4.3.3 Problems Encountered at Well Drilling

(1) Drilling Problem and Borehole Geology

Following problems occurred to the well drilling in the Nejd and were pointed out in PAWR report 86-I-12 and 13.

a) Inter-aquifer groundwater flow and leakage to fissures due to the piezometric difference between aquifers.

b) Loss of water resource and degradation of water quality by intrusion of poor quality water into good quality aquifer as the result above.

c) Deterioration of water quality contaminated by gypsum and other evaporites in Rus formation.

d) Collapse incurred by drilling in marl and shale formation and enlargement of borehole diameter.

It had been anticipated that these problems could arise during the drilling works, so aforementioned casing programme was examined and formulated in order to tap the top of lower UER aquifer exclusively. The work could accomplish the objectives and achieved the results as expected.

During the drilling work, the following borehole geology was clarified.

1) Marl in Rus formation

There was a marly horizon which causes collapse during drilling, mentioned in d) above. The horizon of this marl was found confirmable by cutting sample and borehole logging. In case of borehole logging, this particular horizon tended to have caliper enlarged and relatively higher natural gamma ray emission.

This horizon was detected at around 80 m in depth in all the project boreholes. Drilling discharge was found to increase and electric conductivity of the discharged water changed from 2,000 μS/cm to 5,000 μS/cm and more at this level.

2) Gypsum and evaporites in Rus formation

Under the marly horizon 1), gypsum and evaporite of high electric resistivity follows. This sequence had been observed in previous drillings of other project. Discharged water showed high electric conductivity in continuation with the upper horizon.

3) Lower Rus aquifer

This aquifer was detected at NJD-1, 2 and 3, but for 4. The aquifer had not always been detected also in the past drillings. Some inter-aquifer water exchange probably proceeds between this aquifer and overlying aquifers. Water quality was poor with electric conductivity of 4,000 μS/cm.

4) Aquifer at the top of upper UER formation

This was encountered at around 170 m in depth at each drilling. Water quality was poor. Intra-borehole flow loggings confirmed that this aquifer was one of the thief zones, which could cause inflow from other pressured aquifers.

5) Aquifer at the top of lower UER formation

This was the main target aquifer of this project. The aquifer was in an artesian condition and the water could flow at the surface when the drilling locality was selected in the northern depressed area.

The out-flow did not start suddenly, but the rate gradually increased below a certain depth, and was accelerated at the depth of 5 to 10 meters below this. This same tendency was experienced in other drillings.

These remarkable aspects are summarized with supplements from the precedent drilling data in FIG.4.3.2. Borehole loggings and recommendable casing program are also presented in it.

(2) Precautionary Points of Well Construction

Adequate installation of casing and effective cementing are the only solution to prevent leakage or inter-aquifer flow in the well.

These can be successfully done if the borehole conditions are grasped correctly during drilling.
Precautionary points for casing installation are summarized in the followings.

1) Precautionary points to Rus formation

A horizon of marl in Rus formation causes collapse of borehole and deterioration of water quality.

This horizon has to be cemented and sealed off from the lower horizons, achieving the sealing of gypsum and evaporites in it.

For the sake of this work, it is necessary to monitor the drilling discharge rate and its electric conductivity. Examination of cutting samples is also indispensable.

Drilling should be stopped before encountering the fissured zone of lower UER and casing installation and cementing work should be carried out.

Natural gamma emission, resistivity, borehole caliper, temperature, electric conductivity and borehole water flow should be logged before installation work.

Casing shoe has to be used for cementing and sufficient cement milk has to be injected into the annular space of casing from the bottom.

In case the recurrence of cement milk is not confirmed at the ground surface, another injection should be done from the top.

In short, the annular space must be sealed off completely.

2) Leakage sealing of upper UER formation

After accomplishing the sealing of Rus, drilling of upper UER shall proceed with a smaller diameter drilling bit than the final one. This can avoid the danger when unexpectedly high water pressure is to be encountered (PAWR, 1986).

There is a less pressured aquifer at the top of upper UER. This aquifer is located 20 to 30 meters above the first peak of the remarkable five-peak gamma radiation anomaly horizon. Electric conductivity logging indicates that some amount of poor quality water discharges from this horizon.

When drilling depth approaches to the top of lower UER, drilling discharge starts to increase gradually.

Drilling should be stopped before reaching this level, and borehole geology should be examined by loggings.

After this, the temporary borehole shall be reamed to the designed diameter to the depth of cementing.

Casing shall be installed and cementing shall be carried out.

Reaming work provides a good effect to decrease the water discharge, if there are any, by the accumulation of cuttings at the borehole bottom.

Consequently, cementing will proceed more perfectly.

(3) Summary of Recommendable Drilling Procedure by Stages.

1) Commencement to first casing installation

Surface casing shall be installed to prevent collapse of surface loose deposits.

2) Drilling of Dammam to upper UER

Monitoring of drilling discharge and its electric conductivity, and observation of cuttings are indispensable. The horizon of marl, gypsum/evaporites and fissures can be estimated in reference to the informations availed above.

Drilling shall be stopped before encountering the fissured zone between Rus and upper UER.

In case of no encounter, drilling shall be stopped above the estimated boundary level.

3) First borehole logging

Borehole logging shall follow the above in order to confirm the horizons of marl, gypsum/evaporites and fissures. Intra-borehole water flow shall be logged as well.

4) Second casing installation and cementing

After the logging, casing shall be installed and cementing shall be done.

The annular space between borehole and casing shall be completely cemented.

5) Drilling of upper UER to lower UER

After cementing, the second stage drilling shall be started with a drilling bit of smaller diameter than the final one.

Drill cuttings shall be examined continuously, and drilling discharge and its electric conductivity shall be monitored.

Drilling shall be stopped above the fissured zone of lower UER.

6) Second borehole logging

Reaming depth shall be determined by the logging analyses.

7) Reaming of borehole

The borehole shall be reamed to the final diameter down to the determined depth.

8) Third casing installation and cementing

Casing shall be installed and cementing shall be done. Casing bottom shall be attached with a perforated casing pipe and a cementing collar shoe. The bottom shall be cement-plugged. Bottom sealing shall be attained as much as possible.

9) Drilling of lower UER

Lower UER shall be drilled as a major exploitation aquifer.

10) Third borehole logging

The drilling work shall be finalized by the borehole logging, and the borehole condition shall be confirmed finally.

(4) PAWR supplementaries for the drilling procedure. Following points were supplemented by the PAWR drilling experts.

1) Better drilling practices to control the serious collapse of the Marls. The use of proper stiff-foam combinations and lower air volume.

2) The control of loss circulation and dry fissures before drilling proceeds, especially in the Rus formation by sealing the zones before further drilling.

3) All formations to be isolated so accurate information is available regarding the aquifers in each formation, especially the aquifer heads.

4) Drilling is not to penetrate the upper UER or the lower UER aquifers under any circumstances before the cement grouting of the casing is made immediately above.

5) All grouting data to be provided as this data should furnish the information required to prove the well was successfully grouted. This data must be reported by the contractor and presented with his daily reports.

6) Specific tests (pressure & additional logging) to be carried out to guarantee the grouting of the casing was successful with no leakage occurring.

7) Use of a well-known brand of cementing shoe in all cementing work.

FIG. 4. 3. 2

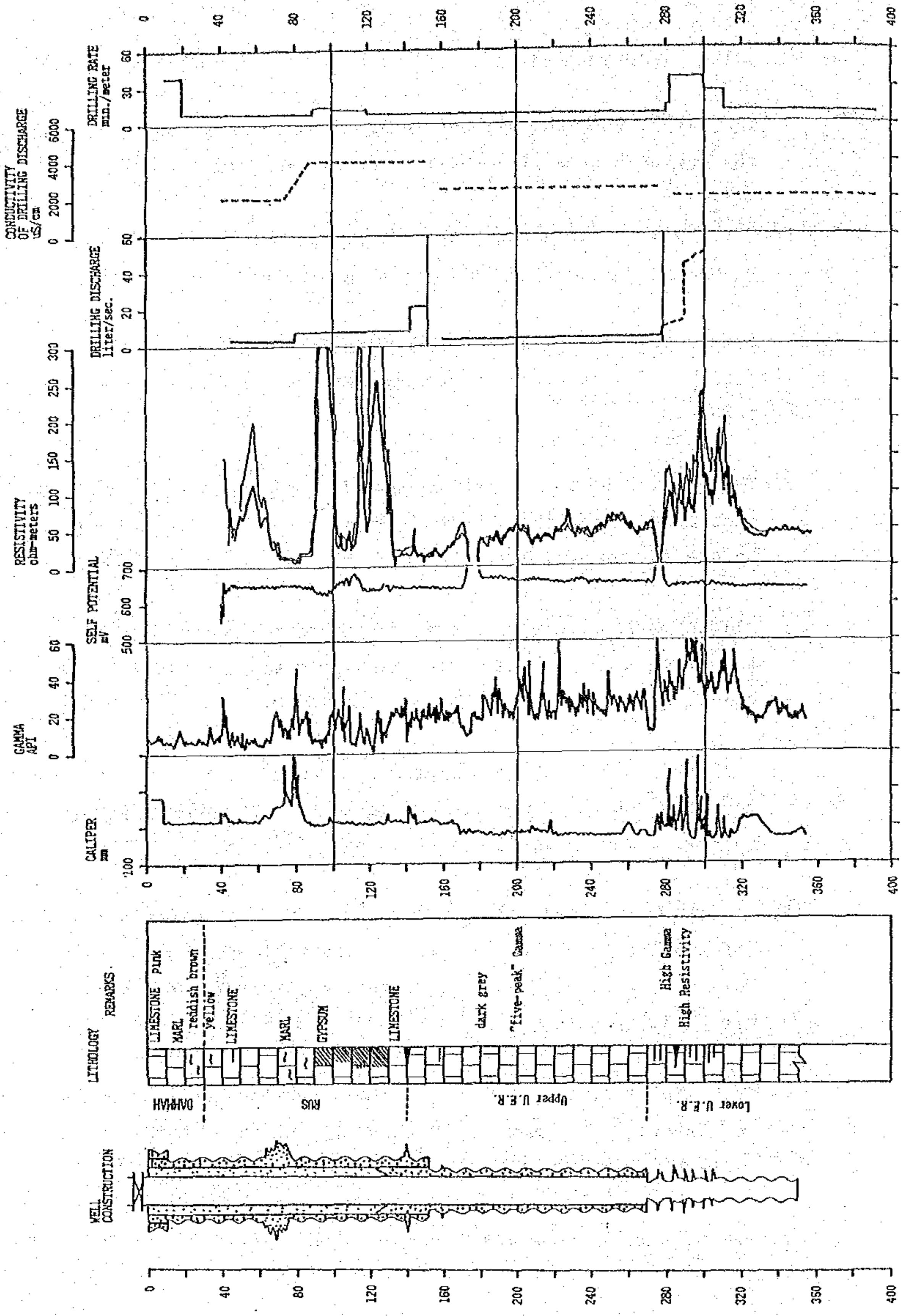


FIG. 4. 3. 2 Well Structure and Project Site Bore Hole Log

4.4 Groundwater Resources Evaluation

Three models of regional groundwater systems are formulated based on the field results and previously published data, namely,

1) Isolated confined aquifer model.

2) Residual gradient model without groundwater recharge.

3) Residual gradient model with groundwater recharge.

These models provide less limitation over the resources in the descending order.

4.4.1 Isolated Confined Aquifer Model

As the most conservative model for the groundwater resources, isolated confined aquifer model can be adopted. This model provides a minimum estimation of the available resource.

The model supposes an isolated stagnant water mass at depth, which is conceivable due to fairly homogeneous radio-carbon ages of the concerned groundwater, reported in the PAWR report, and semi-oval pattern of iso-quality (EC) contours in a relatively small piezometric head gradient zone.

A region of elliptic shape, with major axial length of 160 km (SW-NE) and minor axial length of 90 km (SE-NW), is demarcated along the EC contours between 1,500 μS/cm and 2,000 μS/cm. The total areal extent is calculated to be 11,000 km^2.

For the calculation, the project site was taken as representative location, for it is located in the central part of the elliptical area and the piezometric head just reaches the ground surface. Hydraulic coefficients of the aquifer are derived from the bore hole tests, carried out by the project.

The life times of water extraction, t, to certain drawdowns, Δh, are calculated by the following formula.

$$t = \frac{1}{Q} \cdot A \cdot b \cdot n \cdot k \cdot \frac{\Delta h}{10} = \frac{v}{Q}$$

where,

v : Available water volume (m^3)
Q : Annual water consumption (m^3/yr)
A : Area of confined aquifer (m^2)
b : Aquifer thickness (m)
n : Aquifer porosity
k : Compressibility of water ($kgf^{-1} \cdot cm^2$)
Δh: Drawdown (m)

Adopted values of each factors are as follows,

$A = 1.1 \times 10^{10}\ m^2$
$b = 60\ m$
$n = 0.2$
$k = 0.44 \times 10^{-4}\ (kgf^{-1} \cdot cm^2)$

For the aquifer thickness, b, the above figure was adopted, considering the second karstic zone confirmed at 400 m depth of NJD-1. Aquifer porosity was calculated by the following formula under the condition of perfectly isolated confined aquifer,

$$n = \frac{10S}{k \cdot b}$$

Here, S is storage coefficient. The averaged S for the project site aquifer was 4.6×10^{-5}.
When the average storage coefficient is taken with the aquifer thickness, b = 40 - 60 m, then n is given as following.

$n = 0.15 - 0.26$

For the convenience of further calculation, n = 0.2 is adopted.

Calculation results are listed below:

TABLE 4.4.1 Groundwater Resources Life Time t(yrs) by Isolated Confined Aquifer Model

Final Drawdown (m)	Available Recources (MCM)	Reclamation Area B (ha)	50	100	300	1000
		Annual water consumption Q (MCM)	2.1	4.2	13	42
10	5.8		2.8	1.4	0.5	0.2
50	29		14	7	2.2	0.7
100	58	t (yrs)	28	14	4.5	1.4
200	115		55	28	9.2	2.8
300	169		77	40	13	4

If we consider 100 - 200 m drawdown as the limitation due to the capability of available pumping system and exploitable surplus of present piezometric head, ca. 100 m above the ground level in maximum, the result suggests that initial development scale of 50 ha can be maintained for some practical term of 30 - 60 years.

Further extension could be made based on the data to be produced through the execution of initial development.

4.4.2 Residual Gradient Model without Groundwater Recharge

As preceedingly discussed in section 4.1.2 and 4.1.3, zonal groundwater flow system may prevail in the Nejd.

This conception figures out an aquifer strip starting in SW from the UER outcropping region of the Mahrat Mountains in the coastal area of South Yemen territory, and ending in NE in Umm Al-Samim, a great sabkha (salt marsh), at the north eastern corner of Rub' Al-Khali.

A sketch cross section is given in FIG.4.4.1, in which some hydrogeological features are described: Longitudinal cross-section of Lower UER and piezometric head.

The surface gradient between the project site and Umm Al-Samim is calculated to be 5.4×10^{-4}, which is an intermediate value between the regional piezometric gradient, 9.0×10^{-4}, and the local gradient, 2.3×10^{-4}.

This feature suggests that discharging area of the zonal aquifer is Umm Al-Samim and recharging area is the Mahrat mountains.

As indicated in FIG.4.4.2, the extrapolated piezometric head surface intersects Lower UER formation north east of the outcropping area. This hydrogeological condition and reported radio-carbon ages of the groundwater, ca. 15-24 thousand years, can be explained by residual gradient of fossil groundwater, discussed on the large fossil groundwater basins in North Africa and Arabia by some authors (Burdon, 1977 and Bakiewicz et al., 1982)

Recharging periods of the fossil groundwater, i.e. pluvial periods in South East Arabia, are gradually recognized to have happened at least three times in the late Quaternary between 6,000 yrs BP and 36,000 yrs BP. by the researches on paleo-lacustrine deposits (McClure, 1976).

In this section the model will be discussed in two steps.

1) Determination of reginal transmissivity, T, by supposing lower UER to have been filled with groundwater to the outcropping level during the pluvial period, then to have been emptied to the present level.

2) Using the determined T, further decline of water level in the project area is estimated under the conditions of several water extraction scales, i.e. reclamation scales.

(1) Determination of Regional Transmissivity by the Post-pluvial Decline of Water Level

As the available geological information (1:500,000 Geologic map of MPM, 1968) does not differentiate upper and lower UER formation at the outcropping area in the Mahrat Mountains, the boundary is supposed at 1,000 m above sea level, approximately at the point of two third of the outcropping thickness. And the local formation dip C is supposed to be 5.9 x 10^{-3}, which is steeper than the regional one, i.e. 2.4 x 10^{-3}, considering the orogenic uplift in the coastal mountains.

Mathematical co-ordinate is taken as in the FIG.4.4.3.

When there is a flow of Q in the aquifer, following equations are to be formulated.

For the groundwater flow,

$$Q = TD \cdot \frac{y}{x} = - nDW \cdot \frac{dy}{dt} \qquad \cdots\cdots(1)$$

For the aquifer configuration,

$$y = C\ (x - a_2) + h_2 \qquad \cdots\cdots(2)$$

Where,

T :	Transmissivity	
n :	Porosity of aquifer	n = 0.2
D :	Transversal width of aquifer strip	$D = 60 \times 10^3$ m
W :	Axial width of phreatic surface	$W = 10 \times 10^3$ m
C :	Gradient of aquifer formation	$C = 5.9 \times 10^{-3}$
a_2 :	Present distance from Umm Al-Samim to phreatic part of the aquifer	$a_2 = 556 \times 10\ m^3$
h_2 :	Present level of phreatic surface from Umm Al-Samim	$h_2 = 363$ m

The solved equation is as follows:

$$T = nW \cdot \frac{1}{t}\left[\frac{1}{C}(h_{20} - h_2) + (a_2 - \frac{h_2}{C})\, \ell n\, (\frac{h_{20}}{h_2})\right]$$

Here, h_{20} is the level of outcropping aquifer sole, supposing the aquifer thickness b to be 60 m. h_{20} is then Calculated to be 937 m.

T is calculated for several t, the post-pluvial period. The results are listed below:

t (yrs)	5,000	10,000	15,000	20,000
T (m^2/day)	620	310	210	150

Calculated T falls within the range of the previously observed transmissivity in the Nejd, but tends to be slightly smaller (TABLE 4.4.2).

If there is difference in the transverse width D of the quifer between the outcropping area and the Nejd, T shall be adjusted by the ratio between them. Here, a factor of two could be admissible as the adjusting ratio, so T could increase to 1,240 m^2/day.

For the further discussion T shall be used in the range of 1,240 m^2/day to 210 m^2/day.

(2) Estimation of Life Time of Groundwater Extraction to the Specific Drawdown.

In the non-recharged residual gradient model, chronic decline of piezometric head is derivable. This tendency was actually detected through the long interval observation of piezometric head in the project area (see 4.1.3).

When groundwater mining starts, the decline will be accelerated.

This model is formulated under the scheme presented in FIG.4.4.4.

Here,

- n : Porosity of aquifer $n = 0.2$
- D : Transversal width of aquifer strip $D = 60 \times 10^3$ m
- W : Longitudinal width of the horizontal section of aquifer $W = 25.4 \times 10^3$
- e : Inverse gradient of aquifer stratum. $e = 422.8 = 1/C$
- a : Distance from Umm Al-Samim to the project site $a = 413 \times 10^3$ m
- ho : Height of Umm Al-Samim from the top of lower UER below the project site. $ho = 34.5$ m
- h_{20} : Height of present phreatic surface in Lower UER aquifer from the top of lower UER below the project site. $h_{20} = 338.4$ m
- h_1 : Height of piezometric head at the project site from the top of lower UER below the project site.
- h_2 : Height of phreatic surface in lower UER aquifer from the top of lower UER below the project site.
- Q : Water Extraction based on 68 lit./sec/50 ha
- T : Transmissivity

Following equations are formulated.

Between the drawdown of the phreatic surface and the flow in the aquifer,

$$-n \cdot DW \cdot \frac{dh_2}{dt} = TD \cdot (h_2 - h_1) \cdot \frac{1}{eh_2} \quad \cdots\cdots (1)$$

By the continuation condition at the pumping area,

$$TD \left[\frac{(h_2 - h_1)}{eh_2} - \frac{(h_1 - h_0)}{a} \right] = Q \quad \cdots\cdots (2)$$

Solved formulae are as follows,

$$t = \frac{e \cdot n \cdot W}{T} \left[(h_{20} - h_2) + \left\{ \frac{a}{e}\left(1 - \frac{eQ}{TD}\right) + h_0 \right\} \times \ell n \left(\frac{\frac{Qa}{TD} - h_0 + h_{20}}{\frac{Qa}{TD} - h_0 + h_2} \right) \right]$$

$$h_2 = \frac{ah_1}{a + eh_0 - \frac{Q \cdot e \cdot a}{TD} - eh_1}$$

Life time for the specific drawdowns are calculated in TABLE 4.4.3.

The drawdown proceeds in two stages. In the first stage it occurs mostly in the piezometric loss. Then in the second stage it involves decline of phreatic level.

In these tables two points are remarkable.

1. Life time is generally fairly long, i.e. in the order of thousands years.

2. Initial drawdown puts a limitation to the reclamation scale, i.e. reclamation scale of 1,000 ha is critical.

TABLE 4.4.2 Summary of Hydraulic Properties of Aquifers in the Nejd

Well No.	Total Depth (m)	Depth to Water (m)	Transmissivity (m^2/d)	Specific Capacity (m^3/d/m)	Aquifer Zone
BG117784AA	95	32 (7/ 2/86)	22,000	4,700～ 8,700	Rus
YV892605AA	132	Flowing	10～20,000	640～ 840	Upper UER
ZV099779AA	300	26 (22/ 7/85) 25.86 (22/11/87)	40～ 150	110～ 180	〃
BF263460AA	400	Flowing	400～ 1,000	250～ 280	Lower UER
ZA035301AA	300	〃	—	—	〃
YA715978AA	250	〃	110～ 610	290～ 470	〃
BF298464AA	400	〃	—	—	〃
BF410641AA	287	30.01 (19/ 8/85) 35.05 (21/11/87)	1,700	820～ 3,120	〃
YV760834AA	412	32.9 (13/10/84)	26	18～ 65	〃
YV847043AA	492	69.48 (23/12/84)	60～ 120	170～ 330	〃
YV826118AA	250	112 (13/10/84)	50～ 200	76～ 170	〃
AF920700AA	275	48.75 (24/ 2/85) 44.26 (22/11/87)	1.5	7～ 11	UER ?
AF808848AA	288	44.43 (15/ 3/85) 44.41 (26/10/87)	11,000	390	〃
AE872525AA	257	79.11 (14/ 2/85) 81.55 (26/10/87)	1,000	230～ 320	〃

(Supplemented with PAWR, 1986)

TABLE 4.4.3 Groundwater Resources Life Time t(yrs) by Residual Gradient Groundwater Flow Model without Recharge

1) T =1.240 m²/day

Reclamation Area B (ha)	50	100	300	500	1000
Annual water consumption Q (MCM/yr)	2.1	4.2	13	22	42
Initial drawdown Δh_o (m)	8.3	17	51	84	170
Time for initial drawdoen t_o (yr)	1.9	1.9	1.9	1.9	1.9

	Life time t (yr) for specific drawdown Δh				
Drawdown Δh (m) 50	1450	1070	–	–	–
100	3380	2790	1330	400	–
150	5740	4770	2680	1600	–
200	9180	7300	4080	2750	930

2) T = 620 m²/day

B (ha)	50	100	300	500	1000
Q (MCM/yr)	2.1	4.2	13	22	42
Δh_o (m)	17	33	100	170	>200
t_o (yr)	3.8	3.8	3.8	3.8	–

	Life time t (yr)				
Δh (m) 50	2140	944	–	–	–
100	5580	3880	–	–	–
150	9530	6990	2380	–	–
200	14600	10500	4600	1860	–

3) T = 310 m²/day

	50	100	300	500	1000
B (ha)	50	100	300	500	1000
Q (MCM/yr)	2.1	4.2	13	22	42
Δh_o (m)	33	67	7200	–	–
t_o (yr)	7.6	7.9	–	–	–

Life time t (yr)

Drawdown Δh (m)	50	1890	1070	–	–	–
	100	7760	3350	–	–	–
	150	14000	8300	–	–	–
	200	21000	13200	–	–	–

4) T = 210 m²/day

B (ha)	50	100	300	500	1000
Q (MCM/yr)	2.1	4.2	13	22	42
Δh_o (m)	50	99	7200	–	–
t_o (yr)	12	12	–	–	–

Life time t (yr)

Δh (m)	50	104	–	–	–	–
	100	7990	80	–	–	–
	150	16000	7240	–	–	–
	200	24400	13800	–	–	–

FIG. 4. 4. 1
Flow Model of Lower UER Aquifer
in Dhofar

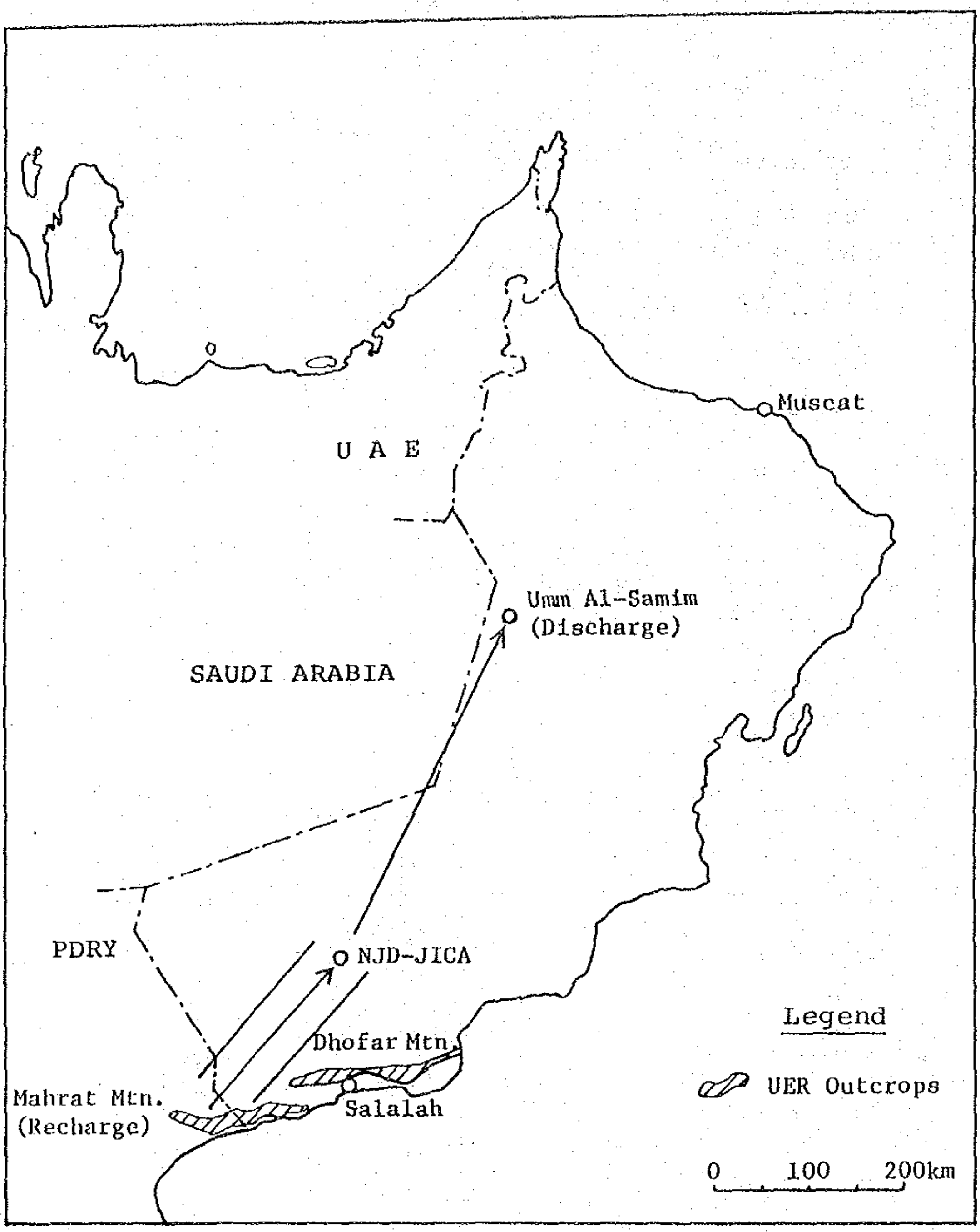


FIG. 4. 4. 2 Cross-Sectional Sketch of UER Groundwater Flow Zone from Mahrat Mtn. in South Yemen to Umm Al-Samim

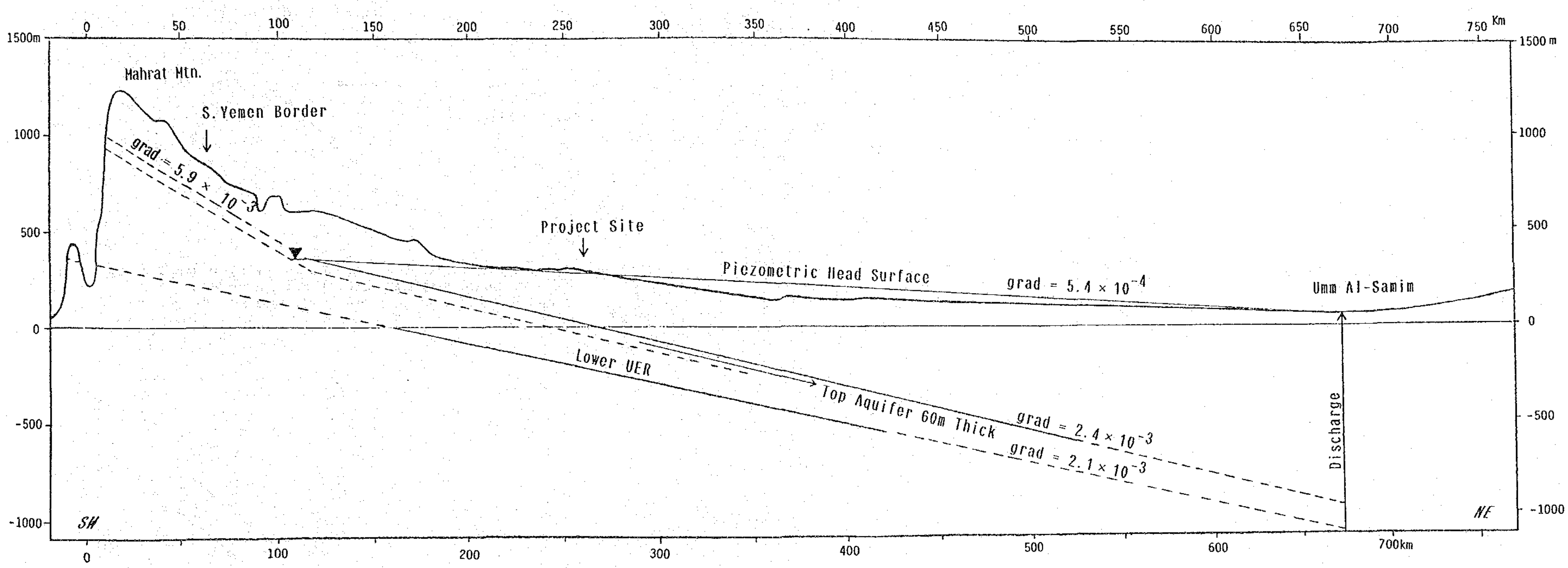


FIG. 4. 4. 3 Geometric Scheme of Residual Gradient Groundwater Flow Model in Post Pluvial Period

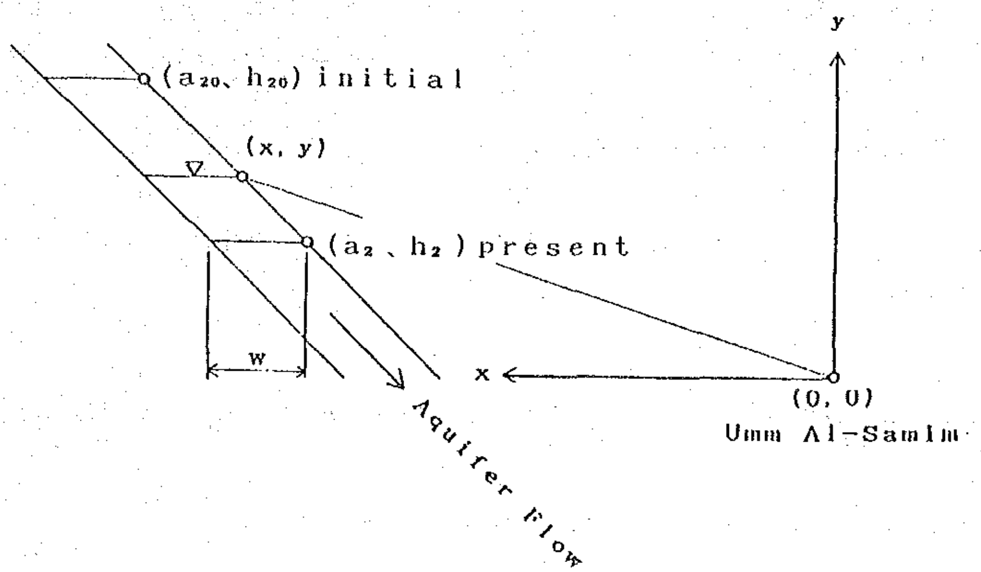
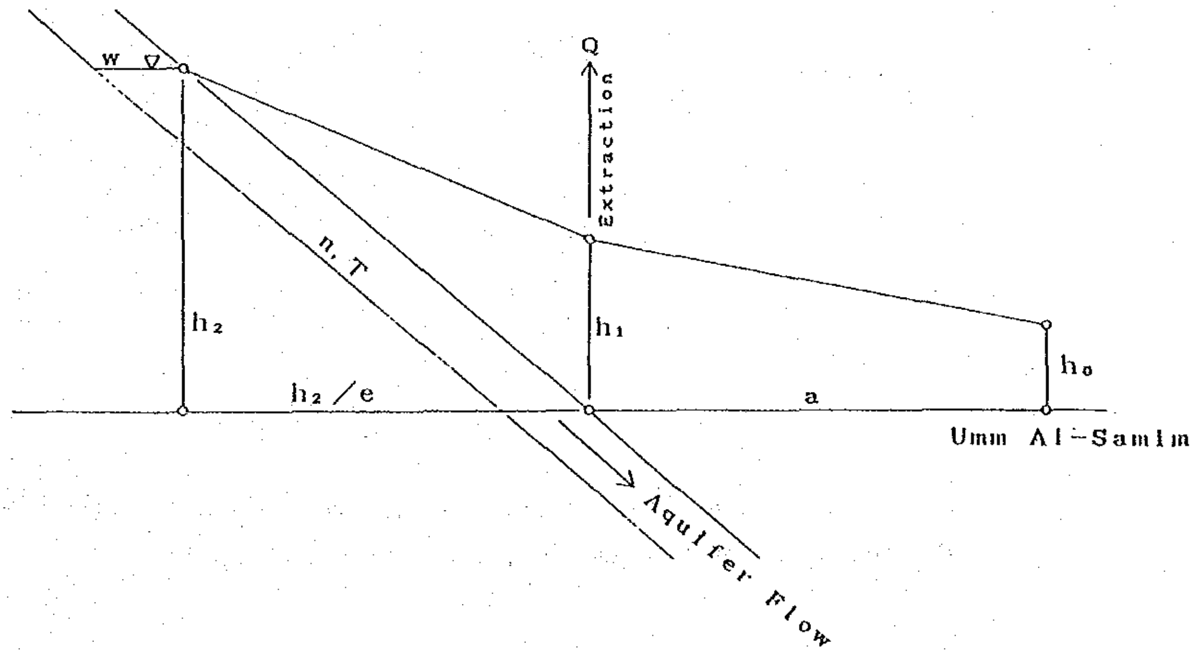


FIG. 4. 4. 4 Geometric Scheme of Residual Gradient Groundwater Flow Model under Influence of Artificial Water Extraction



4.4.3 Residual Gradient Model with Groundwater Recharge

In this model a steady groundwater flow is supposed. In other words the flow system is maintained in a steady state by a recharge which is equal to the present through flow.

This model can be formulated under the same scheme presented in FIG.4.4.4, but only modified by the recharge term P.

Following equations are formulated.

Between the drawdown of the phreatic surface and the flow in the aquifer,

$$-n \cdot DW \frac{dh_2}{dt} = -P + TD\,(h_2 - h_1) \cdot \frac{1}{eh_2} \quad \cdots\cdots (1)$$

By the continuation condition at the pumping area,

$$TD\left[\frac{(h_2 - h_1)}{eh_2} - \frac{(h_1 - h_0)}{a}\right] = Q \quad \cdots\cdots (2)$$

Solved formulae are as follows:

$$P = TD\,(h_{10} - h_0) \cdot \frac{1}{a}$$

$$t = \frac{e}{[1 - \frac{e}{a}(h_{10} - h_0)]^2} \cdot \frac{CW}{T}\ [\{1 - \frac{e}{a}(h_{10} - h_0)\}(h_{20} - h_2)$$

$$+ \{\frac{a}{e} - \frac{aQ}{TD} + h_0\}\ \ell n \frac{\frac{a}{TD}Q}{\frac{a}{TD}Q - h_{10} - \{\frac{e}{a}(h_{10} - h_0) - 1\}\ h_2}\ ]$$

$$h_2 = \frac{ah_1}{(a + eh_0 - \frac{Qea}{TD} - eh_1)}$$

Here,

h_{10} : Present height of piezometric head at the Project site from the top of lower UER aquifer, i.e. h_{10} = 260.4 m

Life time for the specific drawdowns are calculated in TABLE 4.4.4.

Two-stage drawdown process is same with the preceding model. Same period is required for the completion of first stage. But remarkable difference is the existance of equilibrium drawdown. Once equilibrium is established, water can be extracted for ever without causing any further drawdown.

However, initial drawdown is again the restricting term to the reclamation area: 1,000 ha is critical reclamation scale.

TABLE 4.4.4 Groundwater Resources Life Time t(yrs) by Residual Gradient Groundwater Flow Model with Recharge

1) T = 1240 m²/day P = 40500m²/day

		50	100	300	500	1000
Reclamation Area B (ha)		50	100	300	500	1000
Annual water consumption Q (MCM/yr)		2.1	4.2	13	22	42
					Life time t (yr)	
Drawdown Δh (m)	50	∞	9400	–	–	–
	100	∞	∞	3800	800	–
	150	∞	∞	9600	3200	–
	200	∞	∞	∞	6200	1400
Equilibrium Δh (m)		32	65	196	>200	>200

2) T = 620 m²/day P = 20300m²/day

B (ha)		50	100	300	500	1000
Q (MCM/yr)		2.1	4.2	13	22	42
					Life time t (yr)	
Δh (m)	50	18800	3200	–	–	–
	100	∞	19000	–	–	–
	150	∞	∞	4400	–	–
	200	∞	∞	8900	2700	–
Equilibrium Δh (m)		65	130	>200	>200	>200

3) T = 310 m^2/day P = 10130 m^2/day

	B (ha)	50	100	300	500	1000
	Q (MCM/yr)	2.1	4.2	13	22	42

			Life time t (yr)				
Drawdown	Δh (m)	50	6600	—	—	—	—
		100	38000	7600	—	—	—
		150	∞	20800	—	—	—
		200	∞	38900	—	—	—
Equilibrium	Δh (m)		130	>200	>200	>200	>200

4) T = 210 m^2/day P = 6860 m^2/day

	B (ha)	50	100	300	500	1000
	Q (MCM/yr)	2.1	4.2	13	22	42

			Life time t (yr)				
Drawdown	Δh (m)	50	300	—	—	—	—
		100	23400	140	—	—	—
		150	59100	13500	—	—	—
		200	∞	27100	—	—	—
Equilibrium	Δh (m)		193	>200	>200	>200	>200

4.4.4 Summary of the Model Evaluation

Liability of each groundwater flow model is to be verified only through the monitoring of groundwater and exploratory work.

However, the residual gradient groundwater flow model without recharge, presented in 4.4.2, is recommendable as a relatively realistic one.

The isolated confined aquifer model of 4.4.1 cannot be verified through any in-situ groundwater data, but may hold a role to provide an extreme limitation value for the resources evaluation.

The residual gradient groundwater flow model with recharge, discussed in 4.4.3, is probably inconsistent with the present environmental condition in the estimated recharge area of the Mahrat Mountains in the South Yemen. The estimated areal extent of the recharge surface is 1 km of axial width and 60 - 120 km of transverse width, where 120 - 250 mm is required as an annual recharge depth, when an aquifer flow with the transmissivity of 1,240 m^2/day is to be maintained. This recharge can be produced by the precipitation of 6 - 10 times larger depth than itself. Such a large precipitation does not occur in the present arid environment.

4.5 Influence Radius of Groundwater Pumpage and Intra-well Drawdown

4.5.1 Influence Radius of a Single-well Pumpage

In order to reduce the interference in the well-water levels between neighboring groundwater extracting sites, mutual distances have to be kept beyond the influence radius.

However, drawdown caused by water extraction is an non-equilibrium process, so the radius shall be discussed by a definition in which 1, 10, 100 mm drawdown after 24 hours pumpage is regarded as the limit of influence.

An infinitely extending uniform confined aquifer is supposed for the calculation, using the well function, W(u).

$$s = \frac{Q}{4\pi T} W(u) \qquad \cdots\cdots(1)$$

$$u = \frac{r^2 S}{4 t T} \qquad \cdots\cdots(2)$$

So,

$$r = \sqrt{\frac{4Tu}{S}} \times \sqrt{t} \quad = K\sqrt{t}$$

Here,

- s : Drawdown at distance r from the extraction point.
- r : Distance from the extraction point.
- Q : Extraction rate
- T : Transmissivity
- S : Storage coefficient
- t : Running time of extraction

As continuous and constant pumpage of 24 hours is supposed in the definition, so

$t = 1$ day

then the radius r is given by

$r = K$

Hydraulic constants are taken from the figures determined by the project site pumping tests and those derived by the model analysis in 4.4.

$T = 4{,}000,\ 1{,}240,\ 620\ m^2/day$
$S = 4 \times 10^{-5}$

Estimated irrigation demand of a 50 ha farm under the environmental condition at the site is adopted for Q.

$Q = 68$ lit./sec $= 5{,}900\ m^3/day$

Calculated results are given in TABLE 4.5.1.

The results predicts a range of influence radius, 10 - 40 km.

However, due to the aquifer boundary discussed in 4.1.3, apparent T tends to decrease and S increases after sustained pumpage. Consequently r may decrease. A radius of ca. 10 km can be taken as the influence radius.

The accuracy shall be improved by the systematic permanent groundwater surveys.

TABLE 4.5.1 Influence Radius of Single Well Pumpage

1) s = 1 mm

T (m^2/day)	4000	1240	620
W (u)	0.00852	0.00264	0.00132
u	3.34	4.28	4.88
r = K (km)	37	23	17

2) s = 10mm

T (m^2/day)	4000	1240	620
W (u)	0.0852	0.0264	0.0132
u	1.61	2.46	2.99
r = K (km)	25	17	14

3) s = 100mm

T (m^2/day)	4000	1240	620
W (u)	0.852	0.264	0.132
u	0.323	0.892	1.32
r = K (km)	11	11	9

4.5.2 Estimated Intra-Well Drawdown in the Project Site Wells.

Regional piezometric declines are discussed in 4.4 under the presumable groundwater systems. In addition to the regional decline, localized intra-well drawdown overlaps.

Approximation form of the well function W(u) is used for the estimation of intra-well drawdown, although karstic aquifer flow like in the project site may deviate from the theoretical one particularily at the close distance from the pumping point. Intra-well drawdown can be regarded as the drawdown which could be attained in the initial regional drawdown period, discussed in 4.4, under the infinite uniform aquifer model.

Adopted hydraulic constants are as follows,

$$T = 4{,}000,\ 1{,}240,\ 620\ m^2/day$$

$$S = 4 \times 10^{-5}$$

The inter-well distance R between two production wells, bore hole radius r and those of the project wells are taken as follows,

$$R = 1{,}190\ m$$

$$r = \frac{1}{2}\ (8\frac{1}{2}")\ = 0.11\ m$$

The drawdown s is calculated by the following equation.

$$s = \frac{Q}{4\pi T}\ \{W\ (R)\ + W\ (r)\ \}$$

$$= \frac{2.30Q}{4\pi T}\ \log\ [\ (\frac{2.25T\ t}{S})^2 \cdot \frac{1}{r^2\ R^2}]$$

When the initial regional drawdown period is 1.9 years and 3.8 years, and 34 lit./sec is pumped up by both wells, i.e. 68 lit./sec in total for a 50 ha farm,

$Q = 34$ lit./sec

$t = 1.9,\ 3.8$ yr

drawdowns are calculated as in TABLE 4.5.2.

TABLE 4.5.2 Estimated Intra-well Drawdown at the Project Site.

T (m^2/day)	4,000	1,240	620
S (t = 1.9 yr) (m)	2.5	4.8	9.9
S (t = 3.8 yr) (m)	2.5	7.7	15

Roughly speaking 10 m drawdown is presumed as the intra-well drawdown at the project site, when a pilot farm is to be in operation.

4.6 Directory for the Conservation and the Development of the Nejd Groundwaters

Following characteristics are inferred concerning the Nejd groundwaters,

a) Lower UER aquifer bears fossil waters and probably without present-day recharge.

b) Their flow regime is zonal and they flow from SW to NE.

c) The flow is governed by the residual water head gradient generated by the pluvial recharges, and accompanies sustained waterhead decline.

These characteristics derives the following directions for the groundwater conservation and development.

(1) Optimization of Pumping Site Disposition

As there will be massive pumpage in the Nejd someday in the future, it will be indispensable to locate the wells in a network where the pumping interference shall be minimized. At present such fundamental data like the regional distribution of the aquifer hydraulics and the characteristics of aquifer structures are not available. So a tentative disposion scheme of 10 to 20 km mutual distance between pumping sites is to be recommended under the condition of around 50 lit./sec pumpage at each site.

The present survey presumed a zonal aquifer structure along SW-NE axis, both regionally and locally, and the presumed structure may claim wider inter-site distance along the SW-NE than along the SE-NW.

The precision and detail of these aspects shall be clarified along the course of the forthcoming development activity.

Groundwater administration shall be executed according to the H. M. Sultan's Decree of 1988 which declared the water resources a national property.

Such administration is particularily desirable for the Nejd where so many unknowns are left and orderly development is required.

Positive administrative outcomes are expected.

(2) Desirable Rate of Groundwater Development and Exploration of Other Aquifers than Lower UER.

In 1986/87 an interministerial efforts had been made to set up the tentative limit of groundwater development in the Nejd. Through such efforts phased development with 50 lit./sec as a unit rate was proposed.

The conclusion of the present survey is basically the same, but some more conditions have to be supplemented,

1) Any development project should include permanent groundwater monitoring facilities with adequate personnels from responsible administrative bodies.

   At least two years intervals are to be put for the observation and analysis before further development.

2) The scale of succeeding development shall be restricted by the results derived by the above analysis.

   It may not be necessarily the same 50 lit./sec, but some exceeding figures are very possible.

There is no substantial datum acquired by the present project to recommend the development of other groundwater resources than lower UER. At the project site no groundwater was confirmed in Dammam fm. In Rus fm. some minor amount was detected but of high EC exceeding 5,000 $\mu S/cm$.

Upper UER showed some appreciable amount, but the quality was 2,000 - 4,000 μS/cm. The aquifer gave a static water level at ca. 40 m below the ground which indicated less merit than lower UER: Lower UER water was so pressured to reach the ground. Future exploration may confirm the promising groundwater resources other than lower UER, for the qualities and quantities of groundwater are known to be variable in these formations.

For the further exploration ELF-MT electro-magnetic prospecting is recommendable. This method is far simpler than the ordinary geophysical method like conventional electric prospecting and seismic prospecting methods and may differentiate shallow and deep aquifers by the use of several different frequencies.

(3) Administrative System for Groundwater Conservation.

An administrative system is indispensable for the groundwater administration and conservation. Under the system, groundwater monitoring, routine groundwater exploration and development and control of the resources shall be executed.

1) Groundwater Monitoring

The present groundwater administrative systems maintained in the Northern Oman shall be reffered to for the Nejd affairs.

In the north rather many observation wells have been maintained for the routine observation; the areal density is roughly 1 well per 50 km^2.

Less density could be applicable for the Nejd where water exploitation is still at the initial stage and the hydrogeological structure is simple.

In the north one technical staff is assigned for about 20 wells in 1,000 km^2. In the Nejd 40,000 km^2 is presumable as observational area, but the density observation wells can be reduced to one tenth of the north, i.e. 80 wells in total.

The conditions derived from the above requires 4 personnels as the minimum and 80 presonnels as the maximum. The minimum, 4 personnels, shall be exclusively assigned as initial staff.

2) Routine Water Resources Exploration and required method in the subsequent stage.

Groundwater exploration shall be proceeded both by monitorings and by new drillings.

The new drillings for exploration and monitoring have to be made not only in a particularly dedicated project but also in any new groundwater development projects.

Long term constant discharge tests have to be carried out in order to determine the regional aquifer hydraurics. The test term is suggested to be longer than two weeks. If required two months or more are to be adopted. It is recommendable that such long term test shall be carried out within an actual agricultural development operation like experimental or pilot farms. In such cases the pumpted water will not be wasted but utilized as irrigation water.

As emphasized elsewhere in this report, inter-formational leakage through the bore hole has to be avoided. If any new bore holes are to be drilled to a certain aquifer, overlying aquifers have to be drilled for piezometers, which may facilitate leakage analyses more satisfactorily.

3) Development and Control of the Groundwater Resources

For the development and the control strong administrative commitments are essential. The administrative commitments shall be executed not only in the planning of development project but also in the supervision of the project execution.

Restrictions of development location, specification of the drilling program, supervision of the drilling work by highly experienced engineers and specification of well structure are the important factors.

Development locations are to be strictly restricted to achieve less influence to the already established development sites.

It is reported that many undesirable damages to the groundwater resources were caused in the past by the defects in drilling procedure and well structure. So the administrative body has to set up legislative action to the licence system in which every drilling company has to be evaluated of their technical capability for some licence term.

Desirable drilling procedures and well structure are presented in 4.3.3.

In short, a strong administrative commitments are required for the development and the control of the groundwater in the Nejd.

This is purely in accordance with the Sultan's Decree on the groundwater resources.

In order to attain the extreme target of the Decree, excellent Omani staff have to be secured and reliance on the foreign staff has to be gradually reduced.

Water development policy is one of the most fundamental policies in the post-oil strategy. This requires much more stronger roles of Omani staff in the water resources administration.

Reliance on the foreign man-powers has to be shifted more into the training sector and diminished in the substitutional function in expertise for the Omanis.

CHAPTER–5

GUIDELINE FOR AGRICULTURAL DEVELOPMENT IN THE NEJD

CHAPTER 5 GUIDELINE FOR AGRICULTURE DEVELOPMENT IN THE NEJD

Agriculture development is of prime importance for Oman's future economy which at present highly depends upon the oil resource. Agriculture development should be accompanied with increase in the self reliance of food products, improvement of the employment opportunity and so on. Agriculture development in the Nejd is highly anticipated for the promotion of Oman's agriculture.

However, there are many limitations which restrict the implementation of agriculture development, such as unavailability of sufficient data on groundwater, soil and meteorology, and undeveloped infrastructure in the remote area.

Hence this study was carried out in order to develop a "guideline" for the agriculture development. The flow of this chapter is as follows;

1. The present situation of agriculture development in the Nejd
   - To confirm the necessity of agriculture development

2. Potential available for the agriculture development in the Nejd

3. Present problems of agriculture development especially the problems of government planning and unavailability of data necessary

4. Strategy which should be adopted for the agriculture development

5. Agriculture development plan
   - Describes the selection criteria and the plan for agriculture development

This chapter can be used as an aid for planning an agriculture development project in the Nejd.

5.1 Situation of Agriculture Development in the Nejd

(1) National Policies for Agricultural Promotion

Establishment of a post-oil economy is considered as the most important task, for the Government of Oman. For the realization of this task, the highest priority has been placed on agriculture development projects for stable supply of food and increase of employment opportunity.

During the second and third Five-year National Development Plans, stronger encouragement was placed on agriculture sector through introduction of agricultural water resources project, agricultural land development and improvement policy etc.

Moreover at 18th anniversary of National Day (Nov. 1988), H. M. Sultan Qaboos stated that the highest priority should be given to the agriculture promotion policy for the next ten years.

(2) Future Development in the Southern Region

The urbanization has been remarkable in Salalah which is the centre of the southern region. This urbanization process accompanies with high increase of population. The room for further agricultural development is becoming smaller because of the limited land and water resources.

Therefore, there is a high necessity to focus on the agricultural development in the Nejd by using the available land and water resources.

The Nejd development is not only important for the southern region development but also to form a geographically balanced nation as a whole.

(3) High Motivation for Agriculture Development

The agriculture development in the Nejd had been stagnant because of severe natural conditions, poor infrastructure, moratorium of deep well drilling, etc. However, after the confirmation of the existence of groundwater resources, some surveys have been carried out to analyze land and groundwater resources, so as to utilize them effectively for agriculture.

In the agriculture sector, the urgent policies which have special relevancy to the affairs of southern region have been drawn within the frame work of the third Five-Year Development Plan. The establishment of an experimental farm and large scale farm is proposed in it. Moreover, MAF is planning to carry out a survey in order to select a suitable land up to 1,000 ha area for agriculture development in the Nejd.

In 1985, PDO farm was established by the instruction of H. M. Sultan Qaboos. Cultivation techniques of crops suitable for the Nejd have been experimented and they are being established gradually. Additionally the local people have started crop cultivation on a small scale.

As stated above, the motivation for agriculture development in the Nejd is high and hence its development reflects in the government policies.

5.2 Potential Available for Agricultural Development

Agricultural development potentials are summarized as follows:

(1) Suitable Land for Agricultural Development

As a result of topographic condition and soil survey in the Nejd, approximately 19,000 ha areas are classified as land suitable for agricultural development with S2 or higher ranks by land suitability classification.

The data account for 23% of the whole agricultural land (83,000 ha) in Oman and six times of total arable land (3,000 ha) in the southern region. This means that there exists a quite large suitable land for agriculture development in the Nejd.

(2) Groundwater Resources

Groundwater investigations, carried out so far, disclosed the existence of good quality aquifer at the top of the lower UER formation. The aquifer is estimated to extend over 10,000 km in the study area of the project. Present study estimates that approximately 80 billion cubic.m of stagnant fossil water is stored in a confined aquifer. It is desirable to develop groundwater within the range of recharge, however, only a little recharge of groundwater resources is presumable. Therefore, groundwater resources should be considered as limited resources similar to oil resources.

(3) National Highway

The area proposed for the development is located at 150 km north of Salalah and 1,000 km from Muscat.

Muscat-Salalah National Highway runs through the area. It takes two hours from the site to Salalah and ten hours to Muscat by the highway. This road will be a great help for the project implementation.

5.3 Present Problems of Agriculture Development

There are a lot of problems to be settled so as to make agriculture in the Nejd as a self-sustaining industry.

Particular attention should be paid to the fact that the groundwater in the Nejd is categorized as fossil water and is a limited resource as similar to oil. Therefore, in case of utilizing this scarce resource, suitable and appropriate methods which contribute to the prosperity and development of Oman should be adopted.

The present problems of agriculture development in the Nejd are explained as follows:

(1) Problems of Government Planning

1) Coordination between groundwater development and utilization

The available groundwater in the Nejd is very much limited and effective utilization of this scarce resource is necessary. Till now, groundwater development and its conservation have been carried out independently without any coordination between them. This will lead to ineffective utilization of groundwater resource.

A suitable policy is necessary to coordinate the different sectors which utilize the groundwater for various purposes.

2) Concept of national and regional agriculture production plan

The agricultural production plan should be considered from the national level and then should be decided on regional level. Based on the plan for the southern region, the plan for Salalah plain, the Jabal and the Nejd should be decided. For example the type of crop grown, cropping pattern all should be decided and planned at national level and then should be decided at regional level.

(2) Problems of Data Availability

1) Unavailability of information on present water resources condition

The present condition of available groundwater has been pursued by this study and previous groundwater investigations. However, water resource condition and water circulation in the whole area is not available. Moreover amount of water available in a limited area and change of this resource volume in course of time is also not available. Hence a wide and systematic investigation should be carried out in detail, so as to proceed with suitable development projects.

2) Unavailability of present soil & meteorological data

For the effective planning of agriculture development, soil & meteorological data is equally important as that of groundwater resources data.

During the study, detailed soil investigation was carried out at the pilot farm site. For the other areas, already available data from the previous soil investigation were compiled and summarized.

But the data of soil distribution types at various locations is not sufficient and moreover the meteorological data available is not sufficient enough. Hence a detailed survey of these data is necessary for planning of agricultural development projects.

5.4 Strategy for Agriculture Development

5.4.1 Phased Agriculture Development Plan

A phased agriculture development plan is proposed in this study, based on the actual conditions and limitations of the Nejd.

While introducing a new agriculture project, if a project of large scale is introduced suddenly and if any failure occurs, the project loss will be heavy. Because of high uncertainities of groundwater and other resources, it is not advisable to introduce a large scale development project.

The three phases of phased agricultural development plan are as follows:

1. Phase I
   - Establishment of pilot farm; experimentation at pilot farm and collection of data

2. Phase II
   - Development of up to 500 ha area based on the results of phase I.

3. Phase III
   - Further development based on the results of phase II.

Further detail is explained as follows:

(1) Phase I - Establishment of Pilot farm and collection of data

1) In the project area, data necessary for planning and implementing of the agriculture development is highly insufficient. Especially data such as groundwater potential, meteorological data, type of crops suitable, appropriate cultivation technology etc. are lacking which restrict the planning of suitable agriculture development project.

All the data necessary will be collected by experiments and the restricting conditions will be clarified systematically.

The main objectives of the pilot farm are as follows:

1. Experimental cultivation by introducing locally appropriate technology

2. Demonstration and training of Agricultural technology

3. Extension of agricultural technology to the local farms

4. Evaluation of groundwater potential and observation of soil and meteorological conditions

The results of the four activities of pilot farm will be reflected in the promotion of agriculture development in the Nejd.

At first for the purpose of soil reclamation, fodder grass will be grown. After this other crops will be introduced based on the results of the crop cultivation trial and the groundwater evaluation.

2) Evaluation items to step up from Phase I to Phase II

The following items should be considered systematically, in case of shifting from the Phase I development to the Phase II development.

1. Groundwater drawdown accompanying with pumping up should be within the reasonable value.

2. The quality of groundwater should not become worse because of the pumping up operation.

3. There should not be any problems regarding the cultivation technology for fodder grass.

4. Marketability of fodder grass should not be decreased remarkably.

5. Supporting systems to proceed with farm management under commercial base should be clarified.

6. Systematic control system of groundwater should be established.

7. Soil survey for the developed area should be carried out in detail.

8. Training and extension system should be established for the settlers.

(2) Phase II - Development of up to 500 ha area

1) Tentative scale and pace of the development

The systematic agriculture development project will start with the establishment of the pilot farm.
However, the following two items must be clarified in order to make the agriculture as a prime industry of the Nejd.

1. Project development pace (Suitable development pace)
2. Limitation of project area (Maximum development area)

In the phase II of the phased development plan, the development area is assumed temporarily as 500 ha and the prosperity of this development scale should be verified at first.

If the expected results can not be achieved, the development scale should be revised and the prosperity should be studied once again.

2) Establishment of additional farms around the pilot farm

- Based on the results of phase I, the farms will be developed further in the nearby area.

- Development of production wells for irrigating these farms

- Continuation of observation of groundwater level and evaluation of its potential

- Trial cultivation of crops suitable and profitable for the area

- Establishment of an economic self-sustaining farm management system.

3) Improvement of existing farms of local people

- Improvement of the irrigation facilities at existing farms.

- Improvement of cultivation and irrigation technology in these farms based on the results of the pilot farm.

4) Evaluation items to step up from phase II to phase III

At this stage, the project area is temporarily assumed as 500 ha based on the results of groundwater investigation. However, the maximum project area and the suitable development pace should be confirmed in parallel with the progress of the project development.

Therefore the project should be developed gradually while clarifying the groundwater condition. The following items must be clarified by the pilot farm and/or other concerned governmental offices in case of shifting from 500 ha project scale to larger project scale.

1. Clarification of groundwater condition by the groundwater investigation in the whole area.

2. Confirmation of the suitable project development pace and the limitation of the project area based on the groundwater condition.

3. Confirmation of cropping pattern, cultivation technology and marketability for different crops.

4. Establishment of marketing system for the fodder grass and the other crops to be introduced.

The pilot farm will also be continued after the phase II of the phased agriculture development. In addition to the study items started in the phase I, the following items should be continued successively in Phase II.

1. Selection of suitable crops to be introduced.
2. Study the cost of cultivation of the introduced crops.

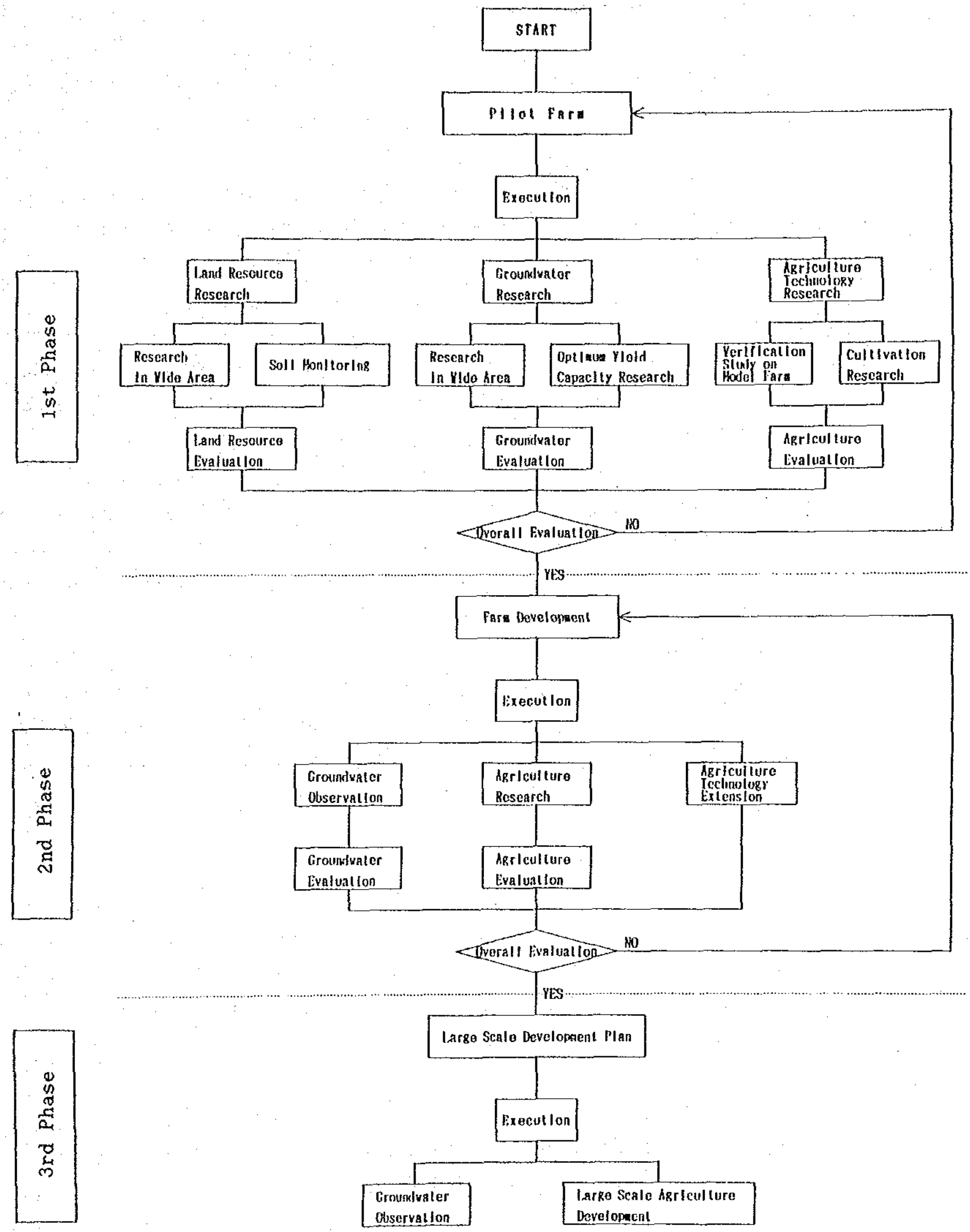
(3) Phase III - Further development based on phase I and phase II

- Based on the result of the First and Second phases, a feasibility study shall be done for the agriculture development of more area.

- Installation of additional observation wells and continuation of groundwater observation and evaluation.

The flow of phased agriculture development is shown in FIG.5.4.1.

FIG.5.4.1 Phased Agricultural Development Diagram



5.4.2 Limitation of Area for Agriculture Development

1) Suitable groundwater model

In this study, the following three models are formulated to evaluate the groundwater resources in the Nejd.

1. Isolated confined aquifer model
2. Residual gradient model without groundwater recharge
3. Residual gradient model with groundwater recharge

The most suitable groundwater model for the regional groundwater system should be verified by further groundwater observation and survey. However, the "residual gradient model without groundwater recharge" seems to be adequate at this stage.

"Isolated confined aquifer model" is used to analyze the possibility of managing the pilot farm of 50 ha area. Based on the analysis, it was confirmed that there is no problem of water supply at least for a period of 10 years.

"Residual gradient model with groundwater recharge" is based on the assumption that the groundwater is recharged in course of time. But this model is impractical, since the groundwater recharge is unconfirmed.

2) Limitation of development area

Based on "residual gradient model without groundwater recharge", it is evaluated that it takes approx. 400 years to fall groundwater level to 100 m level with $T = 1,240\ m^2/day$, for a development area of 500 ha.

Hence it is proposed to introduce a project of 500 ha area as a temporary target and later the development area may be expanded in parallel with this project based on further groundwater evaluations.

5.4.3 Policy Required for Phased Agriculture Development

Policy required for promoting the phased agriculture development project are described as follows:

(1) Governmental planning

1) Establishment of policies for groundwater development and conservation

Discussions are not enough among the concerned sectors regarding the development and conservation of the groundwater resource in the Nejd. The concerned sectors of the groundwater resource including agriculture should discuss about the groundwater development and conservation and establish the plan based on the national policy.

2) Establishment of the development and conservation system for groundwater resource

The royal decree was issued on November 1988, which declared that the groundwater resource should be considered as a public national asset. In this regard, the agriculture development using groundwater should not be carried out without establishing the system based on the long-term governmental policy in harmony with the development and conservation.

3) Adjustment and coordination with the high rank plan

The Nejd is located in a remote area with a little population and the infrastructure facilities are not yet developed. In order to make the agriculture development more effective in future, the adjustment and coordination with the regional development plan in the southern region should be done.

4) Establishment of balanced development policy and project appraisal and advisory committee

Since several government departments are concerned with the agriculture development project in the Nejd, the development policy should be established in consultation with all the relevant departments.

The project appraisal and advisory committee will be established for the purpose of solving the friction among the concerned sectors and to advise a suitable plan fitting with the development policies.

The functions of the committee are as follows:

a) Guidance of development and conservation of available groundwater resource

b) Coordination of the concerned sectors

c) Adjustment of the circumstance for the project development by education and support.

d) Appraisal of development project and planning of new project.

e) Establishment of project execution and management system.

5) Development of regional concept for agricultural production

The regional concept of the southern region should be used for the agricultural production based on the characteristics of each region.

a) Salalah Plain - Farming of vegetables and fruits

At present, there are 1,000 ha of grassland in Salalah Plains. These grasslands can be converted for cultivating vegetables and fruits, since the climate and other factors are suitable for these type of crops.

b) Jabal - Livestock farming

Based on the natural conditions and the present technology of local farmers, livestock farming will be suitable for this area.

c) Nejd - Fodder grass production

It is located next to Jabal which is doing livestock management. Hence if fodder grass is produced in this area, they can be utilized for livestock farming in the Jabal. Moreover considering the climate and farming techniques, it is found that the Nejd is more suitable for fodder grass production.

6) Establishment of suitable cropping pattern, cultivation technology and extension to local farmers

At present several crops, mainly Rhodes grass are cultivated in the Nejd. And suitable cropping pattern and cultivation technology is not yet established. Hence suitable cropping pattern and cultivation technology should be experimented and the results should be diffused to the other areas. Moreover, the most suitable area of a farm from economic view point should be established through the verification test of different farm models.

Major items to be experimented are as follows.

1. Selection of crops to be introduced and establishment of cropping pattern, cultivation technology based on soil/meteorological conditions and marketing potential.

2. Establishment of extension activity for diffusing suitable cultivation technology.

3. Verification of farming system and optimum farm size

(2) Continuation of data collection for further development

The natural conditions should be evaluated in parallel with the progress of the agriculture development project.
Items to be investigated/observed are as follows.

1. Continuous observation of water level at the existing wells
2. Hydrogical/geological conditions in the whole area
3. Continuous observation of meteorological data
4. Detailed soil survey
5. Monitoring of groundwater quality and soil condition

5.5 Agriculture Development Plan

5.5.1 Site Selection

Project site selection should be done carefully by considering several conditions, so as to get the expected results. The conditions restricting the project selection can be divided into the following two categories
i) natural conditions and ii) socioeconomic conditions

(1) Natural conditions

1) Soil condition

Classification of soil obtained from the soil survey is discussed in chapter 3. Among the soil types classified in the area, the land classification which is more suitable for agriculture is 'S2' class. Hence it is considered that the site selection should be made in the area of 'S2' class by land suitability classification.

2) Static groundwater level

The pumping area should be selected in a site where the static groundwater level is at a higher level or level equal to the ground surface so that the primary investment, pumping cost and operation and maintenance cost will be cheaper.

Hence proposed development area should be selected based on the condition mentioned above.

(2) Socioeconomic Conditions

1) Transportation

The project area selection should done in an area where it has good access to the national highway and local gravel roads because of the following reasons.

1. Easy access for construction of the project
2. Easy for transportation of agricultural products to the market
3. Facilitate the agricultural extension activities

At the centre of the development area, there is a national highway running from Muscat to Salalah. This national highway enables to travel from development area to Salalah in 2 hours and to Muscat in 10 hours. Besides, there are local gravel roads connecting the villages with this national highway.

At first a site should be selected along the existing road, and after the confirmation of enlargement of project area, road construction should be done gradually.

2) Existing farms

The project area should be selected in a site which is close to existing farms so that the new farming technology developed at the project area can be diffused easily to the other local farms.

At present the cultivation in the development area is done by trial and error method. The farmers have good spirit for agriculture development and hence introducing the new project may strengthen the agricultural settlement.

FIG.5.5.1 shows the overlapped map of both natural and socioeconomic conditions.

As per FIG.5.5.1, the suitable soil of 'S2' class in large scale is available in four areas. Among them Nagha area and Dauka area are nearer to the national highway which enables easy transportation.

(3) Proposed site for agriculture development

Based on the natural and socioeconomic conditions mentioned above, the selection is proposed to the following four areas for introducing agriculture development project. The advantage of each area is shown below.

1. Nagha area (Area around the proposed Pilot Farm site)	Adjacent to national highway and located at the centre of the existing development area
2. Dauka area	Adjacent to national highway and can expect high pressurized groundwater
3. Shasr area	Adjacent to local road and can expect high pressurized groundwater next to Dauka area
4. Wadi Mokhawrim area	Adjacent to local road and can expect large area of 'S2' soil class. At present there is no residence in this area.

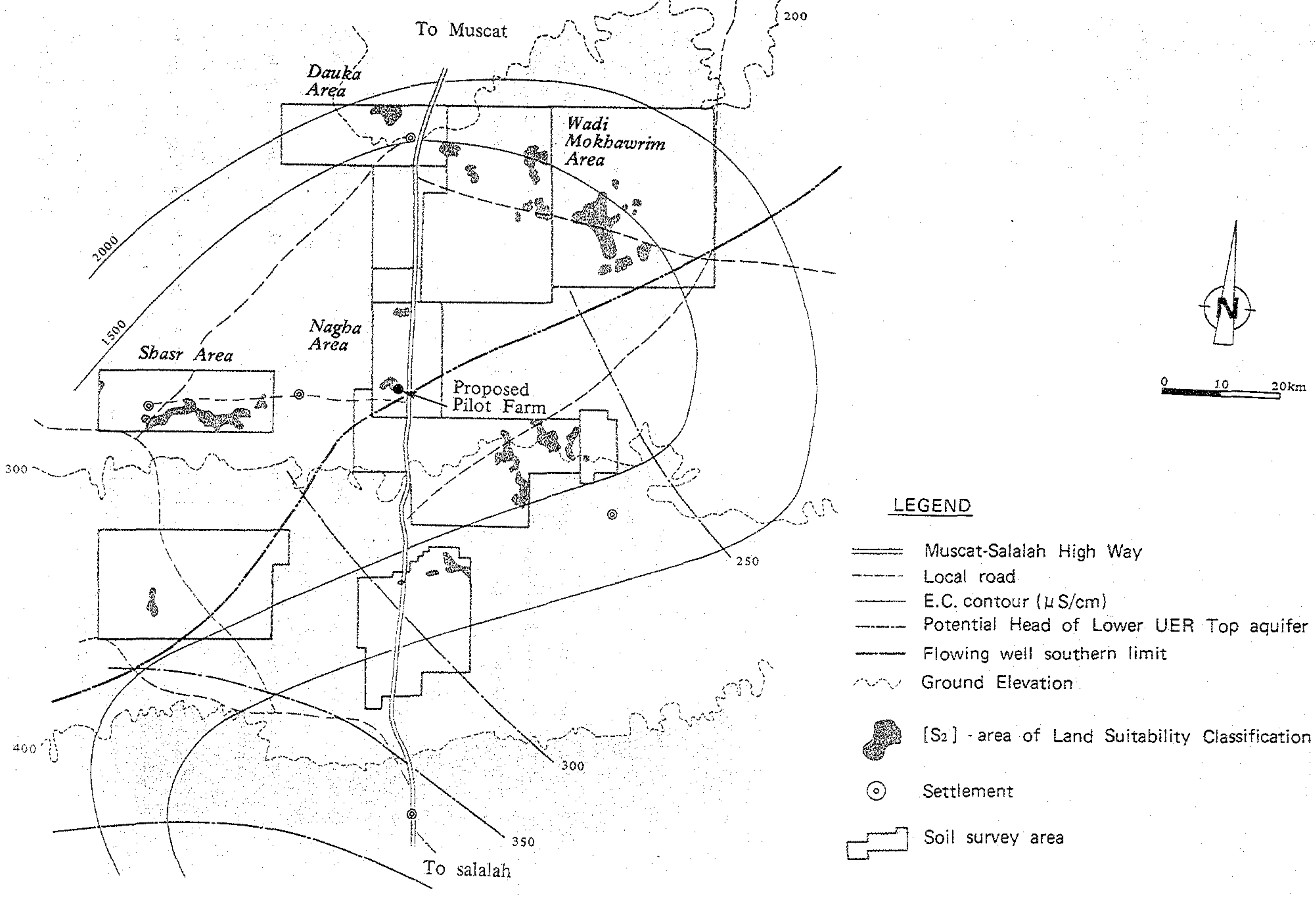
5.5.2 Pilot Farm Plan

Pilot farm plan is discussed in detail in Chapter 6. Summary for this pilot farm is discussed in this section.

(1) Location

The location of pilot farm is approx. 150 km north of Salalah and approx. 1.2 km west of national highway connecting Muscat and Salalah. The reasons for selecting this location are as follows.

FIG.5.5.1 Constraints for the Nejd Agricultural Development



1. Pilot farm can be accessed easily since it is located nearer to national highway.

2. Pilot farm is located at the center point of the existing farms and hence the techniques in pilot farm can be diffused to all the directions.

3. The static groundwater level can be expected at a higher level to the ground surface.

(2) Project area

A farm size of 50 ha is decided based on the results of suitable pumping rate of two test well by this study.

5.5.3 Groundwater Development Plan

In the arid region like the Nejd, any agricultural plan is inevitably under the control of the technical and economical characteristics of available groundwater resources.

Present groundwater investigation disclosed the target aquifer in the project site to be strongly pressured confined one and store almost stagnant fossil water. Since any extraction of water causes inevitable decline of waterhead, there should be two different development schemes which are obviously characterized by the two different hydraulic states. In other words, there are developments with a high potential head under the artesian state and with a low potential head under the phreatic state. The former scheme can enjoy relatively low water cost but the latter high cost, determined by the facility and energy cost, and those effects a concept and system of agricultural development.

The low potential head under the phreatic state is high enough and its available period is long enough. However, from the view of farm management it is impractical to pump up water from 300 m depth. The target groundwater resource for the agriculture development in the Nejd should be within 100 m since the head of an ordinary farming pump is within 100 m.

(1) Target aquifer for agricultural development

Top of the lower UER formation should be developed as a groundwater resources for agricultural development in the Nejd.

It was found that the groundwater with good quality (1,500 μS/cm - 2,000 μS/cm spreads in the project area from the result of this study.

(2) Distance between well sites (Radius of Influence)

For the minimum interference of water levels between the production wells, the mutual distance should be kept beyond the radius of influence.

As discussed in Chapter 4·5, the radius of influence for a draw down of 1 mm to 100 mm after 24 hours of pumpage at a rate of 68 lit./sec (5,900 m^3/day) for an area of 50 ha is found as 10 km to 40 km.

The distance between the two production wells should be low enough which will cause low interference in groundwater level and should be close enough to the farms.

Hence the distance between the production wells of two 50 ha farms is proposed as 10 km which will cause an acceptable draw down of 100 mm over an area of 50 ha.

In case that the agricultural development proceeds and production wells increases, they configure as equilateral triangles. It means that in case of the developed area being located at the centre of production wells, they configure like a hexagon and the centre production well will be influenced by the six surrounding wells.

(3) Proper well-installation

Most of the wells in the Nejd were originally those which were drilled for oil investigation trial and road construction. The following problems occurred to the well drilling in the Nejd.

1. Inter-aquifer groundwater flow and leakage to fissures due to the piezometric difference among aquifers.

2. Loss of water resource and mixing of poor quality water into good quality aquifer as the result of above phenomenon.

3. Groundwater flows out on the ground, left unused and waste of this limited resource.

Suitable drilling method and well structure should be required in order to prevent the above mentioned problems.

5.5.4 Farm Arrangement Plan

(1) Types of farm arrangement

Distribution of wells should be planned in such a way that the distance between the two nearby wells is kept apart from one another so as to avoid the drawdown effect of pumping at each well.
From the viewpoint of groundwater and soil conditions, two types of farm arrangement are considered.

1. Scattered type - In this type, the farms will be located at separate locations close to their production wells

2. Concentrated type - In this type, the farms will be located together at one location although they are separated from their production wells

The development project should adopt either of these two types, considering the advantages and disadvantages of each type.

(2) Scattered type

Management of farms should be executed for each unit. Road net work is necessary for connecting the farms. All the facilities should be arranged separately for each farm. This type requires only a small scale water distribution facilities since the farms are developed near the water resource.

(3) Concentrated type

Management of the farms can be done together. Facilities such as machineries, water management etc. can be used in common. But it requires large scale distribution facilities for delivering water to each farm.
The comparison between these two types is shown in TABLE 5.5.1.

(4) Proposed type

Among these two types "concentrated type" is proposed.
Reasons for this selection are as follows:

1) Concentrated type creates a concept of community which is very much essential for the development project

2) Farm machineries can be purchased and maintained together by farmers' association

3) The infrastructure facilities such as roads, electricity etc. can be developed in common, at one location.

TABLE 5.5.1 Comparison of the Two Types of Farm Arrangement

Type	Development plan	Merit	Demerit
Concent-rated type	1) At first, construct a farm of 50 ha area and production wells 2) Successive monitoring of groundwater in parallel with the farm management 3) Construct another 50 ha farm next to farm 1) after the confirmation of ground-water stability. Production wells should be at required distance interval. 4) Repeat 1) - 3) till developing an area of 150 - 200 ha. 5) Select another area and repeat 1) - 4)	1) Farm area is enlarged forming 'village' 2) Jointly own & use, machineries and facilities 3) Effective water management 4) Have common transport facility	1) Long water distribution line is neces-sary since each farm is located away from the production wells.
Scattered type	1) Construct 50 ha area farm and the production wells 2) Successive monitoring of groundwater in parallel with farm management 3) Construct a new 50 ha farm after the confir-mation of stability of groundwater, keeping necessary distance from the neighboring farm 4) Repeat 1) - 3)	1) Requires only small scale water distri-bution facili-ties since the farms are developed near the water resource	1) Difficult to form village 2) difficult to jointly own machineries and facilities 3) Water is controlled separately for each farm 4) Necessity of constructing new roads

5.5.5 Crop Selection Plan

(1) Basic criteria of crop selection

At present, fodder grass is selected as the most suitable crop for the Nejd. Crop selection for the other commercial crops such as vegetables should be decided by the experimental cultivation at the pilot farm. The cropping pattern will change in accordance with the progress of project development based on the factors of crop selection such as marketing potential and suitable technology in the Nejd. The basic criteria for the crop selection are as follows:

1. Basic data and cultivation technology necessary for introducing a suitable crop is not sufficient at present and hence it should be experimented at the pilot farm and the PDO farm. The suitable crops such as vegetables will be introduced based on the results of the pilot farm.

2. Marketing system necessary for increased production of vegetables in the Nejd are very poor at present. The marketing facilities should be established in accordance with the progress of the project development.

3. Crop cultivation which is effective for soil reclamation should be practiced to improve the soil structure. By the experimental cultivation at the PDO farm, it was verified that Rhodes grass is suitable for soil reclamation. Grass cultivation period is not only helpful for soil reclamation but also provides time for the progress of agriculture development.

(2) Factors influencing in crop selection

1) Fodder grass

a. Rhodes grass which has high talerance for drought and salinity can be cultivated as the reclamation crop to improve the soil structure.

b. It is possible to cultivate high quality grass in a whole year in the dry weather of the Nejd.

c. It is possible to minimize the manpower requirement by the introduction of machineries and it doesn't require any extra facilities for marketing.

d. The cultivation and marketing of Rhodes grass are done at the existing farms and PDO farm in the Nejd and hence the cultivation techniques and marketing are already practiced.

e. There is a demand of fodder grass for cattle grazing at the Jabal with a market price of R.O.100/ton. In future even if the cattle population of the Jabal is destocked to half by the introduction of the destocking programme, a stable supply of the fodder grass will be indispensable for the conservation of the Jabal grasslands.

f. In the southern region, the farm products are assigned in three areas i.e., Salalah Plain, the Jabal and the Nejd for the effective utilization of available resources in each area. In this regard, the farming in the Nejd is proposed as "fodder grass supply area", to supply grass for the cattle population in the Jabal and Salalah plain.

2) Vegetables

a. At present vegetable cultivation is done in a small area for self-consumption only, but the cultivation technique is not yet established.

b. There is no established facilities for storage and preservation of vegetables.

c. PDO farm is doing experimental cultivation for a few vegetables and getting some good results. More tests should be done both at pilot farm and PDO farm so as to establish the cropping pattern.

d. More demand of vegetables is expected in the future, accompanying with the increase of population at Salalah.

3) Fruits

a. There is established cultivation methods for date-palm and lime. There is less limitation for storage and marketing compared with vegetables.

b. They have a secondary advantage that the farm products can be preserved in the trees shadow for some small period of time.

4) Cereals

a. In the Nejd only trial cultivation is done at PDO farm and their cultivation techniques are not established.

b. There is high possibility for introducing large scale cultivation of cereals in the Nejd, since the self-sufficiency rate of cereals is quite low. However, the international market price and the yield benefit of cereals (70 R.O./ton x 5 ton/ha) is quite low in comparison with Rhodes grass (100 R.O./ton x 40 ton/ha). Hence the introduction of cereals should be analyzed in accordance with the national policy.

(3) Crop selection criteria

Crop selection plan for the commercial crops such as vegetables must be decided based on the experimental cultivation at the pilot farm, considering the following factors:

1. Natural conditions
2. Yield benefit
3. Appropriate cultivation technology
4. Marketing potential

Different conditions influencing the selection of crop to be grown is shown in TABLE 5.5.2.

At this stage, it is difficult to decide the cropping pattern suitable for the area. The type of crops and the cropping pattern should be decided based on the experimental cultivation at pilot farm and PDO farm. This results can be diffused to the other farms and the cropping pattern can be established:

1) Natural conditions

This includes soil and water conditions and climate. The area to be selected for the agriculture development should be of 'S2 soil class' with no salt problem. But the water conditions are very much limited; besides this area has a hot climate. Hence the main preferance should be given to the drought tolerance crops. The crops with high or at least medium drought tolerance should be selected.

2) Yield benefit

People will be interested in farming, only if it is advantageous as a business. Hence a suitable crop with high yield benefit should be selected. As per TABLE 5.5.2, tomato ranks higher than all the other crops. Similarly other vegetable crops like squash, carrot, cabbage, cauliflower and cucumber also have the yield benefit slightly higher than Rhodes grass. However the value of benefit alone is not sufficient to decide the crop selection, and the benefit cost ratio should be worked out for each crop. At present, sufficient data is not available for this purpose. Hence during the experimental cultivation at the pilot farm, the benefit-cost ratio for each crop should be worked out and the suitable crop which have the highest benefit-cost ratio should be selected.

3) Availability of suitable technology

Suitable technology which will be appropriate for the Nejd should be established. For example, if vegetables or fruits are selected, preservation and storage facilities and technology under hot climate should be required. Besides the marketing without damage is also necessary.

At present, the Nejd does not have suitable facilities for preservation and storage of vegetables. Hence cultivation of vegetables may not be recommendable, at least during the reclamation period. In this period, suitable facilities and infrastructure should be built up. Vegetables and fruits should be introduced thereafter.

Pilot farm will be responsible for experimenting and analyzing the appropriate technology.

4) Marketing potential

A suitable crop/combination of crops which has high necessity and marketing potential should be selected. At present Rhodes grass can be easily marketed to the nearby Jabal. If vegetables are introduced, they can be marketed to Salalah, however it requires suitable preservation, storage and transport facilities.

Vegetables consumed in Salalah is mostly imported from foreign countries or transported from the northern region. Hence if vegetables will be cultivated in Salalah or in the Nejd, they will have a high marketing potential. Besides the transport cost and foreign exchange can be saved very much.

5) Suitable crop

Considering all the factors mentioned above, at first the highest priority should be given for reclaiming and improving the soil condition. For this purpose Rhodes grass which also have high marketing potential is found more suitable and the fodder grass cultivation can be continued for a period of 2-5 years.

During this duration, it will be the responsibility of pilot farm to experiment the vegetable crops like tomato, carrot, cabbage, cauliflower, squash, etc. and should develop suitable cultivation technology for the Nejd. Besides it should also work out the cost benefit and decide the suitable crop in terms of economic benefit. This crop selection can be diffused to the project area through agricultural extension.

TABLE 5.5.2 Crop Characteristics

Crops	Salt Tolerance 1)	Drought Tolerance	Local Production Max.ton/ha 2)	Local Market-Price R.O./kg 3)	Remarks
Rhodes grass	A	B	45.00	.100	
Alfalfa	B	A	17.00	–	.100 R.O. estimated
Wheat	B	B	4.84 (Hay)	–	.070 R.O. estimated
Barley	B	C	6.19 (Hay)	–	.070 R.O. estimated
Tomato	B	B	129.94	.210	PDO Result : 50-125 ton/ha
Squash	B	A	40.30	.180	〃 25- 40 ton/ha
Cabbage	C	C	32.33	.170	〃 15- 32 ton/ha
Cucumber	–	C	18.83	.220	〃 8- 19 ton/ha
Water melon	–	C	23.9	.110	
Sweet corn	–	C	5.73	.150	〃 4- 6 ton/ha
Potato	C	C	–	.180	
Cauliflower	–	C	21.96	.240	〃 7- 22 ton/ha
Carrot	B	C	15.65	.190	
Lettuce	B	C	22.6	.270	
Egg-plant	C	C	13.1	.110	
Turnip	–	C	10.65	.150	
Radish	–	B	1.08	.060	
Okra	–	C	3.3	.270	
Onion	B	B	–	.120	
Pepper	B	A	–	.180	
Date Palms	A	A	5.0	.320	
Orange	C	A	–	.160	
Lime	–	B	–	.260	

Legend : A ; High B ; Medium C ; Low

Source : 1) USA Salinity Laboratory, FAO Irrigation & Drainage paper No.24

2) Interview with local farmers & A Report on Project Development March 1988, PDO

3) PAMAP (Salalah), Purchase average price, 1987

In accordance with the result of the pilot farm suitable facilities necessary for marketing and transportation should be established.

5.5.6 Organizational Set-up for Project Development

The agriculture development project starting with the establishment of pilot farm necessiates the coordination of different organizations for the effective management of the project.

The various activities to be performed in course of introducing the agriculture development project are as follows:

1. Technical guidance/extension service to the farmers
2. Procurement of production materials and services for storage and marketing of farm products
3. Financing for farming
4. Construction and maintenance of roads, electricity, etc.

Hence coordination of different organizations becomes necessary to perform all these activities; A "Project appraisal and advisory committee" with the representatives of different organizations is required for this purpose. Besides, a project office which will be responsible for the execution and management of the development project and a pilot farm which will be responsible for the experimental investigation and training will also be established.

The organizational chart of the agricultural development project is shown in FIG.5.5.2.

(1) Project appraisal and advisory committee

This committee consists of the representatives of different organizations. This committee is the 'master mind' of the whole project development and is responsible for forming and coordinating pilot farm and project office.

This committee should plan the agricultural development from the long term viewpoint, settlement, infrastructure, finance supporting system, etc.

The concerned governmental departments of this committee is shown below.

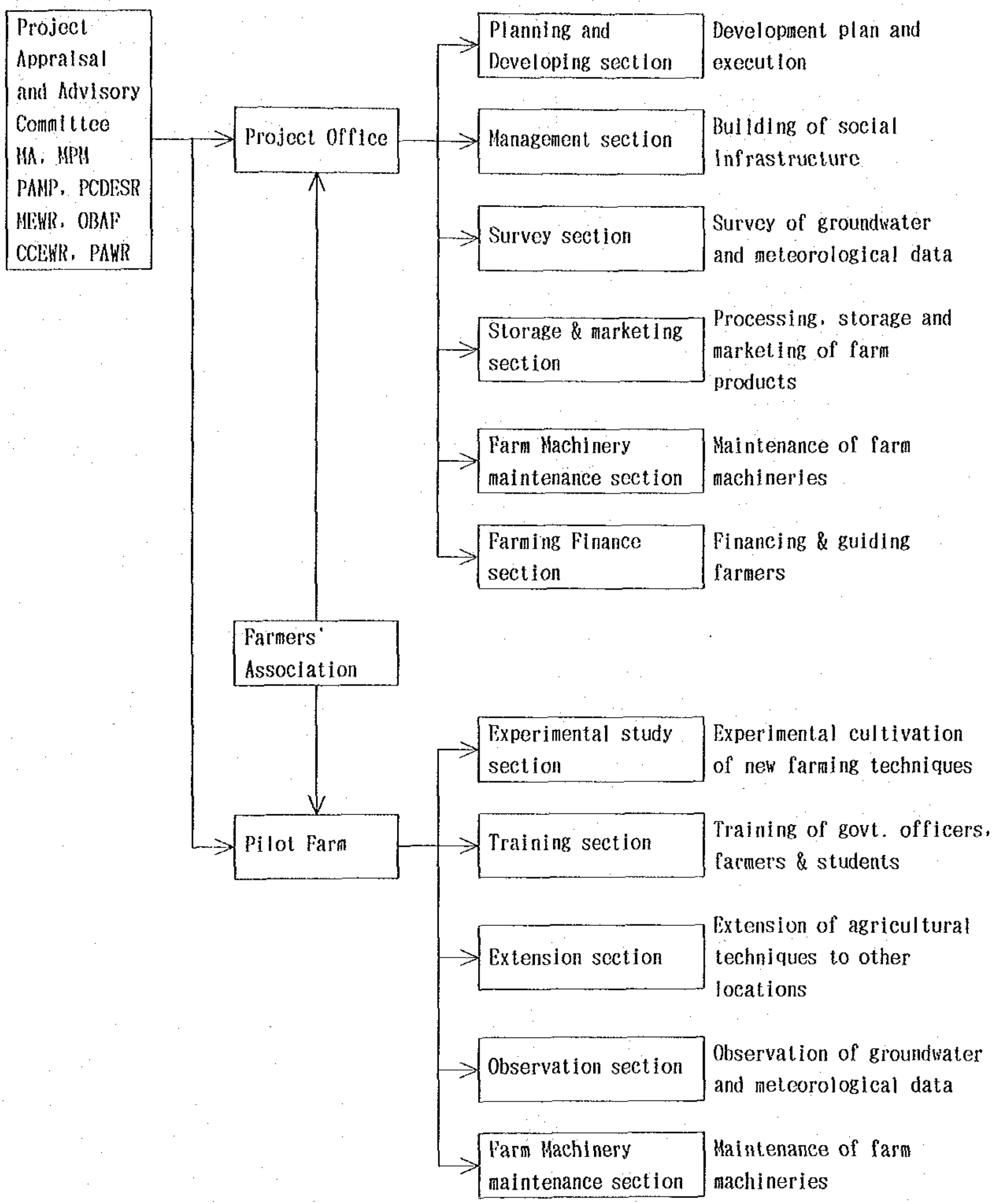
1. Ministry of Agriculture and Fisheries (MAF)
2. Ministry of Environment and Water Resources (MEWR)
3. Ministry of Petroleum and Minerals (MPM)
4. Public Authority for Water Resource (PAWR)
5. Ministry of State and Wali of Dhofar (MSWD)
6. Planning Committee for Development and Environment in the Southern Region (PCDESR)
7. Public Authority for Marketing Agricultural Produce (PAMAP)
8. Oman Bank of Agriculture and Fisheries (OBAF)

(2) Pilot Farm

Pilot farm is expected to work as a pioneer in the project development. The different sections of the pilot farm and its functions are as shown below.

1. Experimental study section
   - For the experimental investigation of appropriate cultivation techniques
2. Training section
   - For carrying out the training activities
3. Extension section
   - For carrying out the extension activities
4. Observation section
   - For carrying out the observation of groundwater and meteorological data
5. Machinery section
   - For carrying out the maintenance of machineries

FIG 5.5.2 Organizational Chart of the Agricultural Development Project



(3) Project office

Project office is responsible for execution and management of the agricultural development project as per the advice of the project appraisal and advisory committee. This office consists of the staffs of concerned government departments, mainly MAF.
The different sections of the project office and its functions are as follows:

1. Planning and Developing section
   - Selection of development area, execution and evaluation of development works
2. Management section
   - Management and maintenance of the social infrastructure
3. Survey section
   - Surveying and observation of the groundwater resource and meteorological data.
4. Storage and marketing section
   - Processing, storage and marketing of the farm products.
5. Farm machinery maintenance section
   - Operation and maintenance of the farm machineries.
6. Farming finance section
   - Financing and guiding for farmer's activities

5.5.7 Mobilization and Settlement Plan

(1) Mobilization plan

1) Concept and objective of mobilization

The main objective of agriculture development project is to introduce agricultural development through the "Omanization" concept. This means that an innovative group of Oman people should take the full responsibility for complete management of the farms and this group will act as the pioneers for the future generation who will shoulder the responsibility of Oman's future agriculture.

Hence a suitable farming group which consists of local people in the Nejd should be selected to take this responsibility. The staffs who take part in this agriculture development project will support this mobilization activity.

2) Mobilization plan

A mobilization plan of farming group and the staffs to be involved in this mobilization activity should be prepared. This plan will be based upon the farming scale, materials/machineries introduced etc.

a) Selection of farming group

"Project appraisal and advisory committee" is in charge of selecting the farming group which will best suit with the purpose. Innovative farming group should be selected based on their desire for adopting new types of farming, experience etc. This group consists of local people of the Nejd.

b) Training before settlement

The farming group should be given enough training at the pilot farm before their settlement. Training period will be equal to one growing season between planting and harvest. Once the farming group has obtained the full experience of all the activities, they can be allowed to work by themselves.

c) Cultivating new farms

The farming group which undertook training at the pilot farm will move to their farms which were constructed by the agricultural development project. This group will be responsible for the full maintenance of the farms thereafter.

(2) Settlement plan

1) Developing new farms

Project appraisal and advisory committee is responsible for the agriculture development project in developing new farms. This committee will establish a project office which will execute and manages the project.

2) Settlement scale and land tenure

The pace of development project mainly depends upon the groundwater condition. The government should decide the number of families/enterprise which should settle at the area to maintain new developed farms. Policies of land tenure, owning of machineries, facilities, etc. should be decided by the government in accordance with government policy.

3) Support facilities after settlement

Enough support should be given to this farming group after the settlement regarding the appropriate farming techniques developed at the pilot farm and social infrastructure etc. Project office should take care of these activities.

4) Establishment of farmers' association

All the development activities of the new farms should be carried out in consultation with respective section of the project office. Besides the farming group will form a farmers' association so that they can discuss about various new developments and problems which occur in their farms. The representative of the group can feed back the problems to the pilot farm and suitable solution can be found out by experimenting at the pilot farm. This association will facilitate for the smooth running of the development project.

CHAPTER-6

PILOT FARM PLAN

CHAPTER 6 PILOT FARM PLAN

6.1 Objectives and Components of Pilot Farm

6.1.1 Objectives of Pilot Farm

The main objectives of pilot farm are as follows:

1. Experimental cultivation
2. Demonstration and training
3. Extension works
4. Evaluation of groundwater potential and observation of soil and meteorological conditions

The objectives in detail, are discussed as follows:

(1) Experimental cultivation

Technology and cropping pattern appropriate to the Nejd will be introduced for the agriculture development of the Nejd. Appropriate cultivation technology which can improve the agriculture will be experimented at the pilot farm, based on the effective use of groundwater and the socioeconomic conditions of the Nejd.

(2) Demonstration and training

The cultivation technology which is found suitable for the Nejd will be demonstrated to the local people, government engineers, agriculture officers and agriculture students through on-farm training at the pilot farm.

(3) Extension works

The appropriate technology experimented at the pilot farm will be diffused to the Nejd through agriculture extension work. Besides the problems of the Nejd will be fed back to the pilot farm and suitable solutions for these problems will be found out.

In addition to this the technical data will be accumulated in this process and these data can be used for further development of the Nejd. These data will also be useful for the formulation of master plans and feasibility studies to the other similar arid regions.

(4) Evaluation of groundwater potential and observation of soil and meteorological conditions

To evaluate the possibility of development of water resources in the future, groundwater level should be observed in the long term period and the groundwater consumption by the pilot farm, which will affect the groundwater resources, will be clarified.

Soil and meteorological conditions should also be observed since these data will be necessary for agriculture development.

6.1.2 Components of Pilot Farm

The components of pilot farm are as follows:

1. Experimental farm
2. Small scale verification farm
3. Large scale verification farm

Facilities required to support these components are as follows:

1. Water supply facilities	:	Production wells
2. Water distribution facilities	:	Farm pond, pump station and pipeline
3. Irrigation facilities	:	Centre pivot, side-wheel, rain gun and drip irrigation system
4. Field arrangement	:	Field plots and farm roads
5. Appurtenant facilities	:	Buildings, power and windbreak facilities

6.2 Farm Management Plan

Based on the objectives of pilot farm the farm management plan can be divided into the following four categories.

1. Crop cultivation plan
2. Training plan
3. Extension plan
4. Groundwater, meteorology and soil observation plan

6.2.1 Crop Cultivation Plan

After establishing the pilot farm, at first it is necessary to improve the soil condition by applying organic matter, fertilizers, etc. Fodder grass will be grown for some period till the soil is cultivated enough and become suitable for the other crops. Hence the crop cultivation plan is divided into two stages:

1. Reclamation stage	:	At this stage fodder grass will be cultivated in the whole pilot farm area to improve the soil condition.
2. Crop cultivation stage	:	After the soil condition is improved and become suitable for other crops, experimental cultivation should be started using the appropriate technology for the Nejd.

The study subjects are as follows:

1. Cultivation trial
   - Introduction of crop
   - Cropping pattern
   - Selection of variety

2. Soil and fertilizer trial
   - Present fertility level of the soil and type of fertilizer to be applied

- Effect of fertilizer application
- Relationship between salt accumulation and irrigation method

3. Irrigation trial
   - Estimation of water requirement of crop to be grown
   - Water saving method
   - Selection of appropriate irrigation method
   - Rationalization of works under each irrigation method

4. Crop protection trial
   - Biological investigation of damage by diseases and insects for the main crops
   - Control of diseases and insects

5. Agricultural machinery trial
   - Performance study of agricultural machinery
   - Unit cost of agricultural machinery

6.2.2 Agriculture Training Plan

To succeed in agriculture in a virgin land, several cultivation techniques and knowledges are required. Continuous technical guidance and education are necessary for the farmers of the existing farms and for the new comers who will engage in agriculture in the near future.

Hence it is planned to establish an agriculture training center within the pilot farm, where the farmers and agriculture students can learn and experience the actual farming techniques.

The training will be done in the following categories:

1. Training for government engineers and agriculture extension officers
2. Training for machinery operators
3. Training for innovative farmers
4. Training for farmers
5. Training for agriculture students

(1) Training for government engineers and agriculture extension officers.

This training will be given to government engineers and agricultural officers who are engaged in agricultural extension work. This training will be given as a part of their actual work.

These officers will learn the appropriate techniques from the pilot farm and transfer these techniques to the farmers of their area. Besides, if any problems will arise in their area, they will bring back the problems to the pilot farm and these problems will be studied at the pilot farm. Hence they can act as a link between the farmers and the pilot farm. The main training items for these officers include:

1. Technical theory
2. Cultivation techniques
3. Machinery operating techniques
4. Irrigation techniques
5. Extension of agriculture techniques and feed back of Agriculture problems
6. Gathering of field informations and data which can be used for future planning and research purposes

The above can be achieved by experimental study done at the pilot farm.

(2) Training for machinery operators

This training will be given to machinery operators working at government departments and the farmers who are managing the machinery by themselves.

Main items of training are as follows:

1. Studying the components and their functions of different farm machinery
2. Inspection and maintenance of these machinery
3. Learning the operating technique

This training can be given as a part of the farming operations at the pilot farm.

(3) Training for innovative farmers

This training will be given to innovative farmers and/or the leaders of the farming group who shoulder the responsibility of developing the farming group. Farming techniques will be spread faster in the Nejd by training this group of farmers. Main items of training are as follows:

1. Learning the appropriate cultivation techniques
2. Learning the operating techniques of farm machineries
3. Learning the appropriate irrigation techniques

(4) Training for farmers

The main focus of training will be given towards learning the appropriate cultivation techniques which includes seeding, fertility management, insects and pests management, harvesting and so on.

(5) Training for agriculture students

Training should be given to the agriculture students who will join Oman's agriculture.

The training will mainly focus on learning different farming techniques by involving themselves into the actual farming activity. The students should stay in the pilot farm for some period so that they can learn the every day activity of the pilot farm.

Besides it is proposed that the students in the Nejd may enter the agricultural schools (e.g. Nizwa Agriculture Institute and Sultan Qaboos University) and after the graduation, they can participate in the management of the pilot farm.