	50	78	95	152	Enumerated
Labor cost (US$)	17	17	19	20	25	Enumerated
Total (US$)	246	414	791	1,156	1,565	
Demand (kWh)	53	105	210	315	420	
Generating cost						
20 Years (US$/kWh)	0.540	0.466	0.448	0.438	0.444	No inflation
30 Years (US$/kWh)	0.483	0.419	0.404	0.396	0.400	No inflation
Inflation =3% (US$/kWh)	0.576	0.499	0.481	0.471	0.477	

2) Battery : Seal, Life=10 Years

	60W	120W	240W	360W	480W	Remarks
Module (US$)	136	262	523	785	1,046	
Controller (US$)	17	34	67	101	135	
Inverter (US$)	0	0	0	0	0	
Battery (US$)	25	80	160	240	321	
Transportation (US$)	9	20	39	57	77	
Material cost (US$)	50	59	78	95	152	Enumerated
Labor cost (US$)	17	18	19	20	25	Enumerated
Total (US$)	253	472	886	1,299	1,756	
Demand (kWh)	53	105	210	315	420	
Generating cost						
20 Years (US$/kWh)	0.640	0.507	0.480	0.470	0.476	No inflation
30 Years (US$/kWh)	0.583	0.460	0.517	0.428	0.433	No inflation
Inflation =3% (US$/kWh)	0.702	0.540	0.511	0.501	0.507	

3) Battery : Made in Syria、 Life=3 Years

	60W	120W	240W	360W	480W	Remarks
Module (US$)	136	262	523	785	1,046	
Controller (US$)	17	34	67	101	135	
Inverter (US$)	0	0	0	0	0	
Battery (US$)	25	50	100	151	201	
Transportation (US$)	9	16	32	47	63	
Material cost (US$)	50	59	78	95	152	Enumerated
Labor cost (US$)	17	18	19	20	25	Enumerated
Total (US$)	253	439	820	1,199	1,622	
Demand (kWh)	53	105	210	315	420	
Generating cost						
20 Years (US$/kWh)	0.640	0.575	0.547	0.538	0.543	No inflation
30 Years (US$/kWh)	0.583	0.527	0.504	0.495	0.602	No inflation
Inflation =3% (US$/kWh)	0.702	0.635	0.607	0.596	0.500	

Table 8.3-10 Cost of mini centralized type PV system

1) Battery : Only for PV, Life = 5 Years

	Mean distance=30m			Mean distance=60m			Remarks
	960W	**2,040W**	**3,000W**	**960W**	**2,040W**	**3,000W**	
Module (US$)	2,093	4,447	6,540	2,093	4,447	6,540	
Controller (US$)	102	218	320	102	218	320	
Inverter (US$)	161	343	504	161	343	504	
Battery (US$)	279	592	871	279	592	871	
Transportation (US$)	139	295	435	144	304	447	
Material cost (US$)	681	1,366	2,048	1,105	2,219	3,328	Enumerated
Labor cost (US$)	76	154	232	76	154	232	Enumerated
Total (US$)	3,532	7,415	10,950	3,960	8,277	12,243	
Demand (kWh)	841	1,787	2,628	841	1,787	2,628	
Generating cost							
20 Years ($/kWh)	0.491	0.486	0.488	0.543	0.535	0.537	No inflation
30 Years ($/kWh)	0.441	0.437	0.438	0.485	0.479	0.481	No inflation
Inflation =3% ($/kWh)	0.526	0.520	0.522	0.579	0.571	0.573	

2)Battery : Seal, Life = 10 Years

	Mean distance=30m			Mean distance=60m			Remarks
	960W	**2,040W**	**3,000W**	**960W**	**2,040W**	**3,000W**	
Module (US$)	2,093	4,447	6,540	2,093	4,447	6,540	
Controller (US$)	102	218	320	102	218	320	
Inverter (US$)	161	343	504	161	343	504	
Battery (US$)	641	1,363	2,004	641	1,363	2,004	
Transportation (US$)	157	334	491	157	342	504	
Material cost (US$)	681	1,366	2,048	1,105	2,219	3,328	Enumerated
Labor cost (US$)	76	154	232	76	154	232	Enumerated
Total (US$)	3,912	5,224	12,139	4,335	9,085	13,432	
Electric energy (kWh)	841	1,787	2,628	841	1,787	2,682	
Generating cost							
20 Years ($/kWh)	0.523	0.518	0.520	0.572	0.567	0.570	No inflation
30 Years ($/kWh)	0.473	0.469	0.471	0.515	0.511	0.513	No inflation
Inflation =3% ($/kWh)	0.556	0.551	0.553	0.606	0.601	0.604	

3) Battery : Made in Syria, Life = 3 Years

	Mean distance=30m			Mean distance=60m			Remarks
	960W	**2,040W**	**3,000W**	**960W**	**2,040W**	**3,000W**	
Module (US$)	2,093	4,447	6,540	2,093	4,447	6,540	
Controller (US$)	102	218	320	102	218	320	
Inverter (US$)	161	343	504	161	343	504	
Battery (US$)	402	854	1,256	402	854	1,256	
Transportation (US$)	129	274	404	129	283	416	
Material cost (US$)	681	1,366	2,048	1,105	2,219	3,328	Enumerated
Labor cost (US$)	76	154	232	76	154	232	Enumerated
Total (US$)	3,645	7,655	11,303	4,068	8,517	12,596	
Electric energy (kWh)	841	1,787	2,628	841	1,787	2,628	
Generating cost							
20 Years ($/kWh)	0.591	0.586	0.588	0.640	0.635	0.637	No inflation
30 Years ($/kWh)	0.541	0.537	0.648	0.582	0.578	0.581	No inflation
Inflation = 3 % ($/kWh)	0.651	0.646	0.538	0.701	0.696	0.699	

f. Summary of the results

The generating costs of individual and mini-centralized PV systems were calculated. The results are summarized as follows:

1) Individual PV systems

Individual PV systems of five different scales, ranging from 60W to 480W, were examined. The findings were as follows:

- When the useful life is 20 years and the inflation rate is 0%, if the overseas batteries for PV system are used, the generating cost of 60W PV system is US$0.54/kWh. When the system size gets larger, the generating cost shows a tendency to decrease. However, when system scale is 480W or over, the trend of generating cost gets larger. Generally, PV system does not have scale merits. Tendency to decrease is due to the price characteristics of PV array structure. This structure is made of steel, and the same structure can be used for systems of various sizes up to a certain size.
- Under the conditions mentioned above, if the useful life of PV module is extended from 20 years to 30 years, generating cost will decrease by about 10%. Useful life of PV module depends on the circumstances. For example, some PV modules that have been used more than 20 years in universities etc., in Japan show no deterioration and are operable. In view of such actual performance, this extension to 30 years is feasible.
- After installation of PV system, the largest task is a replacement of its components. Replacement of batteries is a relatively large factor. Hence use of batteries that are more expensive but longer useful life of ten years was examined. The resulted generating cost, however, was found to be higher by about ten percents. As batteries are used in various fields, technical improvements can be expected in future, which will be resulted in price drops and extended useful life.
- Use of improved Syrian batteries is an important issue in promoting expansion of PV system in Syria. When batteries, which are expected cost of US$0.782/Ah and useful life of three years are used, generating cost is about 20% higher than that of overseas batteries case.

2) Mini-centralized PV systems

Generating costs of mini-centralized PV systems of three different scales, ranging from 960W to 3000W, were calculated. Results were as follows. The costs were calculated for two cases; one is average line length of adjacent houses of 30 m, and the other is average line length of 60m.

- When average line length is 30m, generating costs of mini-centralized PV systems are comparable to those of individual PV systems.
- When average line length is doubled to 60m, generating costs increase about 10% in comparison with a case of 30m.
- As for the batteries, the results of analysis using overseas batteries having 10 years life and Syrian batteries show similar trends as those of individual PV systems.

3) Comparison between individual PV systems and mini-centralized PV systems

In rural area, when distances among houses are long (scattered), individual PV system has advantage to introduce. However, distance is not more than 60m, mini-centralized PV systems has advantage on the following grounds.

- Mini-centralized PV systems use AC 220V. Thus conventional electric appliances are available to use. On the other hand, individual PV systems accept only DC 12V appliances. Such appliances are special devices and may be difficult to purchase in local market.

④Cost comparison between PV systems and grid extension

In rural area having un-electrified villages, it is desirable to use PV systems to complement grid extension rather than to compete with it. Thus PV systems should be used to reduce total cost of electrification plan of the Ministry by substituting more costly grid extension. To evaluate this point clearly, cost comparison was made based on construction costs of PEDEEE and other data.

In supplying electricity by grid lines in Syria, it is a usual style to extend transmission lines of 20kV to the village, install a pole transformer near the village, drop the voltage to 220V, and supply electricity through distribution lines of three-phase four-wire system.

a. Breakdown of installation cost of grid extension

Breakdown of the construction cost of grid lines by PEDEEE was assumed as follows:

Table 8.3-11 Installation cost of grid extension

Item	Unit	Price	Remarks
Transmission line	US$/km	20,000	20 kV
Distribution line	US$/km	12,000	200V, three-phase four-wire system
Transformer	US$/unit	6,900 (25kVA)	
Transformer	US$/unit	7,600 (50kVA)	
Lead-in wire	US$/house	20	
Electricity cost	US$/kWh	0.053	At the exit of transmission line
Distribution loss	%	8	
Transmission loss	%	4	
Power factor	%	85	
Repair cost	%	1	(of total construction cost)
Overhead cost (personnel expenses, etc.)	%	1	(of total construction cost)

b. Comparison of generating cost between grid extension and PV system

The generating cost of PV system is about US$0.6/kWh as calculated above. On the other hand, the generating cost of grid extension was calculated using a parameter of length of grid extension, number of houses and load factor etc. Also, the above-mentioned assumption is taken into account. From a viewpoint of US$0.6/kWh, PV system and grid extension was compared and result is shown in Table 8.3-12 and 8.3-13.

- Even when distance from existing grid line to the village is close, if the number of households in the village is small, the generating cost by grid extension will be expensive. If distance gets longer, generating cost will increase in proportion to distance.
- When distance to the village is 5 km, if the number of customer is about 40 and their power demands are small, generating cost by grid extension cannot be competitive to that of PV system.
- When load factor of grid gets larger, when power demands of customers get larger, generating cost by grid extension naturally decrease. However, in case of power for residence, load factor is low and rare to exceed 30%.

- As a result, in electrification of un-electrified villages, if the number of households is not large, or if power demands of customers are not large, generating cost by grid extension will be high and cannot be economical.
- When the number of households in village is small and distance from existing grid lines to the village is long, introduction of PV system is more advantageous than grid extension.

▨ Advantage for PV system

Table 8.3-12 Power cost by grid supply (Life = 20 years, Increase = 0%)

(1) Demand 100W

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

(2) Demand 300W

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	0.56	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	0.57	▨	▨	▨	▨
	50	0.48	▨	▨	▨	▨
	60	0.43	▨	▨	▨	▨
	70	0.39	▨	▨	▨	▨

(3) Demand 500W

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	0.52	▨	▨	▨	▨
	50	0.44	▨	▨	▨	▨
	60	0.39	▨	▨	▨	▨
	70	0.37	0.57	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	0.45	▨	▨	▨	▨
	40	0.36	0.60	▨	▨	▨
	50	0.31	0.50	▨	▨	▨
	60	0.28	0.44	0.59	▨	▨
	70	0.27	0.40	0.53	▨	▨

☐ Advantage for PV system

Table 8.3-12 Power cost by grid supply (Life = 20 years, Increase = 0%)

(1) Demand 100W

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	50.45	96.72	143.01	189.31	235.60
	6	25.67	48.82	71.97	95.11	118.26
	9	17.46	32.85	48.28	63.71	79.14
	12	13.30	24.87	36.44	48.02	59.59
	15	10.82	20.08	29.34	38.60	47.85
	30	5.87	10.50	15.13	19.76	24.39
	40	4.63	8.10	11.58	15.05	18.52
	50	3.89	6.67	9.44	12.22	15.00
	60	3.39	5.71	8.02	10.34	12.65
	70	3.04	5.02	7.01	8.99	10.98

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	25.24	48.39	71.54	94.68	1117.83
	6	12.87	24.44	36.01	47.58	59.16
	9	8.74	16.46	24.17	31.89	39.60
	12	6.68	12.46	18.25	24.04	29.82
	15	5.44	10.07	14.70	19.33	23.96
	30	2.96	5.28	7.59	9.91	12.22
	40	2.34	4.08	5.82	7.55	9.29
	50	1.97	3.36	4.75	6.14	7.53
	60	1.73	2.88	4.04	5.20	6.36
	70	1.55	2.54	3.53	4.52	5.52

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	16.85	32.28	47.71	63.14	78.57
	6	8.60	16.31	24.03	31.74	39.46
	9	5.85	10.99	16.13	21.28	26.42
	12	4.47	8.33	12.19	16.04	19.90
	15	3.65	6.73	9.82	12.90	15.99
	30	2.00	3.54	5.08	6.62	8.17
	40	1.58	2.74	3.90	5.05	6.21
	50	1.33	2.26	3.19	4.11	5.04
	60	1.17	1.94	2.71	3.48	4.26
	70	1.05	1.71	2.37	3.04	3.70

(2) Demand 300W

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	16.85	32.38	47.71	63.14	78.57
	6	8.60	16.31	24.03	31.74	39.46
	9	5.85	10.99	16.13	21.28	26.42
	12	4.47	8.33	12.19	16.04	19.90
	15	3.65	6.73	9.82	12.90	15.99
	30	22.00	3.54	5.08	6.62	8.17
	40	1.58	2.74	3.90	5.50	6.21
	50	1.33	2.26	3.19	4.11	5.04
	60	1.17	1.95	2.72	3.49	4.26
	70	1.06	1.72	2.38	3.04	3.70

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	8.45	16.17	23.88	31.60	39.31
	6	4.33	8.18	12.04	15.90	19.76
	9	2.95	5.52	8.10	10.67	13.24
	12	2.26	4.19	6.12	8.05	9.98
	15	1.85	3.39	4.94	6.48	8.02
	30	1.03	1.80	2.57	3.34	4.11
	40	0.82	1.40	1.98	2.56	3.13
	50	0.70	1.16	1.62	2.08	2.55
	60	0.62	1.00	1.39	1.77	2.16
	70	0.56	0.89	1.22	1.55	1.88

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	5.65	10.80	15.94	21.09	26.23
	6	2.90	5.48	8.05	10.62	13.19
	9	1.99	3.70	5.42	7.13	8.85
	12	1.53	2.81	4.10	5.39	6.67
	15	1.25	2.28	3.31	4.34	5.37
	30	0.70	1.22	1.73	2.25	2.76
	40	0.57	0.95	1.34	1.72	2.11
	50	0.48	0.79	1.10	1.41	1.72
	60	0.43	0.69	0.94	1.20	1.46
	70	0.39	0.61	0.83	1.05	1.27

(3) Demand 500W

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	10.13	19.39	28.65	37.91	47.17
	6	5.18	9.81	14.44	19.07	23.70
	9	3.53	6.62	9.70	12.79	15.88
	12	2.71	5.02	7.33	9.65	11.96
	15	2.21	4.06	5.91	7.77	9.62
	30	1.22	2.15	3.07	4.00	4.92
	40	0.98	1.67	2.37	3.06	3.75
	50	0.83	1.38	1.94	2.49	3.05
	60	0.73	1.19	1.65	2.12	2.58
	70	0.68	1.08	1.48	1.87	2.27

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	5.09	9.72	14.35	18.98	23.61
	6	2.62	4.93	7.25	9.56	11.88
	9	1.79	3.34	4.88	6.42	7.97
	12	1.38	2.54	3.70	4.85	6.01
	15	1.13	2.06	2.99	3.91	4.84
	30	0.64	1.10	1.56	2.03	2.49
	40	0.52	0.86	1.21	1.56	1.91
	50	0.44	0.72	1.00	1.28	1.55
	60	0.39	0.62	0.86	1.09	1.32
	70	0.37	0.57	0.77	0.97	1.16

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	3.42	6.50	9.59	12.67	15.76
	6	1.77	3.31	4.85	6.39	7.94
	9	1.22	2.24	3.27	4.30	5.33
	12	0.94	1.71	2.48	3.25	4.03
	15	0.78	1.39	2.01	2.63	3.24
	30	0.45	0.75	1.06	1.37	1.68
	40	0.36	0.60	0.83	1.06	1.29
	50	0.31	0.50	0.68	0.87	1.05
	60	0.28	0.44	0.59	0.74	0.90
	70	0.27	0.40	0.53	0.66	0.80

▨ Advantage for PV system

Table 8.3-13 Power cost by grid supply (Demand 500W)

(1) Life = 20 years, Increase = 0%

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	0.52	▨	▨	▨	▨
	50	0.44	▨	▨	▨	▨
	60	0.39	▨	▨	▨	▨
	70	0.37	0.57	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	0.45	▨	▨	▨	▨
	40	0.36	0.60	▨	▨	▨
	50	0.31	0.50	▨	▨	▨
	60	0.28	0.44	0.59	▨	▨
	70	0.27	0.40	0.53	▨	▨

(2) Life = 20 years, Increase = 3%

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	▨	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	0.54	▨	▨	▨	▨
	50	0.46	▨	▨	▨	▨
	60	0.41	▨	▨	▨	▨
	70	0.39	0.60	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		Distance [km]				
(30%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	0.47	▨	▨	▨	▨
	40	0.38	▨	▨	▨	▨
	50	0.33	0.52	▨	▨	▨
	60	0.29	0.46	▨	▨	▨
	70	0.28	0.42	0.56	▨	▨

(3) Life = 30 years, Increase = 0%

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(10%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	▨	▨	▨	▨	▨
	40	▨	▨	▨	▨	▨
	50	▨	▨	▨	▨	▨
	60	▨	▨	▨	▨	▨
	70	0.60	▨	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(20%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	0.56	▨	▨	▨	▨
	40	0.46	▨	▨	▨	▨
	50	0.39	▨	▨	▨	▨
	60	0.35	0.55	▨	▨	▨
	70	0.33	0.50	▨	▨	▨

Load factor / year	No. of house	Distance [km]				
		5	10	15	20	25
(30%)	3	▨	▨	▨	▨	▨
	6	▨	▨	▨	▨	▨
	9	▨	▨	▨	▨	▨
	12	▨	▨	▨	▨	▨
	15	▨	▨	▨	▨	▨
	30	0.40	▨	▨	▨	▨
	40	0.32	0.53	▨	▨	▨
	50	0.28	0.44	0.44	▨	▨
	60	0.25	0.39	0.39	▨	▨
	70	0.24	0.36	0.36	0.59	▨ 0.70

☐ Advantage for PV system

Table 8.3-13 Power cost by grid supply (Demand 500W)

(1) Life = 20 years, Increase = 0%

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (10%)	3	10.13	19.39	28.65	37.91	47.17
	6	5.18	9.81	14.44	19.07	23.70
	9	3.53	6.62	9.70	12.79	15.88
	12	2.71	5.02	7.33	9.65	11.96
	15	2.21	4.06	5.91	7.77	9.62
	30	1.22	2.15	3.07	4.00	4.92
	40	0.98	1.67	2.37	3.06	3.75
	50	0.83	1.38	1.94	2.49	3.05
	60	0.73	1.19	1.65	2.12	2.58
	70	0.68	1.08	1.48	1.87	2.27

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (20%)	3	5.09	9.72	14.35	18.98	23.61
	6	2.62	4.93	7.25	9.56	11.88
	9	1.79	3.34	4.88	6.42	7.97
	12	1.38	2.54	3.70	4.85	6.01
	15	1.13	2.06	2.99	3.91	4.84
	30	0.64	1.10	1.56	2.03	2.49
	40	0.52	0.86	1.21	1.56	1.91
	50	0.44	0.72	1.00	1.28	1.55
	60	0.39	0.62	0.86	1.09	1.32
	70	0.37	0.57	0.77	0.97	1.16

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (30%)	3	3.42	6.50	9.59	12.67	15.76
	6	1.77	3.31	4.85	6.39	7.94
	9	1.22	2.24	3.27	4.30	5.33
	12	0.94	1.71	2.48	3.25	4.03
	15	0.78	1.39	2.01	2.63	3.24
	30	0.45	0.75	1.06	1.37	1.68
	40	0.36	0.60	0.83	1.06	1.29
	50	0.31	0.50	0.68	0.87	1.05
	60	0.28	0.44	0.59	0.74	0.90
	70	0.27	0.40	0.53	0.66	0.80

(2) Life = 20 years, Increase = 3%

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (10%)	3	10.68	20.44	30.21	39.97	49.73
	6	5.46	10.34	15.22	20.10	24.99
	9	3.72	6.97	10.23	13.48	16.74
	12	2.85	5.29	7.73	10.17	12.61
	15	2.33	4.28	6.23	8.19	10.14
	30	1.28	2.26	3.24	4.21	5.19
	40	1.03	1.76	2.49	3.22	3.96
	50	0.87	1.46	2.04	2.63	3.21
	60	0.76	1.25	1.74	2.23	2.72
	70	0.72	1.14	1.56	1.97	2.39

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (20%)	3	5.37	10.25	15.13	20.01	24.90
	6	2.76	5.20	7.64	10.08	12.52
	9	1.89	3.52	5.14	6.77	8.40
	12	1.45	2.67	3.89	5.11	6.34
	15	1.19	2.17	3.15	4.12	5.10
	30	0.67	1.16	1.65	2.13	2.62
	40	0.54	0.91	1.27	1.64	2.01
	50	0.46	0.76	1.05	1.34	1.64
	60	0.41	0.66	0.90	1.14	1.39
	70	0.39	0.60	0.81	1.02	1.22

	No. of house	Distance [km]				
		Distance [km]				
Load factor / year (30%)	3	3.60	6.85	10.11	13.36	16.62
	6	1.86	3.49	5.11	6.74	8.37
	9	1.28	2.36	3.45	4.53	5.62
	12	0.99	1.80	2.62	3.43	4.24
	15	0.81	1.47	2.12	2.77	3.42
	30	0.47	0.79	1.12	1.44	1.77
	40	0.38	0.62	0.87	1.11	1.36
	50	0.33	0.52	0.72	0.91	1.11
	60	0.29	0.46	0.62	0.78	0.94
	70	0.28	0.42	0.56	0.70	0.84

(3) Life = 30 years, Increase = 0%

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (10%)	3	8.84	16.92	24.99	33.06	41.13
	6	4.53	8.56	12.60	16.63	20.67
	9	3.09	5.78	8.47	11.16	13.85
	12	2.37	4.38	6.40	8.42	10.44
	15	1.93	3.55	5.16	6.78	8.39
	30	1.07	1.88	2.69	3.49	4.30
	40	0.86	1.46	2.07	2.68	3.28
	50	0.73	1.21	1.70	2.18	2.67
	60	0.64	1.05	1.45	1.85	2.26
	70	0.60	0.95	1.30	1.64	1.99

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (20%)	3	4.45	8.49	12.52	16.56	20.60
	6	2.29	4.31	6.33	8.35	10.36
	9	1.57	2.92	4.26	5.61	6.95
	12	1.21	2.22	3.23	4.24	5.25
	15	1.00	1.80	2.61	3.42	4.23
	30	0.56	0.97	1.37	1.78	2.18
	40	0.46	0.76	1.06	1.37	1.67
	50	0.39	0.64	0.88	1.12	1.36
	60	0.35	0.55	0.75	0.96	1.16
	70	0.33	0.50	0.68	0.85	1.02

	No. of house	Distance [km]				
		5	10	15	20	25
Load factor / year (30%)	3	2.99	5.68	8.37	11.06	13.75
	6	1.55	2.89	4.24	5.58	6.93
	9	1.07	1.96	2.86	3.76	4.66
	12	0.83	1.50	2.17	2.85	3.52
	15	0.68	1.22	1.76	2.30	2.84
	30	0.40	0.66	0.93	1.20	1.47
	40	0.32	0.53	0.73	0.93	1.13
	50	0.28	0.44	0.41	0.77	0.93
	60	0.25	0.39	0.39	0.66	0.79
	70	0.24	0.36	0.36	0.59	0.70

⑤Cost comparison between PV systems and diesel generators

Diesel generator is commonly considered to be an alternative power source to PV system in rural areas. Minimal capacity of diesel generators available in local market of Syria is 5kW. A diesel generator of this capacity was compared with PV systems.

a. Characteristics of diesel generator

Particulars of diesel generator are shown in Table 8.3-14. Method of power supply from generator to each household is assumed to use same as conventional distribution line. This construction cost is set at US$12,000/km. Mean distance between generator and household is set at 50m. Cost of lead-in wire is set at US$20/household. The useful life of distribution line is set at 20 years. This also applies when the calculation period is 30 years. Distribution loss is set at 8%, which is same as conventional grid system.

Table 8.3-14 Assumption of diesel generator

Item	Unit	Price	Remark
Diesel generator	US$/kW	550	
Fuel price	US$/ℓ	0.14	
Lubricating oil	US$/kg	1.3	
Installation work	US$	20 % of the diesel generator price	
Fuel consumption	US$/kWh	0.4	Thermal efficiency: 21.5 %
Lubricating oil consumption	g/kWh	3	
Useful life	Year	10	

b. Generating Costs

The generating cost of diesel generator varies as shown below with parameters, namely, supply power, mean power consumption of each house and annual load factor:

Table 8.3-15 Generating costs of diesel generator

(1) Useful life: 20 years Interest rate: 6.5% Inflation : 0% (Unit :US$/kWh)

Power	Load factor	Demand (kWh/household · year)	Number of households supplied with electricity					
			3	6	9	12	15	18
100 W	10%	87.6						
	20%	175.2						
200 W	10%	175.2						
	20%	350.4			0.45	0.40	0.36	0.34
300 W	10%	262.8			0.58	0.51	0.46	0.43
	20%	525.6		0.40	0.32	0.29	0.26	0.25
500 W	10%	438.0		0.47	0.38	0.33	0.30	0.27
	20%	876.0	0.41	0.27	0.22	0.20	0.18	0.17

(2) Useful life: 20 years Interest rate: 6.5% Inflation : 3% (Unit :US$/kWh)

Power	Load factor	Demand (kWh/household · year)	Number of households supplied with electricity					
			3	6	9	12	15	18
100 W	10%	87.6						
	20%	175.2						
200 W	10%	175.2						
	20%	350.4			0.50	0.43	0.40	0.37
300 W	10%	262.8			0.64	0.55	0.50	0.46
	20%	525.6		0.45	0.36	0.32	0.29	0.27
500 W	10%	438.0		0.52	0.42	0.36	0.33	0.31
	20%	876.0	0.46	0.30	0.25	0.22	0.21	0.20

(3) Useful life: 30 years Interest rate: 6.5% Inflation : 0%

Same as Table 8.3-15(1).

c. Generating cost comparison with PV systems

PV system is advantageous in shaded areas. Diesel generation is advantageous in other areas. Generating cost of diesel is decreasing when power generated is getting large because fuel cost is low in breakdown of generating cost of diesel. Generating costs of diesel do not decrease even if the number of households is increased in areas where power demand is low. This is because additional costs of distribution line and lead-in wire are required.

However, in case of introduction of diesel generation, the following attention is needed.

- Diesel generation is very rare to find supply power in un-electrified villages.
- Fuel transportation, noise and atmosphere pollution by exhaust gas etc.,

Table 8.3-15 Generating costs of diesel generator

(1) Useful life: 20 years Interest rate: 6.5% Inflation : 0% (Unit :US$/kWh)

Power	Load factor	Demand (kWh/household・year)	Number of households supplied with electricity					
			3	6	9	12	15	18
100 W	10%	87.6	**3.48**	**2.08**	**1.62**	**1.39**	**1.25**	**1.15**
	20%	175.2	**1.77**	**1.07**	**0.84**	**0.73**	**0.66**	**0.61**
200 W	10%	175.2	**1.77**	**1.07**	**0.84**	**0.73**	**0.66**	**0.61**
	20%	350.4	**0.92**	**0.57**	0.45	0.40	0.36	0.34
300 W	10%	262.8	**1.20**	**0.74**	0.58	0.51	0.46	0.43
	20%	525.6	**0.63**	0.40	0.32	0.29	0.26	0.25
500 W	10%	438.0	**0.75**	0.47	0.38	0.33	0.30	0.27
	20%	876.0	0.41	0.27	0.22	0.20	0.18	0.17

(2) Useful life: 20 years Interest rate: 6.5% Inflation : 3% (Unit :US$/kWh)

Power	Load factor	Demand (kWh/household・year)	Number of households supplied with electricity					
			3	6	9	12	15	18
100 W	10%	87.6	**3.82**	**2.26**	**1.74**	**1.48**	**1.33**	**1.22**
	20%	175.2	**1.95**	**1.17**	**0.91**	**0.78**	**0.71**	**0.65**
200 W	10%	175.2	**1.95**	**1.17**	**0.91**	**0.78**	**0.71**	**0.65**
	20%	350.4	**1.02**	**0.63**	0.50	0.43	0.40	0.37
300 W	10%	262.8	**1.33**	**0.81**	0.64	0.55	0.50	0.46
	20%	525.6	**0.71**	0.45	0.36	0.32	0.29	0.27
500 W	10%	438.0	**0.83**	0.52	0.42	0.36	0.33	0.31
	20%	876.0	0.46	0.30	0.25	0.22	0.21	0.20

(3) Useful life: 30 years Interest rate: 6.5% Inflation : 0%

Same as Table 8.3-15(1).

c. Generating cost comparison with PV systems

PV system is advantageous in shaded areas. Diesel generation is advantageous in other areas. Generating cost of diesel is decreasing when power generated is getting large because fuel cost is low in breakdown of generating cost of diesel. Generating costs of diesel do not decrease even if the number of households is increased in areas where power demand is low. This is because additional costs of distribution line and lead-in wire are required.

However, in case of introduction of diesel generation, the following attention is needed.

- Diesel generation is very rare to find supply power in un-electrified villages.
- Fuel transportation, noise and atmosphere pollution by exhaust gas etc.,

d. Situation of PV systems and future utilization

Generating costs of PV systems and their alternative systems such as diesel generators and grid extension were compared. Based on results of economic comparison, the findings were as follows:

- Generally, supply of electricity by diesel generators is very cheap in comparison with other systems.
- As generating costs of PV systems are not restricted by the number of houses, PV systems are more economical than diesel generators when the number of houses is small.
- Grid extension is comparable to other supply systems only when distance of extension is 5 km or less and the number of houses is about 40 or more.

According to a comprehensive evaluation, which includes technical and economical aspect and actual conditions of un-electrified villages of Syria, we conclude that PV systems are expanded based on the following findings.

- When the number of houses is small and capacity factor is low, generation cost of diesel system is higher than that of PV systems.
- Number of households in un-electrified villages in Syria is about twenty or under in many cases. Moreover, in recent years, these houses are away from grid lines, and are scattered, with two or three households being together.
- Hence PV systems are optimal to electrify such villages. One advantage of PV systems is that their needs of maintenance are small.
- Useful life of diesel generators is assumed to be ten years. However, if maintenance is not adequate, serious failures may happen. This is risky and procurement of fuel and operation management is complicate.
- In future, even if grid lines are extended to a village using PV systems, these PV systems may be utilized to reinstall in another rural area or these systems may be connected to the grid. In short, these resources can be used efficiently.

(3) Examination of water pumping costs by surplus power of mini-centralized PV systems

As for individual PV systems, its surplus power after charging batteries during the day is small. Hence its applications are limited. On the other hand, as for mini-centralized PV systems of which capacities are rather large, a substantial amount of surplus power is generated. In Syria where precipitation is small, securing water resources is very important. Hence surplus power of mini-centralized PV systems is utilized to pump up water more efficiently, and, enhance livelihood of villagers and reduce costs. In the case of water pumping with surplus power, costs of PV systems are covered by supply of electricity for lighting, TV, etc. Therefore, additional costs for water supply facilities such as pumps and tanks are needed. In the following, water cost was examined.

①Method of investigation

a. Analysis of surplus power by mini-centralized system

In the mentioned above, mini-centralized systems of 1～3kW were selected for electrification and examined. Here daily mean surplus power for water pumping was examined, by month, of 2～3kW mini-centralized systems. The results are shown in Table 8.3-16.

Table 8.3-16 Surplus power by mini-centralized PV system (Wh/day)

Scale	No. of Houses	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
2kW	6	0	0	1233	1233	1850	1850	1850	1850	1233	1233	0	0
	9	0	0	617	1233	1233	1233	1850	1850	1233	617	0	0
	12	0	0	617	1233	1233	1233	1233	1233	1233	617	0	0
3kW	9	0	0	1833	2750	2750	2750	2750	2750	2750	2750	0	0
	12	0	0	1833	1833	1833	2750	2750	1833	1833	917	0	0
	15	0	0	0	1833	1833	2750	2750	1833	1833	917	0	0

As shown in Table 8.3-16, surplus power is closely related to consumption. When the number of houses to be supplied power is small, surplus power will be larger. Surplus power decreases with the increase in the number of houses to be supplied.

b. Analysis of water pumping cost

Method of determining water cost is as follows: The above-mentioned surplus power of mini-centralized systems is used to calculate potential water quantity by month for various heads. On the other hand, costs of facilities for water pumping are calculated and pumping water cost is determined from the calculation result of yearly potential water quantity.

②Calculation of potential water quantity

As mini-centralized PV systems provide AC power through inverters, AC pump is used to pump up water. As for selection of pumps, the following two pumps for low head and medium / high heads are considered, respectively.

- Low head pump : SP 3A-10
- Medium / high head pump : SP 2A-15

These two pumps operate with AC 200V - 1.1kW. Potential duration of operation of these pumps were calculated from surplus power as shown below:

Table 8.3-17 Operating hours of PV water pumping (hr)

Scale	No. of Houses	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
2kW	6	0	0	1.1	1.1	1.7	1.7	1.7	1.7	1.1	1.1	0	0
	9	0	0	0.6	1.1	1.1	1.1	1.7	1.7	1.1	0.6	0	0
	12	0	0	0.6	1.1	1.1	1.1	1.1	1.1	1.1	0.6	0	0
3kW	9	0	0	1.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0	0
	12	0	0	1.7	1.7	1.7	2.5	2.5	1.7	1.7	0.8	0	0
	15	0	0	0.0	1.7	1.7	2.5	2.5	1.7	1.7	0.8	0	0

On the other hand, discharges quantity (m^3/hr), which was calculated from characteristics of these two pumps (Fig. 8.3-3), is shown in Table 8.3-18. It is considered to be optimal to start operation of pump around 11:00 A.M. when the output of PV system is to be max. The wiring loss is considered to be 2%.

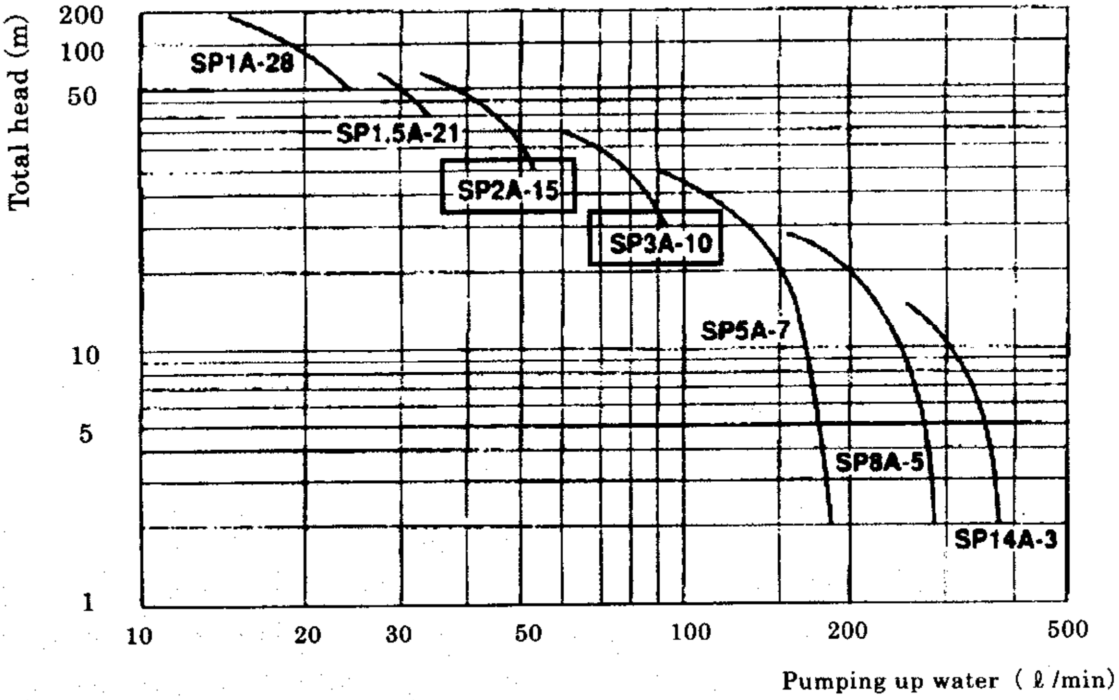

Fig.8.3-3 Characteristics of pump

Table 8.3-18 Pumped-up water by head

Low head (SP 3A-10)		Medium and high head (SP 2A-15)	
Head (m)	Water (m³/hr)	Head (m)	Water (m³/hr)
30	4.8	80	2.3
40	4.5	90	2.0
50	4.1	100	1.7
60	3.5	110	1.4
70	2.9	120	0.7

③Particulars for pumping water cost

Water pumping by using surplus power requires additional facilities such as a pump, piping, cable and a storage tank for pumped water. Costs of these facilities and materials were assumed on the basis of the information collected in Syria as follows.

a. Pump and related items

Water pumping from a deep well is not economical in case of PV system. Hence low head range is set from 30 to 70m, and medium / high head range is set from 80 to 120m, respectively. As for pumps, SP 3A-10 and SP 2A-15, which is products of Grundfos and has many actual results, were selected.

Table 8.3-19 Installation cost data for water pumping

Item	Model	[US$]	Life[year]	Remark
Pump	· SP 2A-15	1,300 /unit	10	
	or			
	· SP 3A-10	1,210 /unit	10	
Cable				Considering voltage drop
	· 8sq	1.4 /m	20	·Depth of Well above 75m
	· 14sq	2.3 /m	20	· above 127m
	· 22sq	2.7 /m	20	· above 200m
Pipe	· zinc pipe	14	20	
Others	—	273 /m	20	

*Considering 20m galvanized piping on the ground, work cost is 5% of construction cost

b. Tank and the related items

Breakdown of installation cost of water pump and tank reveals that cost of tank has a high weight even when storage capacity is 10m^3. Hence the above-mentioned construction cost of tank is set as standard, and investigation was focused on a case in which construction cost can be reduced to one half by cooperation of villagers. In calculation of expenses, each facility item is depreciated for the durable years. Water pumping cost is examined on the basis of mean costs of respective items of their durable years.

Table 8.3-20 Construction cost for tank

Item	Model	[US$]	Life[year]	Remark
Tank	Fixed portion	1,818	20	
	Proportional portion with quantity	1,364 /m^3		
Others	—	909		

*Work cost is 5% of construction cost

(4) Results of investigation

Surplus power of a mini-centralized system is used to pump up water from a freshwater well (groundwater veins in Syria are brackish in many cases, but freshwater veins are also present among them). In this case, this freshwater well is in or near the village in which mini-centralized system is installed. We calculate pumping water cost and results are shown in Table 8.3-21 and Table 8.3-22. These results indicate the following:

①As for the scale of mini-centralized system, 3kW system generates a greater quantity of surplus power than 2kW system. Thus the yearly water quantity of 3kW system is larger than that of 2kW system. Water pumping cost of the former is lower than that of the latter.

②When case of low head and case of medium / high head are compared with each other, the result is obvious; lower head can pump up greater quantity of water. Thus the cost of the former is lower.

Examination by head indicates the following:

③Case of low head (depth of well: 30 ~ 70m)

- Case of 2kW system, 12 houses, well depth is 70m, water quantity in October in dry season is $48m^3$/month. If one person consumes 15 liters a day, the system can supply water to about 100 persons. As the water pumping cost is about US$1, it is economical when compared with case of purchasing freshwater that transported by a tank lorry. In other months, quantity is $100m^3$/month or more, and there is no problem.
- Case of 3kW system, 15 houses, well depth 70m, water quantity in October is 71 m^3/month. Water can be provided to about 150 persons.

④Case of medium / high heads (depth of well: 80 ~120m)

- Case of 2kW system, 12 houses, well depth 120m, water quantity is only 12 m^3/month. This water can be provided to only 25 persons. The unit price of water also rises to US$5/$m^3$.
- Case of 3kW system, the trends are similar to those of 2kW system

On the basis of the findings mentioned above, we may conclude as follows:

- When customers increase and connect to mini-centralized system relative to its capacity, surplus power will be reduced and difficult to pump up water from deep well.
- When depth of well is from 30 to 70m approx, it will be economical to pump up water by using surplus power even if family constitution is taken into consideration.
- Generally, a large quantity of water from fresh water well is pumped up by diesel pump etc, it can damage water vein and shorten the service life of the well. When surplus power is used for AC pump, as water is pumped up by a limited power, it will assure the use of water resources over a long period.

Table 8.3-21 Cost of pumping up water by surplus (Low head pump : SP3A-10)

Svcale of system	Supplyed house	Head [m]	Pump up water [m^3/Month]												Total [m^3]	Cost / year [\$]				Cost [\$/m^3]			
																Life : 20 years			30 years	Life : 20 years			30 years
																Cost of tunk				Cost of tunk			
																Normal	50% of normal		50% of normal	Normal	50% of normal		50% of normal
			1	2	3	4	5	6	7	8	9	10	11	12		Increase= 0%	Increase= 0%	Increase= 3%	Increase= 0%	Increase= 0%	Increase= 0%	Increase= 3%	Increase= 0%
2kW	6	30	0	0	163	158	245	237	245	245	158	163	0	0	1614	1031	793	828	643	0.639	0.491	0.513	0.398
		40	0	0	153	148	230	223	230	230	148	153	0	0	1515	1054	817	851	661	0.696	0.539	0.562	0.436
		50	0	0	140	135	209	203	209	209	135	140	0	0	1380	1078	840	874	679	0.781	0.609	0.633	0.492
		60	0	0	119	115	179	173	179	179	115	119	0	0	1178	1101	863	897	696	0.935	0.733	0.761	0.591
		70	0	0	95	92	143	138	143	143	92	95	0	0	941	1124	886	920	714	1.194	0.942	0.978	0.759
	9	30	0	0	82	158	163	158	245	245	158	82	0	0	1291	1031	793	828	643	0.799	0.614	0.641	0.498
		40	0	0	77	148	153	148	230	230	148	77	0	0	1211	1054	817	851	661	0.870	0.675	0.703	0.546
		50	0	0	70	135	140	135	209	209	135	77	0	0	1110	1078	840	874	679	0.971	0.757	0.787	0.612
		60	0	0	60	115	119	115	179	179	115	60	0	0	942	1101	863	897	696	1.169	0.916	0.952	0.739
		70	0	0	48	92	95	92	143	143	92	48	0	0	753	1124	886	920	714	1.493	1.177	1.222	0.948
	12	30	0	0	82	158	163	158	163	163	158	82	0	0	1127	1031	793	828	643	0.915	0.704	0.735	0.571
		40	0	0	77	148	153	148	153	153	148	77	0	0	1057	1054	817	851	661	0.997	0.773	0.805	0.625
		50	0	0	70	135	140	135	140	140	135	70	0	0	965	1078	840	874	679	1.117	0.870	0.906	0.704
		60	0	0	60	115	119	115	119	119	115	60	0	0	822	1101	863	897	696	1.339	1.050	1.091	0.847
		70	0	0	48	92	95	92	95	95	92	48	0	0	657	1124	886	920	714	1.711	1.349	1.400	1.087
3kW	9	30	0	0	243	353	365	353	365	365	353	365	0	0	2762	1031	793	828	643	0.373	0.287	0.300	0.233
		40	0	0	228	331	342	331	342	342	331	342	0	0	2589	1054	817	851	661	0.407	0.316	0.329	0.255
		50	0	0	208	301	311	301	311	311	301	311	0	0	2355	1078	840	874	679	0.458	0.357	0.371	0.288
		60	0	0	177	257	266	257	266	266	257	266	0	0	2012	1101	863	897	696	0.547	0.429	0.446	0.346
		70	0	0	142	206	213	206	213	213	206	213	0	0	1612	1124	886	920	714	0.697	0.550	0.571	0.443
	12	30	0	0	243	235	243	353	365	243	235	122	0	0	2039	1031	793	828	643	0.506	0.389	0.406	0.315
		40	0	0	228	220	228	331	342	228	220	114	0	0	1911	1054	817	851	661	0.552	0.428	0.445	0.346
		50	0	0	208	201	208	301	311	208	201	104	0	0	1742	1078	840	874	679	0.619	0.482	0.502	0.390
		60	0	0	177	171	177	257	266	177	171	89	0	0	1485	1101	863	897	696	0.741	0.581	0.604	0.469
		70	0	0	142	137	142	206	213	142	137	71	0	0	1190	1124	886	920	714	0.945	0.745	0.773	0.600
	15	30	0	0	0	235	243	353	365	243	235	122	0	0	1796	1031	793	828	643	0.574	0.442	0.461	0.358
		40	0	0	0	220	228	331	342	228	220	114	0	0	1683	1054	817	851	661	0.626	0.485	0.506	0.393
		50	0	0	0	201	208	301	311	208	201	104	0	0	1534	1078	840	874	679	0.703	0.548	0.570	0.443
		60	0	0	0	171	177	257	266	177	171	89	0	0	1308	1101	863	897	696	0.842	0.660	0.686	0.532
		70	0	0	0	137	142	206	213	142	137	71	0	0	1048	1124	886	920	714	1.073	0.845	0.878	0.681

Table 8.3-22 Cost of pumping up water by surplus (Medium and High head pump : SP2A-15)

Svcale of system	Supplyed house	Head [m]	Pump up water [m³/Month]												Total [m³]	Cost / year [$]				Cost [$/m³]			
																Life : 20 years			30 years	Life : 20 years			30 years
																Cost of tunk				Cost of tunk			
			1	2	3	4	5	6	7	8	9	10	11	12		Normal	50% of normal		50% of normal	Normal	50% of normal		50% of normal
																Increase= 0%	Increase= 0%	Increase= 3%	Increase= 0%	Increase= 0%	Increase= 0%	Increase= 3%	Increase= 0%
2kW	6	80	0	0	78	76	118	114	118	118	76	78	0	0	776	0	940	977	758	0.000	1.211	1.259	0.977
		90	0	0	68	66	102	99	102	102	66	68	0	0	673	1203	965	1001	777	1.788	1.434	1.487	1.155
		100	0	0	58	56	87	84	87	87	56	58	0	0	573	1227	989	1026	796	2.141	1.726	1.791	1.389
		110	0	0	48	46	72	69	72	72	46	48	0	0	473	1252	1014	1051	815	2.647	2.144	2.222	1.723
		120	0	0	24	23	36	35	36	36	23	24	0	0	237	1276	1038	1075	834	5.384	4.380	4.536	3.519
	9	80	0	0	39	76	78	76	118	118	76	39	0	0	620	1178	940	977	758	1.900	1.516	1.576	1.223
		90	0	0	34	66	68	66	102	102	66	34	0	0	538	1203	965	1001	777	2.236	1.794	1.861	1.444
		100	0	0	29	56	58	56	87	87	56	29	0	0	458	1227	989	1026	796	2.679	2.159	2.240	1.738
		110	0	0	24	46	48	46	72	72	46	24	0	0	378	1252	1014	1051	815	3.312	2.683	2.780	2.156
		120	0	0	12	23	24	23	36	36	23	12	0	0	189	1276	1038	1075	834	6.751	5.492	5.688	4.413
	12	80	0	0	39	76	78	76	78	78	76	39	0	0	540	1178	940	977	758	2.181	1.741	1.809	1.404
		90	0	0	34	66	68	66	68	68	66	34	0	0	470	1203	965	1001	777	2.560	2.053	2.130	1.653
		100	0	0	29	56	58	56	58	58	56	29	0	0	400	1227	989	1026	796	3.068	2.473	2.565	1.990
		110	0	0	24	46	48	46	48	48	46	24	0	0	330	1252	1014	1051	815	3.794	3.073	3.185	2.470
		120	0	0	12	23	24	23	24	24	23	12	0	0	165	1276	1038	1075	834	7.733	6.291	6.515	5.055
3kW	9	80	0	0	116	169	175	169	175	175	169	175	0	0	1323	1178	940	977	758	0.890	0.711	0.738	0.573
		90	0	0	101	147	152	147	152	152	147	152	0	0	1150	1203	965	1001	777	1.046	0.839	0.870	0.676
		100	0	0	86	125	129	125	129	129	125	129	0	0	977	1227	989	1026	796	1.256	1.012	1.050	0.815
		110	0	0	71	103	106	103	106	106	103	106	0	0	804	1252	1014	1051	815	1.557	1.261	1.307	1.014
		120	0	0	35	51	53	51	53	53	51	53	0	0	400	1276	1038	1075	834	3.190	2.595	2.688	2.085
	12	80	0	0	116	113	116	169	175	116	113	58	0	0	976	1178	940	977	758	1.207	0.963	1.001	0.777
		90	0	0	101	98	101	147	152	101	98	51	0	0	849	1203	965	1001	777	1.417	1.137	1.179	0.915
		100	0	0	86	83	86	125	129	86	83	43	0	0	721	1227	989	1026	796	1.702	1.372	1.423	1.104
		110	0	0	71	69	71	103	106	71	69	35	0	0	595	1252	1014	1051	815	2.104	1.704	1.766	1.370
		120	0	0	35	34	35	51	53	35	34	18	0	0	295	1276	1038	1075	834	4.325	3.519	3.644	2.827
	15	80	0	0	0	113	116	169	175	116	113	58	0	0	860	1178	940	977	758	1.370	1.093	1.136	0.881
		90	0	0	0	98	101	147	152	101	98	51	0	0	748	1203	965	1001	777	1.608	1.290	1.338	1.039
		100	0	0	0	83	86	125	129	86	83	43	0	0	635	1227	989	1026	796	1.932	1.557	1.616	1.254
		110	0	0	0	69	71	103	106	71	69	35	0	0	524	1252	1014	1051	815	2.389	1.935	2.006	1.555
		120	0	0	0	34	35	51	53	35	34	18	0	0	260	1276	1038	1075	834	4.908	3.992	4.135	3.208

8.3.3 Water pumping with PV systems

In Syria the annual precipitation is unevenly distributed to some regions. Rainfall also concentrates in rainy season of winter. In particular, in summer fine weather continues day after day and atmosphere temperature is very high. Moreover, as for groundwater, fresh water veins and veins of brackish water of which salinity contents is about one tenth of seawater are mixed in some places. With the rise in standard of living in recent years, water requirements for domestic use and irrigation requirements for agricultural production have increased significantly. As a result, demands for water have increased drastically. In villages on the plains there are old wells, but many of these wells have been dried up. Villagers having no water supply system periodically purchase water. Purchased water is carried by a tank lorry to their houses and stored in underground tank near houses. The mountainous areas have much precipitation in winter, and the residents in these areas guide rainwater from the roofs into underground wells for use.

On the plains a large quantity of water is pumped up from wells by diesel engine to cultivate cotton in summer. The residents told us that these wells were shallow wells in the past but they had to dig the wells deeper and deeper to get sufficient quantity of water with considerable costs. As the groundwater quantity is small, if pumping of large quantity of water is continued, water veins will dry up early. Hence the Ministry of Irrigation has a license system for digging of wells.

As described above, the water supply conditions in Syria are very severe, and water treatment facilities have been installed near large cities to recycle water. Under such circumstances, the significance of water pumping with PV system may be summarized as follows:

①It serves to prolong the effective use of groundwater.

When compared with diesel pump, PV water pumping can lift water only in the daytime. Thus it will hardly dry up underground water veins.

②It enables appropriate use of water for agriculture as well as for domestic use.

It is said that if a diesel pump is used, even new fresh water well will be dried up in ten years. In contrast, when PV system is used, the residents will use water within the limit of pumped water, and this ensures rational use of water. As for agriculture, use of drip irrigation allows effective usage of water.

③It can secure supply of drinking water for livestock in extensive glazing land.

PV system requires no fuel and systems are almost maintenance-free and can operate automatically. Such systems are effective in securing drinking water for livestock kept in extensive glazing land.

④It extends inhabitable area.

As PV system easily secures electricity and water in rural areas, it contributes to extend inhabitable area.

As for PV system water pumping, its economics are important. In the following, economics of PV water pumping will be compared with that of diesel pumping that is extensively used in Syria.

(1) Assumptions for economic comparison between PV pumping and diesel pumping

When water for domestic use is pumped from a well, important points of consideration are positional relationship between well and village and water transfer method. Here the objective of comparison in economics is to determine which is more advantageous as power source, PV system or diesel engine. To simplify the comparison by eliminating common factors as much as possible, the following assumptions were made.

①Scope of cost calculation

As for the scope of cost calculation, depth of well is used as a parameter, a high tank to feed water is installed near well, and cost of water pumped up to that tank is compared.

②Quantity of water pumped

When a diesel engine is used for pumping, water quantity can be changed according to the duration of pump operation when fuel is refilled and operation is continued. In case of PV system, pumping can be made only in the daytime when the sun shines. Hence comparison between them can be made only when the pumping water quantity is limited. From the viewpoint of effectively using the precious water resources, the pumping costs of both methods are compared with each other by limiting the quantity of diesel pumping to that of PV system pumping.

③Latest pumping technology with PV system

The pumping technology with PV system has advanced in recent years. However, general-purpose pumps of high reliability are limited up to about AC 2kW in capacity. Pumps not higher than this capacity are considered.

(1) Model case for cost comparison

The following drawing indicates model of cost comparison.

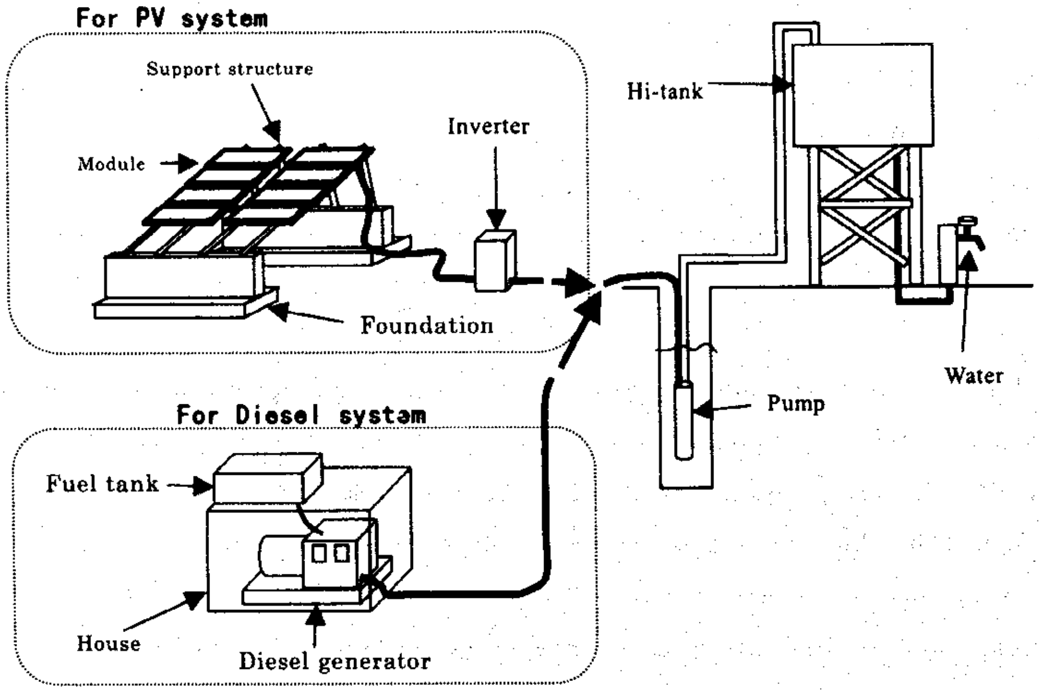

Fig.8.3-4 Model for cost comparison

(2) Basic data for economic comparison

In order to make economic comparison between PV water pumping and diesel pumping, the basic data of both systems are estimated respectively to meet the case of PV electrification.

Table 8.3-23 Cost parameters for PV/diesel pumping (¥2.5/SP) (46SP/US$)

1) PV system (US$)

Item	Specification		Unit price	Price
Module	Output power 120W	8	275	2,200
Sub-array structure	Number of mounting panels	8	40	320
Construction	Cement (m^3)	2	30	60
Labor	Cable, Wiring	2	20	40
Sub-array total	Output power(W)	960		2,620
Inverter	**SA-1500 (1.5kW, US$500/kW)**			750

Table 8.3-24 Cost parameters for PV/diesel pumping (¥2.5/SP) (46SP/US$)

2) PV/Diesel

Item	Value
Insolation (kWh/m²*day)	5.0
Interest rate (%)	6.5
Diesel generator capacity (kW)	5.0
Diesel generator price (US$)	2,750
Useful life of PV module (year)	20
Useful life of inverter (year)	10
Useful life of diesel (year)	10
Useful life of pump (year)	20
Diesel fuel price (US$/l)	0.14
Lube oil price (US$/kg)	1.3
Nominal fuel consumption (l/kWh)	0.4
Nominal lube consumption (g/kWh)	3
Maintenance of diesel (US$/year)	185

(3) Cost comparison of PV pumping

The results of cost calculation using above parameters are listed below. Considering that the village population of coming PV water supply will be less than 500 and the water demand will be 20～30 liter per person one day, then total water quantity for the village will be 10～15m^3 if it is used for their life. According to the Table, if the application system is up to 40～50m of total head, then PV water pumping is more economical than diesel under the condition of PV module price of 2005 and inflation rate of 0%.

For now, prices in Syria is fairly stable, but 2～3% of inflation can be observed. In the Table above, under inflation rate of 3% the economically possibly area for PV pumping expands to total head of 70m. The water level of most of the wells in Aleppo is up to 50～60m(interview from the Aleppo Water Authority), therefore most wells can be applied with PV water pump. When the life of PV module expands to 30 years, the applicable area also expands. This life is not clear at present, however, more than 20 years will be expected and life of 30 years is considered feasible. According to the mentioned above result, introduction from 2005 is economically feasible. To introduce PV water pump more economically, it is recommended to start with relatively shallow (up to 50m) wells.

Table 8.3-25 Water cost of PV pumping system (unit : US$/$m^3$)

1) PV module life 20years, inflation 0%

	Water Quantity (m^3/day)							
Total head (m)	5	10	15	20	25	30	35	40
10								
20								
30						0.22(0.05)	0.20(0.05)	0.19(0.04)
40				0.28(0.08)	0.24(0.06)	0.22(0.05)	0.22(0.06)	
50		0.47(0.16)	0.34(0.11)	0.28(0.08)	0.24(0.08)	0.24(0.07)		
60		0.47(0.16)	0.34(0.11)	0.31(0.11)				
70	0.84(0.32)	0.47(0.16)	0.34(0.11)					
80	0.85(0.32)	0.47(0.16)	0.39(0.15)					
90	0.85(0.32)	0.48(0.16)						
100	0.86(0.32)	0.54(0.22)						
110	0.87(0.32)							
120	0.87(0.32)							
130	0.87(0.32)							
140	0.88(0.32)							
150	0.88(0.32)							

2) PV module life 20 years, inflation 3%

	Water Quantity (m^3/day)							
Total head (m)	5	10	15	20	25	30	35	40
10								
20								
30							0.21(0.06)	0.20(0.05)
40						0.23(0.06)	0.23(0.07)	
50				0.29(0.09)	0.25(0.09)	0.25(0.08)		
60			0.35(0.12)	0.32(0.12)				
70			0.35(0.12)					
80		0.48(0.17)	0.40(0.16)					
90		0.49(0.17)						
100		0.55(0.23)						
110								
120	0.88(0.33)							
130	0.88(0.33)							
140	0.89(0.33)							
150	0.89(0.33)							

3) PV module life 30years, inflation 0%

	Water Quantity (m^3/day)							
Total head (m)	5	10	15	20	25	30	35	40
10								
20								
30								
40							0.21(0.06)	
50						0.23(0.06)		
60				0.30(0.10)				
70								
80			0.37(0.13)					
90								
100		0.50(0.19)						
110								
120	0.83(0.28)							
130	0.83(0.28)							
140	0.84(0.28)							
150	0.84(0.28)							

Table 8.3-25 Water cost of PV pumping system (unit : US$/$m^3$)

1) PV module life 20years, inflation 0%

		Water Quantity (m^3/day)							
		5	10	15	20	25	30	35	40
Total head (m)	10	**0.69(0.19)**	**0.39(0.09)**	**0.29(0.06)**	**0.24(0.05)**	**0.21(0.04)**	**0.19(0.03)**	**0.18(0.03)**	**0.17(0.02)**
	20	**0.69(0.19)**	**0.39(0.09)**	**0.29(0.06)**	**0.24(0.05)**	**0.21(0.04)**	**0.19(0.03)**	**0.20(0.05)**	**0.19(0.04)**
	30	**0.69(0.19)**	**0.40(0.09)**	**0.29(0.06)**	**0.24(0.05)**	**0.21(0.04)**	0.22(0.05)	0.20(0.05)	0.19(0.04)
	40	**0.70(0.19)**	**0.46(0.09)**	**0.34(0.11)**	0.28(0.08)	0.24(0.06)	0.22(0.05)	0.22(0.06)	
	50	**0.70(0.19)**	0.47(0.16)	0.34(0.11)	0.28(0.08)	0.24(0.08)	0.24(0.07)		
	60	**0.71(0.19)**	0.47(0.16)	0.34(0.11)	0.31(0.11)				
	70	0.84(0.32)	0.47(0.16)	0.34(0.11)					
	80	0.85(0.32)	0.47(0.16)	0.39(0.15)					
	90	0.85(0.32)	0.48(0.16)						
	100	0.86(0.32)	0.54(0.22)						
	110	0.87(0.32)							
	120	0.87(0.32)							
	130	0.87(0.32)							
	140	0.88(0.32)							
	150	0.88(0.32)							

2) PV module life 20 years, inflation 3%

		Water Quantity (m^3/day)							
		5	10	15	20	25	30	35	40
Total head (m)	10	**0.70(0.20)**	**0.40(0.10)**	**0.30(0.07)**	**0.25(0.06)**	**0.22(0.05)**	**0.20(0.04)**	**0.19(0.04)**	**0.18(0.03)**
	20	**0.70(0.20)**	**0.40(0.10)**	**0.30(0.07)**	**0.25(0.06)**	**0.22(0.05)**	**0.20(0.04)**	**0.21(0.06)**	**0.20(0.05)**
	30	**0.70(0.20)**	**0.41(0.10)**	**0.30(0.07)**	**0.25(0.06)**	**0.22(0.05)**	**0.23(0.06)**	0.21(0.06)	0.20(0.05)
	40	**0.71(0.20)**	**0.47(0.10)**	**0.35(0.12)**	**0.29(0.09)**	**0.25(0.07)**	0.23(0.06)	0.23(0.07)	
	50	**0.71(0.20)**	**0.48(0.17)**	**0.35(0.12)**	0.29(0.09)	0.25(0.09)	0.25(0.08)		
	60	**0.72(0.20)**	**0.48(0.17)**	0.35(0.12)	0.32(0.12)				
	70	**0.85(0.33)**	**0.48(0.17)**	0.35(0.12)					
	80	**0.86(0.33)**	0.48(0.17)	0.40(0.16)					
	90	**0.86(0.33)**	0.49(0.17)						
	100	**0.87(0.33)**	0.55(0.23)						
	110	**0.88(0.33)**							
	120	0.88(0.33)							
	130	0.88(0.33)							
	140	0.89(0.33)							
	150	0.89(0.33)							

3) PV module life 30years, inflation 0%

		Water Quantity (m^3/day)							
		5	10	15	20	25	30	35	40
Total head (m)	10	**0.67(0.17)**	**0.38(0.08)**	**0.29(0.06)**	**0.24(0.04)**	**0.21(0.03)**	**0.21(0.03)**	**0.19(0.02)**	**0.17(0.02)**
	20	**0.67(0.17)**	**0.38(0.08)**	**0.29(0.06)**	**0.24(0.04)**	**0.21(0.03)**	**0.21(0.03)**	**0.19(0.04)**	**0.18(0.03)**
	30	**0.67(0.17)**	**0.48(0.08)**	**0.29(0.06)**	**0.24(0.04)**	**0.21(0.03)**	**0.21(0.05)**	**0.19(0.04)**	**0.18(0.03)**
	40	**0.68(0.17)**	**0.49(0.08)**	**0.33(0.09)**	**0.27(0.07)**	**0.23(0.06)**	**0.23(0.05)**	0.21(0.06)	
	50	**0.68(0.17)**	**0.44(0.14)**	**0.33(0.09)**	**0.27(0.07)**	**0.23(0.06)**	0.23(0.06)		
	60	**0.69(0.17)**	**0.45(0.14)**	**0.33(0.09)**	0.30(0.10)				
	70	**0.80(0.28)**	**0.45(0.14)**	**0.33(0.09)**					
	80	**0.81(0.28)**	**0.45(0.14)**	0.37(0.13)					
	90	**0.81(0.28)**	**0.45(0.14)**						
	100	**0.82(0.28)**	0.50(0.19)						
	110	**0.83(0.28)**							
	120	0.83(0.28)							
	130	0.83(0.28)							
	140	0.84(0.28)							
	150	0.84(0.28)							

Table 8.3-26 Water cost for diesel pumping system (unit : US$/m³)

1) Inflation 0%

		Water Quantity (m³/day)							
		5	10	15	20	25	30	35	40
Total head (m)	10	0.79(0.29)	0.45(0.15)	0.33(0.10)	0.27(0.08)	0.24(0.06)	0.21(0.05)	0.20(0.05)	0.19(0.04)
	20	0.80(0.30)	0.45(0.15)	0.33(0.10)	0.28(0.08)	0.24(0.06)	0.22(0.05)	0.20(0.05)	0.19(0.04)
	30	0.81(0.31)	0.46(0.16)	0.34(0.11)	0.28(0.08)	0.25(0.07)	0.22(0.06)	0.21(0.05)	0.19(0.05)
	40	0.83(0.32)	0.47(0.17)	0.35(0.12)	0.29(0.09)	0.25(0.08)	0.23(0.07)	0.21(0.06)	
	50	0.84(0.32)	0.48(0.17)	0.35(0.12)	0.29(0.09)	0.26(0.08)	0.23(0.07)		
	60	0.85(0.33)	0.49(0.18)	0.36(0.13)	0.31(0.10)				
	70	0.87(0.34)	0.49(0.19)	0.37(0.13)					
	80	0.88(0.35)	0.50(0.19)	0.38(0.14)					
	90	0.89(0.36)	0.51(0.20)						
	100	0.90(0.36)	0.52(0.20)						
	110	0.91(0.37)	0.53(0.21)						
	120	0.93(0.38)							
	130	0.94(0.38)							
	140	0.95(0.39)							
	150	0.97(0.40)							

2) Inflation 3%

		Water Quantity (m³/day)							
		5	10	15	20	25	30	35	40
Total head (m)	10	0.77(0.27)	0.44(0.14)	0.32(0.09)	0.27(0.07)	0.23(0.06)	0.21(0.05)	0.20(0.04)	0.18(0.04)
	20	0.78(0.28)	0.44(0.14)	0.33(0.10)	0.27(0.07)	0.24(0.06)	0.22(0.05)	0.20(0.05)	0.19(0.04)
	30	0.79(0.29)	0.45(0.15)	0.33(0.10)	0.28(0.08)	0.24(0.06)	0.22(0.06)	0.20(0.05)	0.19(0.04)
	40	0.81(0.30)	0.46(0.15)	0.34(0.11)	0.28(0.08)	0.25(0.07)	0.22(0.06)	0.21(0.05)	
	50	0.82(0.30)	0.46(0.16)	0.35(0.11)	0.29(0.09)	0.25(0.07)	0.23(0.06)		
	60	0.83(0.31)	0.47(0.17)	0.35(0.12)	0.30(0.10)				
	70	0.84(0.32)	0.48(0.17)	0.36(0.12)					
	80	0.85(0.32)	0.49(0.18)	0.37(0.13)					
	90	0.87(0.33)	0.50(0.18)						
	100	0.87(0.33)	0.50(0.19)						
	110	0.89(0.34)	0.50(0.19)						
	120	0.90(0.35)							
	130	0.91(0.35)							
	140	0.92(0.36)							
	150	0.93(0.37)							

From the interview of the Water Authority, it costs 30～40(SP/m³) to facilitate water supply to rural villages for high cost case. Since this cost includes additional piping cost, it cannot directly compared to our analysis, but it seems to come closer to the cost of PV pumping. Rural water supply will be urged to target smaller villages such as 100 of villagers from larger village such as 500 of villagers in the future. Therefore, such as smaller system is relatively cost much. Specially, PV water pumping is economical compared to alternative ways, but it has the feature of requiring larger initial invest. Therefor, funding is important subject to make PV water pump expansion in future.

(4) Comparison with other alternatives

There are some other alternatives such as grid extension, diesel engine pump, lorry water supply and piping extension. Cost of each ways depends on the situation of the targeted village, but generally there is tendency of described in table 8.3-27. From the Table, PV water pumping can be a promising way of rural water supply.

Table 8.3-27 Comparison with other alternatives

Method	Comparison
Grid extension	Grid extension costs ~US$12,000/km. The cost of PV is ~ US$5,000/kW Grid extension can be simplified and cost reduced for such small application, but still PV pump is more economical when well locates more than 3km away from grid line.
Diesel engine pump	This method is a bit cheaper than diesel generation because it works without generator and motor, but some mechanics needed in addition and maintenance for this is costly. Overall economics is almost same with the way of diesel generator.
Lorry supply	Manpower cost of lorry water supply is 10,000SP/month. Fuel and depreciation cost is needed in addition. This is very costly way. This is recommended to use for emergency water supply.

(5) Direction of PV water pumping

Based on technical and economic evaluation of PV water pumping, the following points were found.

- Regarding small scale water pumping system, when pumping head is less than 50m and water quantity is less than 20m³/day, PV system takes advantage compared with diesel pumping.
- If [PV module price : US$2.13/W] that expect at 2005 is applied, 2kW or less of PV array scale pumping system takes advantage compared with diesel system.
- Distance from grid line is more than 3km, PV pumping system is taken advantage than grid extension.

The current status of rural water supply by the Water Authority is described as following figure. (Interview survey from the Ministry of Housing and Utilities)

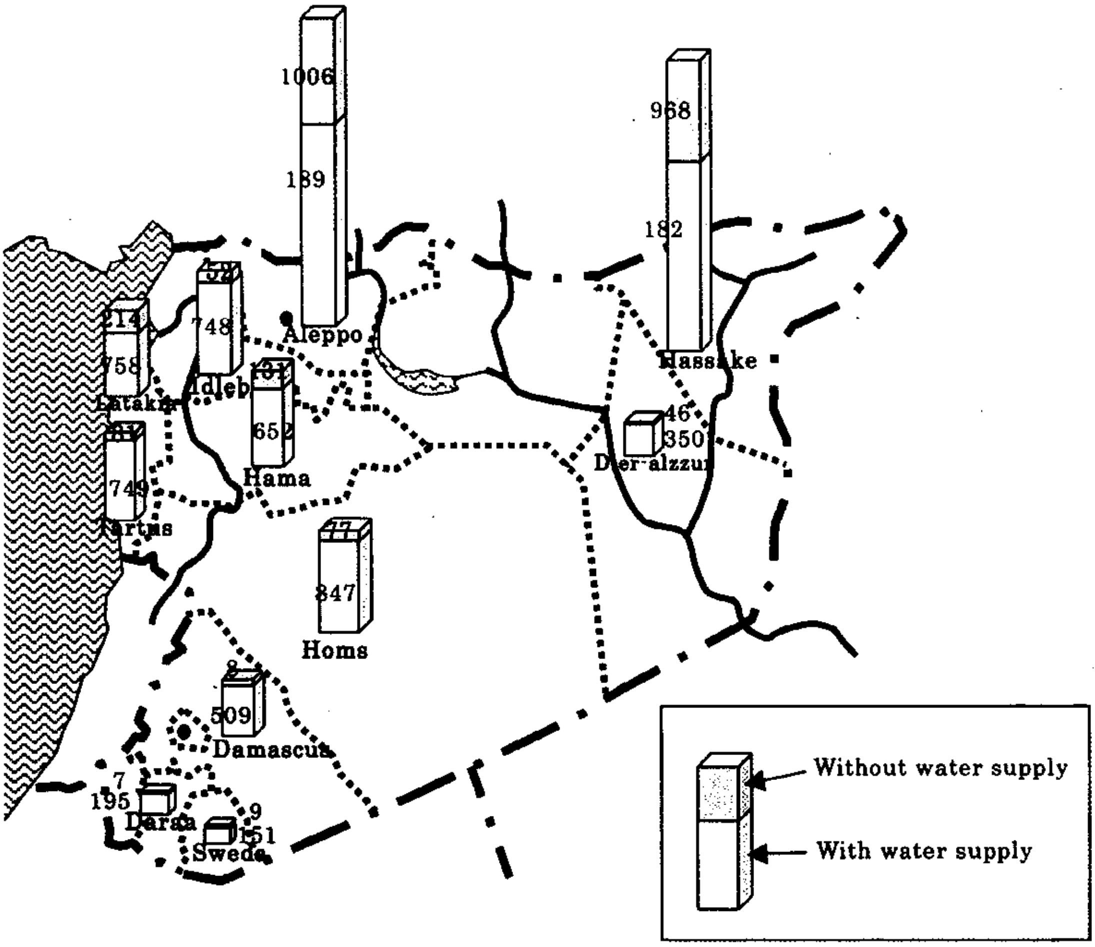

Fig.8.3-5 Situation of rural water supply by the Water Authority

According to Fig8.3-5, it is known that Aleppo and Hassake has much more villages without water supply by the Water Authority. As is the case with electrification, the villages of these two prefectures are so small and so sparsely distributed and have difficult accessibility. That also causes facilitating water supply to be very costly. So these villages are left without water supply for long time.

For introducing PV water pumping, first some experimental projects for relatively small applications in Aleppo and Hassake are suggested. Small applications such as less than $20m^3$/day of one day water demand is almost economical even under current price of PV module US$5/W. By those experimental projects, useful experiences can be accumulated along with Zarzita and Kalif systems and those experiences will be effectively projected in the real PV system introduction.

Around 2005, the related organizations will master the technology of PV water pumping and the price of PV module come to US$2.13/W, then the real PV water pump dissemination will begin. Therefore, if PV water pumping system introduction is promoted, procedure of village water supply increase options widely. Also, investment fund for development of village water supply will be used effectively and villages that have no water supply are available to set up water system. These water systems will contribute to improve the life of rural area.

8.3.4 Desalination system with PV systems

Water resources in Syria is said to be about 25 billion tons, of which surface water and ground water are assumed to be about 22 billion tons and three billion tons respectively. While, water demand in Syria for 1995 was 14.4 billion tons (13.6 billion tons for irrigation and 800 million tons for household). Because they were 4.5 billion tons and 300 million tons respectively for 1997, the demands for each usage increased 30 times and 2.6 times respectively. According to the estimation of the government of Syria, water demand in the country would keep rising with rapid increase in its population and industrial development to be 17 billion tons in 2000 and 23.5 billion tons in 2025. It seems certain with these figures that there would be a shortage of water in the near future. Already such phenomena as lowering of ground water levels in wells and deterioration of well water quality are noted. The main cause for these phenomena is considered to be excessive intake of ground water. The situation would be serious in the area where no surface water is available.

Under these circumstances, it seems necessary to make fresh water out of salty ground water. Therefore, we have conducted a preliminary study on the introduction of water desalination system into Syria in the future.

(1) Distribution of groundwater salinity

The distribution of ground water in Syria by its salinity is as shown in Fig.8.3-6. As shown in the map, the higher salinity ground water is distributed in the southeastern part of the country, which is arid or semi arid with relatively small rainfall. Because the acceptable salinity level for drinking water is up to 1000 ppm by WHO standard, groundwater is unsuitable for drinking in most of the region.

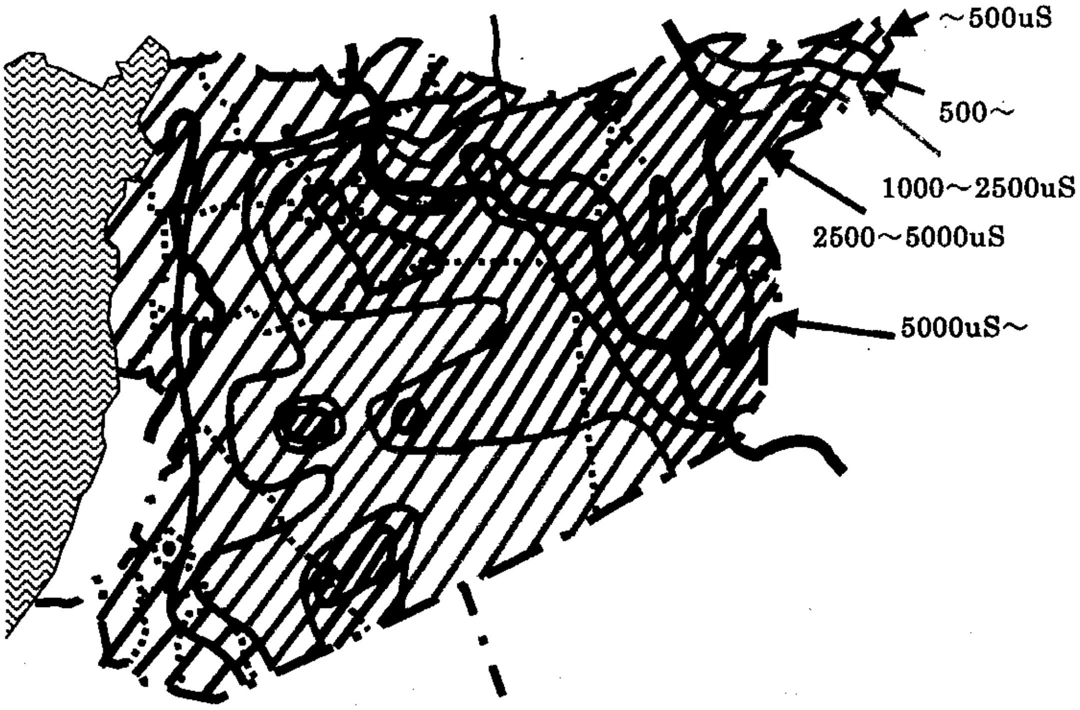

Fig.8.3-6 Map of groundwater salinity distribution

(2) Utilization of PV water pumping/desalination system

①Background

The desalination system by PV system is most suitable for use in such regions in Syria as no electricity is supplied and the supply of suitable fresh water is not enough. Especially the possibility of using the system in Badia area, which is an arid area in Syria, is high. In these regions there are few large towns and cities because most of the people in the region are non-those who settle down or Bedouin who live on livestock rising. The number of people living in Badia is about 700,000 and Bedouin accounts for more than 90% of the population, or about 650,000. There are only small number of fresh water wells, public and private, the water quality of which are acceptable by drinking water standards, and most of the Bedouins have no choice but using more or less saline water, the salinity exceeding the standard value. On the other hand, improving Bedouin's life environment would contribute to stabilization and development of Syria's livestock raising industry. The grid extension into the Badia area could hardly be expected unless the numbers of those who settle in the region increase. Therefore, the Badia is regarded as a promising region for future development of PV water pumping/desalination system. With this background a preliminary investigation was carried out on the feasibility of applying the above-mentioned system in the Badia area.

②Drinking water supply center in Badia

The image of a PV water pumping/desalination system applied in Badia is a water supply center or centers for those who settle down there and Bedouins. The water supply center consists of facilities of well water pumping and desalination system, which is basically similar to the system in Kalif and the operation control facilities. The scale of the system is decided based on well capacity and the number of beneficiaries. It might be said that the scale of water supply system would decide the population of the beneficiaries. If a water supply system in which Bedouin, the beneficiaries of the center, come to the nearest water center by tank-trucks and get fresh water is taken, scores of such water center would be required here and there to supply necessary amount of fresh water. The system would also provide high benefit and conveniences to them. Suppose the average distance that Bedouin travel to get fresh water is scores of km at most, the number of beneficiaries would be the population in the radius of scores of kilometers from the center. Of course, this figure includes that of those who settle down.

The fresh water demand and supply situation in the entire Badia is not known well. However, necessary amount of drinking water was calculated on trial by putting considerable assumption. Suppose the number of people who depend on groundwater is assumed to be 400,000, and the allocation of drinking water per person is assumed to be two liters a day, which is nearly the minimum necessity, the total amount required per day becomes about 800m^3.

On the other hand, the pumping rates at the several existing wells surveyed in Badia of Hama were about 10 to 20m^3/hr. The capacities of those wells are unknown. However, supposing the capacity to be about 20m^3/hr, the total amount of water to be pumped up would be 110 to 120m^3 a well, because annual average sunshine hours of 5.5 to 6 per day can be expected there. The amount of fresh water, its electric conductivity being about 500μ S/cm, to be obtained would be about 70 to 85 m^3. Therefore, to supply the above-mentioned necessary amount, about ten such water supply centers, as a whole would be required in Badia.

③Water desalination technologies

As the technologies of brackish water desalination with PV system and solar thermal energy, the following three methods are general.

1) RO membrane method
2) ED method
3) Solar thermal evaporation method

As for solar thermal evaporation method, the technology has existed since long time ago, however, its technical feasibility has not been proven, and continuous and stable operation cannot be expected. Therefore the technology was put out of the object of detailed examination. On the other hand, RO membrane method and ED method are well proven technologies. The methods have long been used for desalinating boiler feed water in power plants. Also RO membrane method has been proven to be applicable to well water in semi-arid area in Syria. With these it is assumed that there would be no technical problems.

④Economic investigation

The case to set up a PV water pumping/desalination system in a specific site as a model case was assumed in the concept of the water supply center as above-mentioned, and roughly estimated equipment cost or initial cost and operation cost were calculated on trial (Table 8.3-28, 8.3-29). Athrea in Hama county and Moukhlef in Aleppo county were chosen as installation sites. As the methods of water desalination, RO membrane method and ED method were taken. The following conditions were set in conducting this investigation:

a. Quality of desalinated water shall be designated to be reasonable as drinking water for the beneficiaries. In this study the designed electric conductivity of product water was set to be about 500 μ S/cm. As a salt rejection rate is 99% or more in RO membrane system, the desalinated water directly out of the membranes would have the electric conductivity of scores of μ S/cm. Therefore the electric conductivity was adjusted to about 500 μ S/cm by mixing certain amount of well water into the desalinated water.

b. High salinity contents shall be used as drinking water for domestic animals, or sheep etc.

c. Prices for spare parts shall be estimated based on market prices in Japan. However, according to SSRC/HIST request to use international plant cost, these prices are adjusted to meet international cost, which described in late.

d. Transportation cost sum sea transportation for 4% of plant cost and inland transportation for 1% of plant cost.

Which method, RO membrane method or ED method, is more economical for water desalination should be judged case by case. In case of desalinating groundwater of relatively high salinity as 7000 μ S/cm, the operation cost for ED method is higher compared to RO membrane method by about 60%. The difference come from that the spare parts cost is about 46% higher and the labor expense about 30%. On the other hand, in case of groundwater of relatively low salinity as about 3000 μ S/cm, ED method shows more economical. It is true that for both methods the larger the scale of desalination equipment the lower the initial cost and operation cost per unit. However, the degree seems to be more conspicuous for ED method.

⑤Application for sea water desalination

More serious shortage of fresh water in Syria can be foreseen because of a possible restriction in river water taking, relative decrease in the groundwater reserve, etc. Seawater desalination is one of reasonable measures against this situation. RO membrane method is the most economical way of making fresh water out of relatively high salinity water, and is regarded as the best technology to be used for seawater desalination. However, because the grid line has already been widely extended in the coastal area, it would be reasonable to use PV system not as the main power supply but as a supplemental power system.

⑥Specific sites for case study

On the basis of the information provided by SSRC/HIAST and the Aleppo Water Authority, the study team considered the cases of the following two specific sites:

It was decided to conduct the study on the bellow-mentioned sites, which were selected based on the information gathered from the counterpart, water authorities, etc.:

· Athrea, Hama County	(Site A)
· Moukhlef, Aleppo County	(Site B)

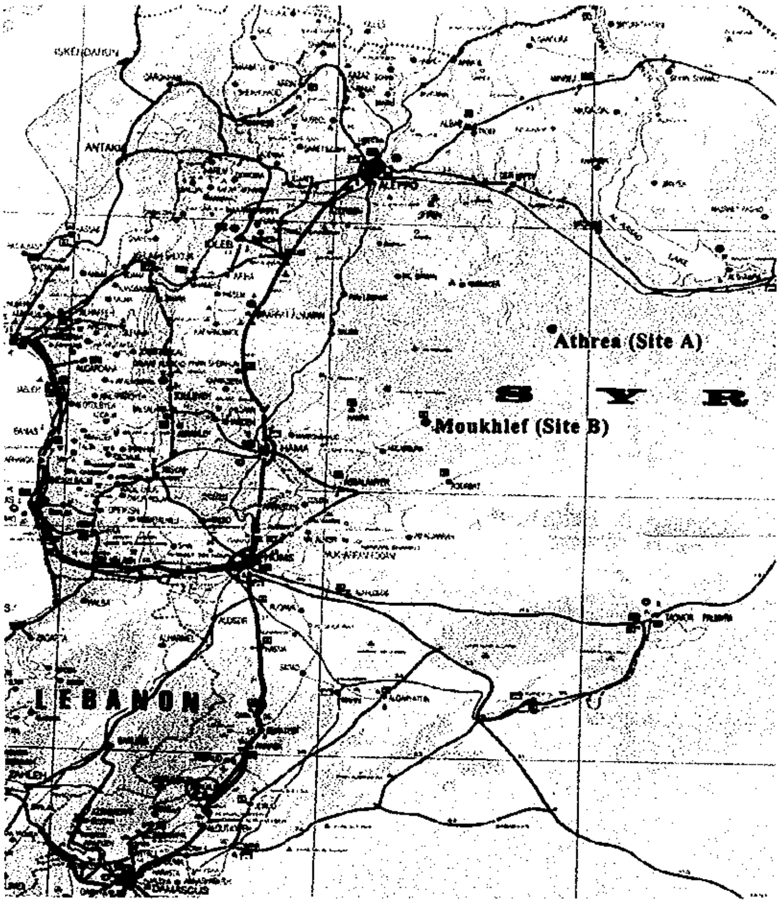

Fig.8.3-7 Candidate sites for case study of PV desalination system

Normally, about several thousands of Bedouins live around Site A, and the area is far away from grid lines. Thus the conditions of the area are suitable to introduce a brackish water desalination system that is powered by a PV system. On the other hand, the salinity contents of the water of a well at Site B is much higher than that of Site A. Site B is selected as a candidate so that we can consider application of the systems to brackish water of much higher concentration in future.

(2) Assumption

①Installation and commissioning period of the equipment

It was assume that the desalination equipment would be installed at the sites in 2005. By that time the Ministry of Housing and Utilities and the Aleppo Water Authority is expected to have acquired the technology on the operation and maintenance on the desalination system.

②Assumption of equipment cost and operation cost

As for PV system, like economic feasibility study on village electrification and water pumping, the prices as of 2005 were employed. Whereas, for desalination equipment, plant cost of both RO and ED apply international price including transportation fee. The costs of civil work, materials for the work and consumables were estimated based on actual cost for the civil work at Kalif and other information gathered at surveys. However, SSRC/HIAST pointed out that the prices of the plants of RO membrane method and ED method were expensive in comparison with the international prices of such plants. It was decided to recalculate by considering the plant price data obtained by SSRC/HIAST.

③ International prices of RO unit obtained by SSRC/HIAST

The plant prices, by capacity, of these plants for treating seawater are as follows:

Table 8.3-28 International prices by capacity of plants of RO method

System Scale	250 m^3/day	300 m^3/day	500 m^3/day
Price	US$191,250	US$234,813	US$361,250

When a correlation diagram is drawn from this table, it is as shown below. The plant price is proportional to the capacity with some bias.

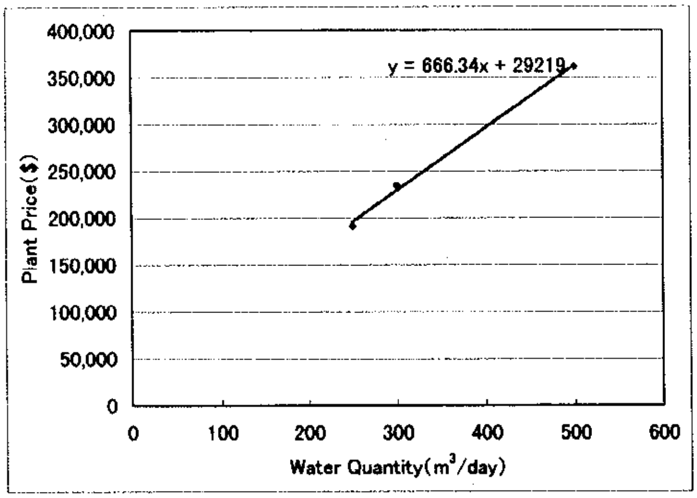

Fig.8.3-8 Prices of desalination plants by capacity

④Methods of setting the plant prices of RO method and ED method

Scale and cost for respective desalination facility is assumed as follows.

a. Assumption of desalination capacity

Based on the water demand of Kalif and the result of village survey in Badia, Hama, water production quantity in the case of RO and ED method at spot A is classified as follows.

1) RO A1-1 : 13.2m³/hr→320m³/day, A1-2 : 6.5m³/hr→160m³/day
A1-3 : 3.25m³/hr→80m³/day

2) ED A2-1 : 14.7m³/hr, A2-2 : 7m³/hr, A2-3 : 3.5m³/hr

b. Cost setting

The above-mentioned correlation equation of plant price by capacity was used to assume the prices of RO membrane plants of which capacities are equivalent to those planned to be installed in Badia. The case A1-1 of the largest capacity corresponds to 320 m³/day, and the case of the lowest capacity corresponds to 80 m³/day. Moreover, as these plants are to treat brackish water rather than seawater, one half of the above-mentioned capacities will do in practice. Thus their capacities are considerably lower than the range of application of the correlation equation. Hence we estimated the prices of plants that are comparable to the international prices by assuming the following conditions:

- Capacity for treating seawater of the case A1-1 of the largest capacity (the initial price: US$619,000) is equivalent to 160m³/day. The international price of the plant of this capacity only is estimated by the correlation equation. If prices of plants of which capacities are smaller than this value are estimated by the correlation equation, the prices of plants will drop greatly to unrealistic levels.
- Prices of other plants of RO membrane method were estimated by applying the price decrease ratio of the plant of the largest capacity. On the other hand, the international prices of plants of ED method were not available. Hence the plant prices were estimated by a method similar to that mentioned above.
- Operating costs were those based on the domestic survey for both the plants of RO membrane method and ED method.

⑤Technical conditions

The amounts of insolation at Kalif were estimated by using the data obtained from meteorological station at Zarzita. Salinity of product water was, as above-mentioned, set to be 500 μS/cm. Salinity contents are designated to satisfy the beneficiaries and to meet the Syrian standard for drinking water quality.

(3) Specifications of desalination systems

①Desalination equipment

a. Desalination system at Site A

In this study, RO membrane system with water production capacities of 13.2 m^3/hr, 6.5m^3/hr and 3.25m^3/hr and ED system with the capacity of 14.7m^3/hr and 3.5m^3/hr were examined. In case of RO membrane method, the electric conductivity is low, around 50 μ S/cm, well below the allowable level in the Syrian drinking water quality standard. To make the salinity level of the product water meet the designed 500 μ S/cm, necessary amount of well water is mixed with desalinated water.

As for the cost for operation and maintenance of the system, all the machines and spare parts were assumed to be procurable in Syria The prices of those imported from Europe, etc. were estimated to be about 70% of the market prices in Japan. The specifications based on these assumptions are shown in Table 8.3-29.

Table 8.3-29 Specifications and costs of desalination system for Site A

Item		Unit	Cases of R O Membrane Method			Cases of ED Method		
			A1-1	A1-2	A1-3	A2-1	A2-2	A2-3
Specifications	Well Water Feed	m^3/hr	20	10	5	20	10	5
	Desal. Water Prod.	m^3/hr	13.2	7	3.3	14	7	3.5
	Recovery Rate	%	50	50	50	70	70	70
	E.C. of Desal. Water (Designed	μ S/cm	50	50	50	500	500	500
	Electr. Consumption	kWh/m^3	1.89	2.8	3.0	0.85	0.85	0.85
	Max. Elec. Consum'n.	KW	25.7	16.5	9.0	15.8	8.2	4.4
	Well Water Mixed	m^3/hr	3	1.5	0.75	0	0	0
	Product Water	m^3/hr	13	6.5	3.25	14	7	3.5
Initial Cost	Equipment	US$	619,000	374,000	248,000	508,000	435,000	362,000
	Civil Work	US$	76,000	53,200	44,600	76,000	53,200	44,600
	Total	US$	695,000	427,200	292,600	584,000	488,200	406,600
Running Cost	Consumables	US$/$m^3$	0.05	0.05	0.05	0.03	0.03	0.03
	Spare parts	US$/$m^3$	0.08	0.81	0.90	0.79	1.06	1.27
	Labor	m^3	0.21	0.04	0.09	0.02	0.04	0.09

b. Desalination at Site B

It is assumed that a desalination system is to be introduced to Site B of which salinity contents are higher than that of Site A. The desalinated water production capacity of the system is about 10m^3/hr. Both systems of RO and ED are considered. The particulars for the examination are shown in Table 8.3-30.

Table 8.3-30 Specifications and costs of desalination system for site B

Item		Unit	Cases of R O Membrane	Cases of ED
			B1	B2
Specifications	Well Water Feed	m³/hr	20	13.3
	Desal. Water Prod.	m³/hr	10	10
	Recovery Rate	%	50	75
	E.C. of Desal. Water (Designed)	μ S/cm	500	500
	Electr. Consumption	kWh/m³	1.89	2.9
	Max. Elec. Consum'n.	KW		
	Well Water Mixed	m³/hr	3	0
	Product Water	m³/hr	11	10
Initial Cost	Equipment	US$	619,000	553,000
	Civil Work	US$	76,000	61,000
	Total	US$	695,000	614,000
Running Cost	Consumables	US$/m³	0.08	0.05
	Spare parts	US$/m³	0.80	1.75
	Labor	US$/m³	0.02	0.03

②PV system

In each case, the scale of PV system driving desalination system is planned taking into consideration of on raw water, pumping up, produced water and operation hours of desalination, based on typical insolation in November when sun is declining. The installation cost and work cost of PV system for desalination is estimated on reference to actual data of the centralized PV system in Zarzita and the desalination system in Kalif.

For reducing installation cost, inverter controller is adopted outside type. Further, the battery capacity is selected minimum where it is houses the box fabricated on the site. Those cost data is shown in the Table 8.3-31.

Table 8.3-31 Cost for PV system

	Item	Unit	Cases of R O Membrane Method				Cases of ED Method			
			A1-1	A1-2	A1-3	B1	A2-1	A2-2	A2-3	B2
Equipment Spec.	PV module	KW	48	36	18	48	31	16	8.4	74.4
	Inverter	KW	30	20	10	30.0	20	10	5	40
	Controller	A	200	200	100	200	170	90	50	310
	Battery	kWh	96	72	36	96	72	36	21.6	144
	Pump	kW	2.2	1.5	1.1	2.2	2.2	1.5	1.1	2.2
Installation Cost	PV module	US$	144,000	108,000	54,000	144,000	91,800	48,600	25,200	223,200
	Inverter	US$	15,000	10,000	5,000	15,000	10,000	5,000	2,500	20,000
	Controller	US$	1,000	1,000	500	1,000	850	450	250	2,550
	Battery	US$	4,000	3,000	1,500	4,000	3,000	1,500	900	6,000
	Pump	US$	5,050	4,040	3,670	5,050	5,050	4,040	3,670	4,640
	Installation	US$	11,790	9,489	6,309	11,790	7,881	5,022	4,187	20,432
	Total Cost	US$	180,840	135,529	70,979	180,840	118,581	64,612	36,707	276,822

(4) Study results

①Pumping rate / daily operable hours of desalination system

Consumption of desalination system varies depending on production rate, operation hours, etc. Usually, desalination system is operated continuously without repetition of shut down and startup for the sake of keeping the product water quality constant. To certify the amount of fresh water to be produced a day, it is necessary to clarify the operation hours of pumping and desalination system.

On the other hand, it is characteristic that PV module itself heats up in generating power, which causes decrease in output. This decrease has to be taken into consideration in designing the power output of PV system. Meteorological data of insolation and air temperature are required for the designing. In this study these figures at the sites were estimated based on actual data obtained 1997 through 1998. The profile of these figures can be assimilated to quadratic curve as shown in Table. 8.3-32,8.3-33.

Table 8.3-32 Atm. temperature at Zarzita

Month	Formula	R^2
1	$T=-0.0541h^2+1.4602h-2.0993$	0.8396
2	$T=-0.0730h^2+2.0437h-0.1559$	0.9206
3	$T=-0.0759h^2+2.0656h-3.8801$	0.9415
4	$T=-0.1021h^2+2.8315h-1.4102$	0.9320
5	$T=-0.1393h^2+3.6474h-1.1473$	0.9246
6	$T=-0.1549h^2+4.0589h-2.2097$	0.9622
7	$T=-0.0547h^2+1.3719h-0.5639$	0.8553
8	$T=-0.0710h^2+1.9382h-2.1444$	0.8752
9	$T=-0.1114h^2+2.7186h-2.8122$	0.9560
10	$T=-0.1400h^2+3.6423h-3.2413$	0.9498
11	$T=-0.1414h^2+3.7101h-5.9482$	0.9487
12	$T=-0.1408h^2+3.7271h-6.1786$	0.9561

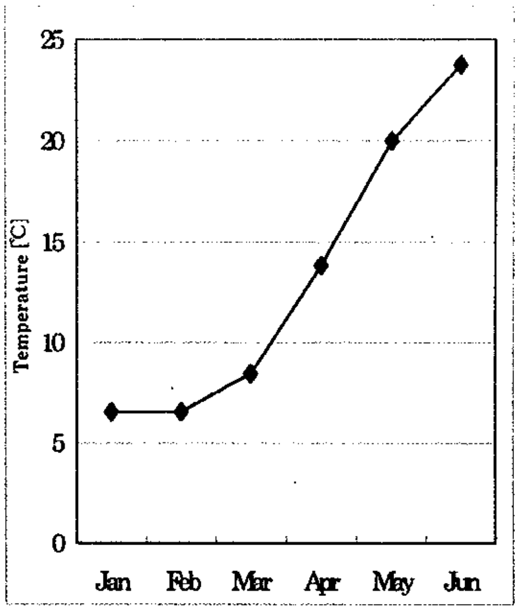

Fig.8.3-9 Atm. temperature at Zarzita (January – June)

Table 8.3-33 Atm. insolation at Zarzita

Month	Formula	R^2
1	$T=-0.0125h^2+0.2792h-1.1444$	0.7419
2	$T=-0.0177h^2+0.4041h-1.6913$	0.8982
3	$T=-0.0174h^2+0.3968h-1.6212$	0.9305
4	$T=-0.0180h^2+0.4056h-1.6026$	0.9431
5	$T=-0.0203h^2+0.4601h-1.8092$	0.9529
6	$T=-0.0210h^2+0.4727h-1.8280$	0.9449
7	$T=-0.0169h^2+0.3750h-1.4932$	0.8375
8	$T=-0.0115h^2+0.2591h-1.0630$	0.8153
9	$T=-0.0211h^2+0.4708h-1.8525$	0.8986
10	$T=-0.0219h^2+0.4883h-1.8814$	0.9273
11	$T=-0.0215h^2+0.4864h-1.9081$	0.9401
12	$T=-0.0229h^2+0.5170h-2.0470$	0.9375

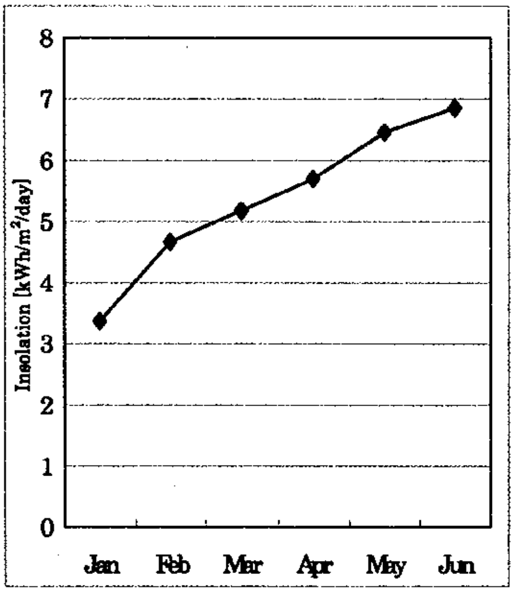

Fig 8.3-10 Atm. insolation at Zarzita (January – June)

Based on the above-mentioned, PV system output can be estimated by the following equation.

$$P_t = C \times I_t \times (1 - 0.005 \times (T_t - \alpha)) \times \beta \times \gamma$$

Here,

P_t : PV system power output, [kW]

C : System power output [kW]

0.005 : Coefficient of power output reduction by temperature increase [/℃]

I t : Insolation at time t [kW/㎡]

T t : Atmospheric temperature at time t [℃]

α : Atmospheric temperature at 20℃ of PV cell (Estimated to be 5℃)

β : Output reduction rate caused by smeared surface, wiring loss, etc. (0.05)

γ : Decrease in battery terminal voltage (0.85)

The estimation was conducted on all the cases.

②Well water pumping and desalination quantity

The operation hours of pumping, the amount of pumped water and the fresh water production rate are indicated in Tables 8.3-34 and 8.3-35.

Table 8.3-34 Operable hours of PV water pump and water pumping quantity

Case	Quantity	Daily average operation hours [hr]											
	[m³/hr]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A1-1	22.2	4.5	6.9	7.2	7.5	8.7	8.9	8.9	9.0	8.9	8.1	6.3	4.4
A1-2	12.0	4.3	6.5	7.0	7.1	8.2	8.5	8.4	8.5	8.5	7.7	6.0	4.1
A1-3	9.0	2.8	4.2	4.4	4.6	5.3	5.4	5.4	5.4	5.4	4.9	3.8	2.7
A2-1	22.2	4.3	6.6	7.0	7.2	8.2	8.5	8.5	8.7	8.5	7.8	6.0	4.2
A2-2	12.0	4.0	6.2	6.5	6.8	7.8	8.0	8.0	8.1	8.0	7.3	5.6	4.0
A2-3	9.0	2.9	4.4	4.6	4.8	5.5	5.7	5.7	5.8	5.7	5.2	4.0	2.8
B1	22.2	4.5	6.9	7.2	7.5	8.7	8.9	8.9	9.0	8.9	8.1	6.3	4.4
B2	16.2	4.3	6.6	6.9	7.2	8.2	8.5	8.5	8.6	8.5	7.7	6.0	4.1

Case	Quantity	Total amount of pumped water for each month [m³]												
	[m³/hr]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
A1-1	22.2	3,097	4,289	4,955	4,995	5,987	5,927	6,125	6,194	5,927	5,574	4,196	3,028	60,294
A1-2	12.0	1,600	2,184	2,604	2,556	3,050	3,060	3,125	3,162	3,060	2,864	2,160	1,525	30,950
A1-3	9.0	781	1,058	1,228	1,242	1,479	1,458	1,507	1,507	1,458	1,367	1,026	753	14,864
A2-1	22.2	2,959	4,103	4,817	4,795	5,643	5,661	5,850	5,987	5,661	5,368	3,996	2,890	57,730
A2-2	12.0	1,488	2,083	2,418	2,448	2,902	2,880	2,976	3,013	2,880	2,716	2,016	1,488	29,308
A2-3	9.0	809	1,109	1,283	1,296	1,535	1,539	1,590	1,618	1,539	1,451	1,080	781	15,630
B1	22.2	3,097	4,289	4,955	4,995	5,987	5,927	6,125	6,194	5,927	5,574	4,196	3,028	60,294
B2	16.2	2,159	2,994	3,465	3,499	4,118	3,315	4,269	4,319	4,131	3,867	2,916	2,059	41,111

Table 8.3-35 Operable hours and fresh water production quantity

Case	Quantity	Daily average operable hours [hr]											
	[m³/hr]	1	2	3	4	5	6	7	8	9	10	11	12
A1-1	13.2	4.9	7.6	8.0	8.3	9.6	9.8	9.8	10.0	9.8	9.0	6.9	4.8
A1-2	6.5	5.1	7.8	8.3	8.5	9.8	10.1	10.0	10.2	10.1	9.2	7.1	4.9
A1-3	3.3	4.8	7.3	7.7	8.0	9.2	9.4	9.4	9.4	9.5	8.6	6.7	4.6
A2-1	14.0	4.7	7.3	7.7	8.0	9.1	9.4	9.4	9.6	9.4	8.6	6.6	4.6
A2-2	7.0	4.8	7.4	7.8	8.1	9.3	9.5	9.5	9.7	9.5	8.7	6.7	4.7
A2-3	3.5	5.0	7.6	8.1	8.4	9.6	9.9	9.9	10.1	9.9	9.1	7.0	4.8
B1	10.7	4.9	7.6	8.0	8.3	9.6	9.8	9.8	10.0	9.8	9.0	6.9	4.8
B2	10.0	5.2	8.0	8.4	8.7	10.0	10.3	10.3	10.5	10.3	9.4	7.3	5.0

Case	Quantity	Monthly fresh water production [m³]												
	[m³/hr]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
A1-1	13.2	2,005	2,809	3,274	3,287	3,928	3,881	4,010	4,092	3,881	3,683	2,732	1,964	39,546
A1-2	6.5	1,028	1,420	1,672	1,658	1,975	1,970	2,015	2,055	1,970	1,854	1,385	987	19,989
A1-3	3.3	484	664	776	780	927	917	947	947	926	866	653	463	9,350
A2-1	14.0	2,040	2,862	3,342	3,360	3,949	3,948	4,080	4,166	3,948	3,732	2,772	1,996	40,195
A2-2	7.0	1,042	1,450	1,693	1,701	2,018	1,995	2,062	2,105	1,995	1,888	1,407	1,020	20,376
A2-3	3.5	543	745	879	882	1,042	1,040	1,074	1,096	1,040	987	735	521	10,584
B1	10.7	1,625	2,277	2,654	2,664	3,184	3,146	3,251	3,317	3,146	2,985	2,215	1,592	32,056
B2	10.0	1,612	2,240	2,604	2,610	3,100	3,193	3,193	3,255	3,090	2,914	2,190	1,550	31,551

③Other assumptions for cost calculation

In calculating the cost, the interest rate is set at 6.5%. As for the rate of inflation, two cases, namely, 0% and 3%, are considered. Expected lives of the components of PV system and desalination system are as shown in Table 8.3-36.

Table 8.3-36 Expected lives of system components

	Item	Life [year]	Remark
PV system	PV	20 (30)	( ) is case of 10 years extension of useful life
	Inverter	10	
	Controller	10	
	Battery	3	
	Structure	20 (30)	
Desalination system	Desalination facility	20 (30)	
	Structure	20 (30)	

④Evaluation of desalination systems

a. Produced water cost at Site A

Water cost is discussed based on annual produced water with parameters the scale of desalination system, for both RO and ED respectively.

- In the same scale of desalination system on RO and ED, respectively, produced water would be nearly same. Usually, produced water is increasing due to lengthen sunshine hours from February to August and gradually decreasing from September. During the least insolation in winter, producing water become minimum, but fortunately living water would be expected from rainfall to be useful. Also, the diluted water from desalination system is useful for livestock.

- If water consumption is about 15l/day/person, How many people could provide for living water is shown in the Table 8.3-37.

Table 8.3-37 No. of people supplied drinking water (Oct.)

Scale / Supply	A1-1	A1-2	A1-3	Remark
No. of people	7,920	3,987	1,862	Supply amount 15l/day/person

Under the above-mentioned conditions, the mean cost of desalinated water throughout the year is as shown in Table 8.3-38. Findings include the following:

Table 8.3-38 Desalination water cost at Site A

a) RO Membrane method

Item			A1-1			A1-2			A1-3		
			Capability of producing water 13.2[m^3/h] Water 39,546[m^3/year]			Capability of producing water 6.5 [m^3/h] Water 19,989[m^3/year]			Capability of producing water 3.25 [m^3/h] Water 9,350 [m^3/year]		
Condition	Item	Unit	PV	Desalination	Total	PV	Desalination	Total	PV	Desalination	Total
Life: 20 year Inflation rate: 0%	Fixed cost	$	12,997	19,740	32,737	9,776	12,588	22,364	5,259	9,193	14,452
	Variable	$	396	34,623	35,019	298	18,129	18,427	159	9,825	9,984
	Annual cost	$	13,393	54,363	67,756	10,074	30,717	40,791	5,418	19,018	24,436
	Fixed cost	$/$m^3$	0.33	0.50	0.83	0.49	0.63	1.12	0.56	0.98	1.54
	Variable	$/$m^3$	0.01	0.88	0.89	0.01	0.91	0.92	0.02	1.05	1.07
	Cost	$/$m^3$	0.34	1.38	1.72	0.50	1.54	2.04	0.58	2.03	2.61
Life: 20 year Inflation rate: 3%	Fixed cost	$	13,336	19,740	33,076	10,027	12,588	22,614	5,412	9,193	14,605
	Variable	$	530	46,334	46,864	399	24,261	24,660	212	13,149	13,361
	Annual cost	$	14,585	66,074	80,659	10,426	36,849	47,818	5,624	22,342	28,286
	Fixed cost	$/$m^3$	0.34	0.50	0.84	0.50	0.63	1.13	0.58	0.98	1.56
	Variable	$/$m^3$	0.01	1.17	1.18	0.02	1.21	1.23	0.02	1.41	1.43
	Cost	$/$m^3$	0.35	1.67	2.02	0.52	1.84	2.36	0.60	2.39	2.99
Life: 30 year Inflation rate: 0%	Fixed cost	$	11,346	19,740	31,086	8,528	12,588	21,116	4,613	9,193	13,806
	Variable	$	396	34,623	35,019	298	18,129	18,427	159	9,825	9,984
	Annual cost	$	11,742	54,363	66,105	8,826	30,716	39,543	4,772	19,018	23,790
	Fixed cost	$/$m^3$	0.29	0.50	0.79	0.43	0.63	1.06	0.49	0.98	1.47
	Variable	$/$m^3$	0.01	0.88	0.89	0.01	0.91	0.92	0.02	1.05	1.07
	Cost	$/$m^3$	0.30	1.38	1.68	0.44	1.54	1.98	0.51	2.03	2.54

Interest rate 6.5%

b) ED method

Item			A2-1			A2-2			A2-3		
			Capability of producing water 14 [m^3/h] Water 40,193 [m^3/year]			Capability of producing water 7 [m^3/h] Water 20,376 [m^3/year]			Capability of producing water 3.5 [m^3/h] Water 10,584 [m^3/year]		
Condition	Item	Unit	PV	Desalination	Total	PV	Desalination	Total	PV	Desalination	Total
Life: 20 year Inflation rate: 0%	Fixed cost	$	8,691	17,437	26,128	4,834	13,853	18,687	2,884	11,558	14,443
	Variable	$	261	33,956	34,217	144	23,178	23,322	84	14,839	14,923
	Annual cost	$	8,952	51,393	60,345	4,978	37,031	42,009	2,968	26,397	29,366
	Fixed cost	$/$m^3$	0.22	0.43	0.65	0.24	0.68	0.92	0.27	1.09	1.36
	Variable	$/$m^3$	0.01	0.84	0.85	0.01	1.14	1.15	0.01	1.40	1.41
	Cost	$/$m^3$	0.23	1.27	1.50	0.25	1.82	2.07	0.28	2.49	2.77
Life: 20 year Inflation rate: 3%	Fixed cost	$	8,958	17,437	26,395	4,993	13,853	18,846	2,996	11,558	14,554
	Variable	$	349	45,442	45,791	193	31,018	31,211	113	19,859	19,972
	Annual cost	$	9,828	62,879	72,186	5,496	44,871	50,367	3,109	31,417	34,735
	Fixed cost	$/$m^3$	0.22	0.43	0.65	0.25	0.68	0.93	0.28	1.09	1.37
	Variable	$/$m^3$	0.01	1.13	1.14	0.01	1.52	1.53	0.01	1.88	1.89
	Cost	$/$m^3$	0.23	1.56	1.81	0.26	2.20	2.46	0.29	2.97	3.26
Life: 30 year Inflation rate: 0%	Fixed cost	$	7,633	17,437	25,070	4,262	13,853	18,115	2,566	11,558	14,124
	Variable	$	261	33,956	34,217	144	23,178	23,322	84	14,839	14,923
	Annual cost	$	7,894	34,217	59,287	4,406	37,031	41,437	2,650	26,397	29,047
	Fixed cost	$/$m^3$	0.19	0.43	0.62	0.21	0.68	0.89	0.24	1.09	1.33
	Variable	$/$m^3$	0.01	0.84	0.85	0.01	1.14	1.14	0.01	1.40	1.41
	Cost	$/$m^3$	0.20	1.27	1.47	0.22	1.82	2.03	0.25	2.49	2.74

Interest rate 6.5%

Under the above-mentioned conditions, findings include the following:

- Greater the system capacity, lower cost of desalinated water. For instance, when production rate is about 10m^3/hr, desalinated water cost is US\$2.38/m^3 for ED, and US\$2.80/m^3 for RO. Water cost of ED is about US\$0.5/m^3 cheaper than RO.
- As for cost characteristics of desalination, water cost of RO tends to decrease with increase in capacity. On the other hand, cost of ED is substantially constant.
- If inflation rate is assumed to be 3 %, produced water cost increases about 1%.
- Life is extended from 20 years to 30 years, effect on produced water cost is a decrease by about 10 %.

b. Desalinated water cost at Site B

At Site B, the salinity content is higher than that of Site A. The unit cost of desalinated water of RO and that of ED are compared with each other. Both systems are of the same capacity.

- Water desalination capacity of RO system is 10.7m^3/hr, and that of ED system is 10.0m^3/hr. The quantity of desalinated water by month of ED system is a little lower than that of RO system.
- As for a number of people who can receive drinking water from these systems, when it is judged from the quantities of desalinated water in October, RO system can supply water to about 6,320 persons and ED system about 6,270 persons, respectively.
- When salinity contents rises, RO method is more advantageous than ED method in terms of desalinated water cost. When the useful life is 20 years and inflation rate is 0%, the water cost is US\$3.29/m^3 for RO, and that for ED is US\$4.23/m^3, respectively; the latter is higher by about 30%.

Table 8.3-39 Desalination water cost at Site B

Item			RO			ED		
			Capability of producing water 10.7 [m³/h] Water 32,056 [m³/year]			Capability of producing water 10 [m³/h] Water 31,551 [m³/year]		
Condition	Item	Unit	PV	Desalination	Total	PV	Desalination	Total
Life: 20 year Inflation rate: 0%	Fixed cost	$	12,997	15,016	28,012	19,707	12,789	32,496
	Variable	$	396	28,993	29,389	607	57,854	58,461
	Annual cost	$	13,392	44,009	57,401	20,314	70,643	90,957
	Fixed cost	$/m³	0.41	0.47	0.88	0.62	0.41	1.03
	Variable	$/m³	0.01	0.90	0.92	0.02	1.83	1.85
	Cost	$/m³	0.42	1.37	1.79	0.64	2.24	2.88
Life: 20 year Inflation rate: 3%	Fixed cost	$	13,336	15,016	28,352	20,148	12,789	32,937
	Variable	$	530	38,801	39,331	813	77,424	78,237
	Annual cost	$	14,586	53,817	67,683	21,982	90,213	112,195
	Fixed cost	$/m³	0.42	0.47	0.89	0.64	0.41	1.05
	Variable	$/m³	0.02	1.21	1.23	0.03	2.45	2.48
	Cost	$/m³	0.44	1.68	2.12	0.67	2.86	3.53
Life: 30 year Inflation rate: 0%	Fixed cost	$	11,346	15,016	26,361	17,108	12,789	29,897
	Variable	$	396	28,993	29,389	607	57,845	58,461
	Annual cost	$	11,741	44,009	55,751	17,715	70,643	88,358
	Fixed cost	$/m³	0.35	0.47	0.82	0.54	0.41	0.95
	Variable	$/m³	0.01	0.90	0.91	0.02	1.83	1.85
	Cost	$/m³	0.36	1.37	1.73	0.56	2.24	2.80

Interest rate 6.5%

Desalination systems using PV systems have been examined in many aspects. The prices of water desalinated by these systems are still high, and it would be difficult for these prices to be competitive at the time of introduction. However, considering the present conditions in Syria, or strained balance between water demand and supply and decreased quality of groundwater, we firmly believe that the desalination systems would play an important role in improving such water conditions. The cost of the desalination systems could be reduced by technological innovations in future.

8.4 Summary of findings

In this chapter, economic analysis of PV systems was carried out and proposal on the planning materials of PV systems were considered. The findings will be summarized as follows:

(1) Decreasing trend of unit prices of PV system components

Development of PV systems has been accelerated in the advanced industrial countries, and due to improvements of components and trends of mass production, the unit prices of these components are showing a tendency to decrease. It is economically very significant to properly grasp these technical trends and promote expansion of PV systems in Syria.

(2) Economic analysis of PV systems

If kerosene lamp and battery-powered TV in un-electrified villages are substituted by 60W individual PV system around 2005, ratio of the cost of the former to the cost of the latter is about 4 : 1. It is much economical to use PV system.

In the above-mentioned case, if the cost of the former for 20 years, which is the useful life of PV system, is considered as the benefit, discount rate which the cost of the latter will equal the benefit, or EIRR is about 70%. Thus PV systems in un-electrified villages are very advantageous.

(3) Proposal of materials for a plan of PV systems

The year 2005 was set as the target data of development, and various applications of PV systems, in particular, electrification and pumping/desalination were examined by mainly assuming the generating cost and water cost.

①Electrification with PV systems

As for PV systems, individual PV systems and mini-centralized PV systems were examined. Centralized PV system, which was installed in Zarzita, was out of scope because there are few similar villages in Syria.

a. Individual PV systems

Five kinds of individual PV systems, of which module capacity ranges from 60 W, (multiples of 120W), to 480W, were examined. The results are as follows:

- An interest rate of 6.5%, inflation rate of 0%, useful life of 20 years, and batteries for PV system (useful life of 5 years) were used as the standard conditions for calculation of generating cost. Generating cost of 60W individual PV system is US$0.54/kWh, and that of 480W system is US$0.444/kWh.

- Wet type batteries having a useful life of 10 years have been developed. When such batteries are used, the unit cost (US$/Ah) increases. As a result, the generating cost is increased by about 10%. Use of Syrian batteries, of which useful life is three years, rather than the standard batteries increases the generating cost by 20%. Accordingly, further efforts are needed to improve Syrian batteries.
- If the useful life of PV systems is extended by 10 years from that of the standard conditions, the generating cost will decrease by about 10%. If inflation is 3%/year, generating cost will increase by about 7%.

b. Mini-centralized PV systems

As for the sizes of mini-centralized PV systems, three cases, 960W, 2040W and 3000W, were examined. These PV systems can supply electricity from several to ten-plus houses that are adjacent to each other; the number of houses depends on the size of these houses. The line distances of underground cables change with the adjacent conditions of these houses and, in turn, have effects on the generating cost. Here, for simplicity, two cases, average line distance of 30m and average line distance of 60m, were examined.

- When the average line distance is 30m, generating costs of mini-centralized PV systems are a little higher than those of individual PV systems. When the average line distance gets longer to 60m, cost of cables will get larger, and generating costs, depending on system scale, will increase by about 7 to 10%.
- As mini-centralized PV systems are shared by customers, their capacity factors are higher than those of individual PV systems. Moreover, daytime surplus power by mini-centralized PV systems can be utilized. Even if these villages are eventually electrified by grid extension, as these systems are large in size, they can be used for grid connection through inverters. However, individual PV systems are small in size and inverter is necessary to connect to grid line. This inverter is more expensive, it will be necessary to reinstall and use them in some other rural areas.
- One example of use of surplus power by mini-centralized PV systems is water pumping. By assuming that a well is present near the installation site, we

examined water pumping. Pumping quantity depends on a depth of well and insolation. In summer, when demand and supply conditions of drinking water is tight, several hundreds cubic meters of water can be pumped at a unit price of pumping of US\$1/m^3 or less. As PV system is friendly to the environment, and unlike diesel-powered pumps, PV-powered pumps do not make excessive pumping. In this case, although surplus power is free, new additional investments related to the pump and water supply tank are taken into consideration.

c. Comparison of generating cost of PV system and grid extension

- If we assume that capacity factor of the electrified village is about 10% just like that of PV systems, when the number of households is 70 in the village and the distance from existing grid lines to the village is 5km or over, it will be more economical to install PV systems.
- Even if demand increases in the village and the annual load factor increases from 10% to 30%, unless demand of each house increases to 300W or over, grid extension is not economical.
- It is rational from the viewpoint of economical equipment investment that the Electric Authority gives an emphasis on village scale in its policy of electrification of un-electrified villages. In future the Electric Authority will be expected to consider introduction of PV system as an alterative power supply system.

d. Comparison of generating cost of PV system and diesel power generation

- Capacity of diesel power generation systems that is available in Syria is 5kW, and the useful life of such systems is considered to be 10 years. As for this diesel power generation, the supply condition of diesel power generation of which generating cost is comparable to that of PV system is that when the number of households is three and power demand of each household should be 500W or over. When the number of households is six, the required power demand drops to 300W. Accordingly, diesel power generation is economical when a fairly large number of households are present.
- Electrification with diesel power generation in Syria is difficult to find, probably because it might compete with the Electric Authority. Electrification with diesel power generation is accompanied with noise, and if careful maintenance is not

made, the metal may be damaged. Furthermore, as electricity cannot be stored, the operation of the system till midnight is not desirable because of the noise.

②Water pumping with PV system

Diesel engines are used extensively in agricultural villages in Syria to pump water for drinking and irrigation. Here we compared the unit price of pumping with PV system, being an alternative power source for pumping, and that of pumping with a diesel engine. Facilities that are common to both systems are excluded from this comparison. Comparison was carried out by giving attention to the difference of both systems. Pumping water quantity of diesel engine is assumed to be equal to that of PV systems.

- Range in which the unit cost of pumping with PV systems is more advantageous than that of pumping with diesel engine is up to the head of 60m when the pump discharge is $5m^3$/day. When the pump discharge is $10m^3$/day, the advantageous range is reduced to the head of 40m. When the useful life of PV system is extended to 30 years or when inflation rate is 3%/year, economics of pumping with PV system will be improved more than those of pumping with diesel engine.
- Fields of application of pumping with PV system having the above-mentioned characteristics include, because PV system is maintenance-free, pumping of drinking water, drip irrigation, and pumping of drinking water for livestock kept in extensive grazing land.