Annexe B　Rehabilitation Works for Khettaras

Annexe B Rehabilitation Works for Khettaras

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B.1 Present Condition of Khettaras

B.1.1 Introduction of Khettara

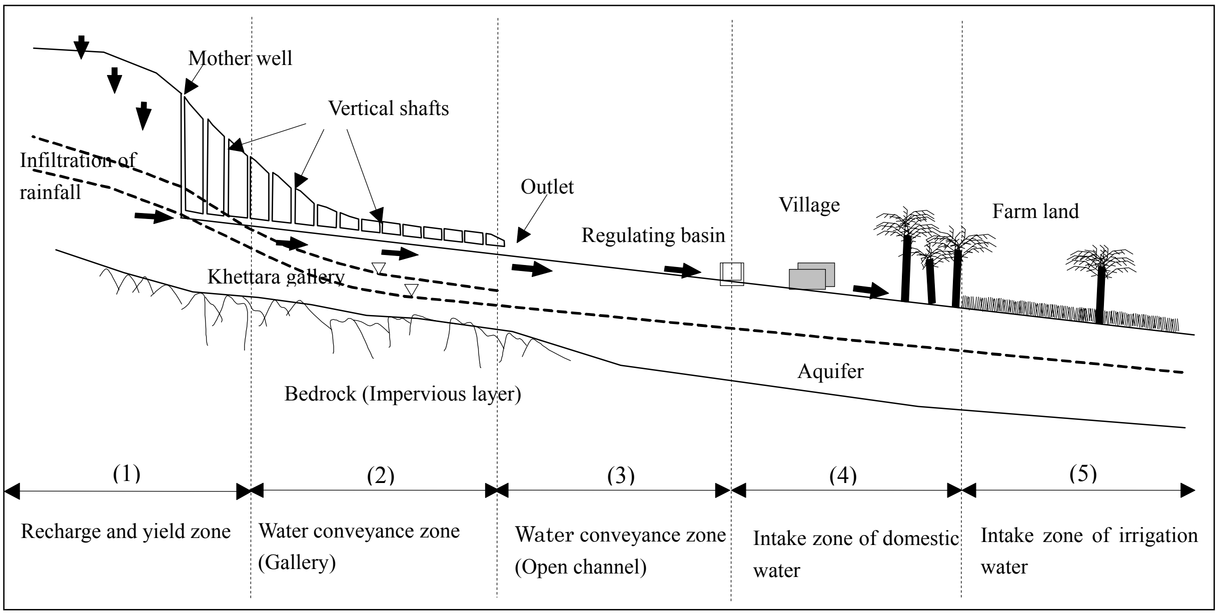
The khettara is a traditional water conveyance system of the groundwater or riverbed water (subsoil water) of the river (wadi) to villages for long distance through small tunnel (gallery) that was dug by manpower in subsurface ground. The khettaras were introduced to the Maghrib countries from Iran before several hundreds years. Water conveyance system like a khettara is called "quanat" in Iran, "karez" in and surround of Pakistan and Afganistan, "foggara" in and surrounding countries of Oman to Algeria. The khettaras in Morocco were distributed widely in Morocco, especially around the Tafilalet region, Marrakech and Agadir. There exist about 570 khettaras in the Tafilalet region according to the census in 1967, however about 410 khettaras are recognized as a productive khettaras, and remaining 160 khettaras were already abandoned due to drying up of khettara flow since 1970s.

Diffusion of Khettaras

Water through khettara is utilized for a domestic water and irrigation use, however amount of khettara flow is so limited that command area has been left in small area, therefore khettara water is carefully and effectively utilized by the inhabitants. Since groundwater utilized by khettaras are limited and yield is easily influenced by a slight fluctuation of the groundwater level, continuous maintenance works such as dredging of gallery is inevitable to preserve khettara flow for hundreds years by farmers. Meanwhile it may be said that water conveyance system not by motor pump but by gravity is very soft and harmonized system to nature, accordingly it is so sustainable method to carefully and effectively utilize the groundwater.

Since the khettaras are located in the arid to semi-arid regions, a fluctuation of annual rainfall amount considerably affects khettara discharge. Several khettaras in the region have dried up or remarkably decreased their water flow due to mainly a decline of the groundwater level caused by continuous drought since 1997. Consequently, 191 khettaras are productive among 410 khettaras, however others are in no use because of the decline of groundwater level as well as heavy load for khettara maintenance work. In addition, shifting the water source from khettara to pump use has accelerated deterioration of water use system previously consisting of only khettaras. An amount of khettara flow from 191 khettaras is estimated at about 36 Mm^3 per annum, and this amount is larger than that storaged in the Hassan Addakhil dam of 26 Mm^3 in 2002. Since khettara flow is stable and quantitatively much preferable than dam water which is susceptibly fluctuated by rainfall, accordingly maintenance of khettara flow is most essential to realize upgrading rural life, sustainable agricultural productivity in the Tafilalet region.

The schematic diagram of khettara is illustrated below.



Schematic Diagram of Khettara

(1) Recharge and yield zone: is located at most upstream area of the khettara. Rainfall or flood water infiltrates into the ground, and springs out into the khettara gallery through generally gravel and sand layers. Several khettaras are located in the base rock at upstream of the gallery to collect groundwater in fissure. Collecting gallery type is also applied to effectively collect the riverbed water (subsoil water).

(2) Water converyance zone (gallery) is located immediately downstream of zone (1). As groundwater level is lower than the gallery base, infiltration (leakage) of khettara water is observed mainly in this zone, especially foundation is composed of pervious layer such as gravel and sand layers.

(3) Water conveyance zone (open channel) is found at where gallery is located in shallow depth. Gallery in this zone is covered with concrete slab or plain rock to prevent from sand desposition in the gallery. Many of gallery in this zone have been rehabilitated with concrete or masonry at present.

(4) Intake zone of domestic water: is located in and around villages. Water is used for potable water, and domestic water supply. Concrete channel is provided for the purpose in almost all khettaras.

(5) Intake zone of irrigation water (irrigatuion canal): is extended to the farmland area. Most of khettaras have a regulating basin to control irrigation water, mainly for storage purpose.

B.1.2 Distribution of Khettaras

The ORMVA/TF covers area of 77,250 km^2 in the Provinces of Errachidia and Figuig, in which 60,000 ha is irrigated by water from khettaras and flood flow. It is defined in the study report that there were 570 khettaras in the provinces, however 160 have dried up before 1970s as explained in Sub-Chapter B.1.1. In this regard, 410 khettaras are defined as a "productive" khettara, and 160 khettaras are "abandoned". Furthermore, 410 productive khettaras are categorized into two groups, one is those which have khettara flow at present, and others which have dried up recently however they have potential to produce khettara flow when groundwater is recovered with adequate rainfall. The former amounted to 191 khettaras and titled as "productive" khettaras, and latter amounted to 219 khettaras and defined as "re-productive" khettaras in the report.

The khettaras located in and around the Tafilalet region are shown on Figure B.1.1. These khettaras are delineated with topograhical and geo-hydorological conditions as shown on Table B.1.1.

Zoning of Khettaras

Zones	Commune Rural	Total Khettaras	Productive Khettaras	River Basin
A	Goulmima,Tinjdad	137	80	Gheris and Todrhariver
B	Beni-Tadjit,Gourrama	24	20	Guir river
C	Boudenib	8	8	Guir river
D	Fezna,Jorf,Arab-Sabbah-Gheris	69	21	Right bank of Gheris river
E	Sifa	25	14	Right bank of Gheris river
F	Rissani,Taouz	44	11	Downstream of Ziz river
G	Alnif	103	37	Maider river
Total		410	191	

The following are basic information on these khettaras:

1) Number of khettaras: About 60 % of khettaras are located at Zone A and G. Most of khettaras in Zone A are located in the river basins of the Gheris and Todrha rivers which supply adequate groundwater from the High Atlas mountain ranges.

2) Discharge of khettaras: Total discharge of 191 productive khettaras is estimated at about 1.1 m^3/sec according to the discharge measurement in the beginning of 2005.

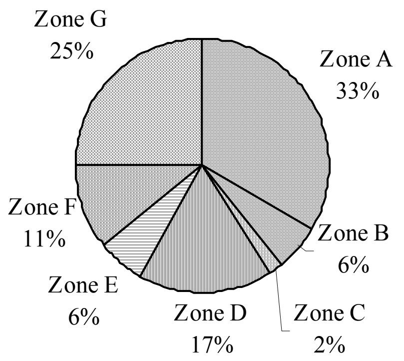
Compared with average discharge of 4.5 lit/sec of whole productive khettaras, khettaras in Zones B and C have adequate flow because geographically Zone B is composed of a pluvial area and most of khettaras are located along the river bank of the Guir and Bouanane rivers or their tributaries. Khettaras in Zones D and E have large discharge of 11 to 13 lit/sec. On contrary to this, khettaras in Zones F and G have smaller discharge of about 2.0 to 2.3 lit/sec comparing with average discharge of 5.7 lit/sec. It is therefore concluded that relatively large amount of groundwater is supplied to the yield zone of the khettaras in Zones D and E from the rivers of the Gheris and Todrha. Through khettaras in Zone F are located at downstream of the Ziz river basin, decrease of floods, which constantly supplied groundwater through riverbed, has caused of decline of the khettara flow. Besides from these areas, khettara flow is minimized in Zone G due to a shortage of rainfall as well as smaller watershed area of each khettara.

3) Khettara length: Khettara length reflects topographic and geo-hydrological characteristics of each khettara zone. For example, khettaras in Zones A, B and G have shorter length of about 1,300 to 2,500 m compared with average length of 3,200 m of whole khettaras since these zones are located in the hilly area. On contrary to these, khettaras in Zones C, D, E and F have longer length of about 4,900 m or more because these khettaras are located at downstream of the river basins of the Gheris, Ziz and Guir and khettara galleries are extended in the subsurface of permeable gravel and sand layers of the widely spread river deposits.

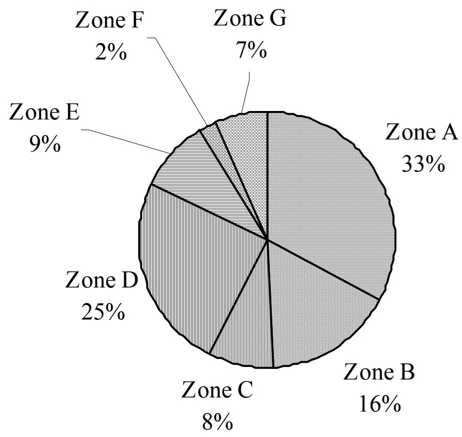
General Feature of Khettaras by Zone

	No. of Khettaras	Productive Khettaras	Total Discharge (lit/sec)	Average Discharge (lit/sec)	Length	
					Total Length (m)	Average Length (m)
Zone A	137	80	359	4.5	221,351	1,616
Zone B	24	20	179	8.9	32,178	1,341
Zone C	8	8	93	11.6	46,650	5,831
Zone D	69	21	270	12.8	384,403	5,571
Zone E	25	14	96	6.9	159,722	6,389
Zone F	44	11	25	2.3	215,550	4,899
Zone G	103	37	73	2.0	252,580	2,452
Total	410	191	1,094	5.7	1,312,434	3,201

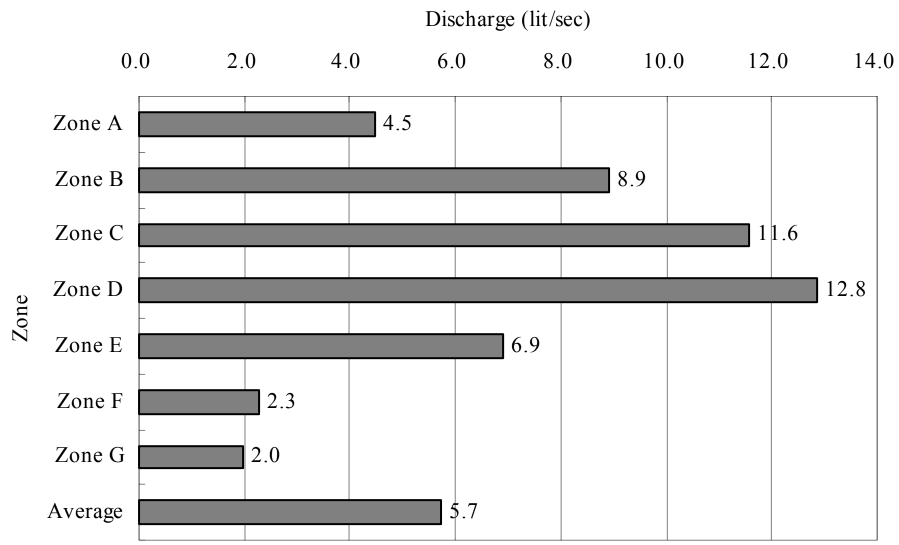
Number of Khettaras



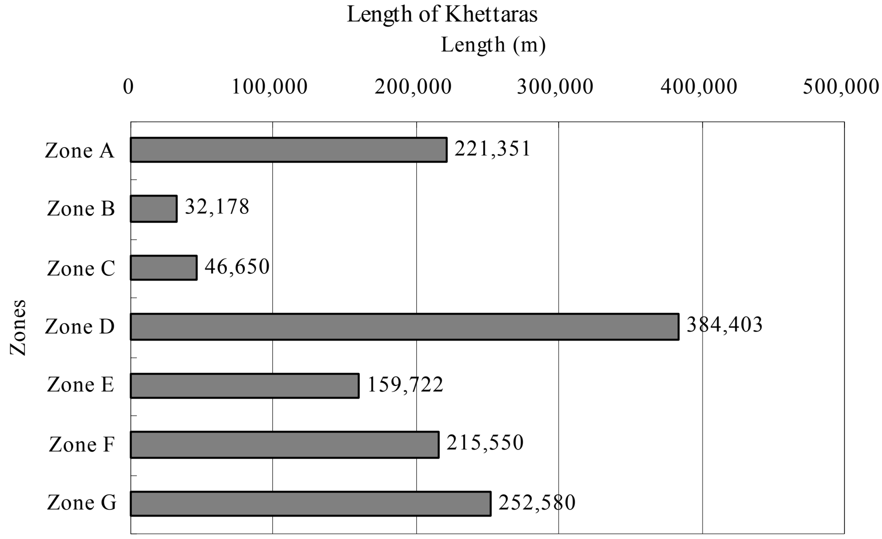
Discharge of Khettaras by Zone

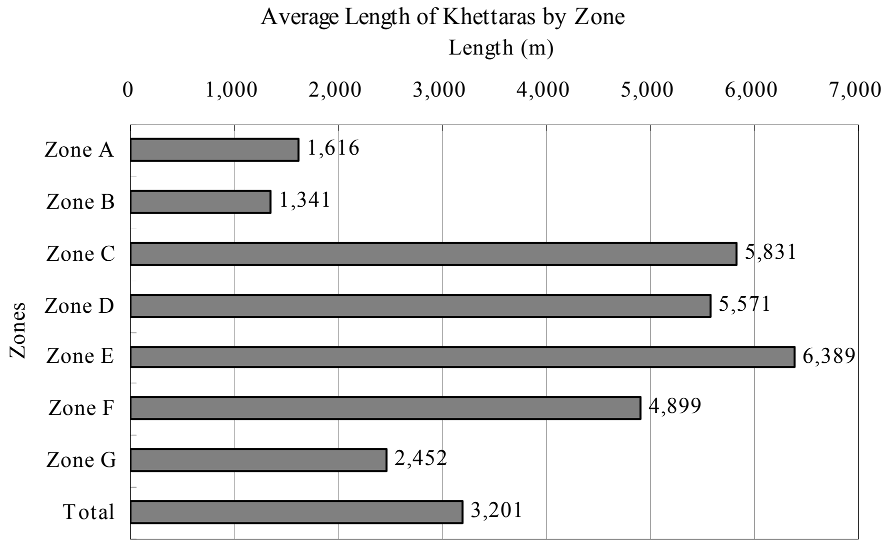


Average Dischrage of Khettaras



Length of Khettaras





Khettara distribution and their discharge are plotted in each zone by symbol mark in Figure B.1.2 to B.1.7. The following are characteristic features of khettara distribution:

1) <u>Zone A</u>: In Zone A, khettaras are distributed in three (5) areas, i.e., Tinejdad, Mellaab, Ait Hani - Aghbalou, Assoul and Amellago areas. Ait Hani - Aghbalou, Assoul and Amellago areas are located in the mountenous area (High Atlas) and most of khettaras have perennial flow. In Tinejdad area, several khettaras along the Todrha river have recently dried up due to drawing down of the groundwater level. However khettaras along the Tanguerfa river and those located in river deposits downstream the Timkit gorge have relatively large discharge of 5 to 10 lit/sec. Khettaras located along the Tourhach river originated from Anti Atlas ranges also well maintained, however continuous drought causes decrease of the khettara flow. In Mellaab area, khettaras are located at the right and left banks of the Ferkla river. Khettaras at the left bank have their recharge zone at downstream of the Timkit gorge and the Gheris river. Khettaras at the right bank are located along several tributaries of the Ferkla river. Several khettaras have dried up due to continuous drought. (refer to Figure B.1.2)

2) <u>Zone B</u>: There are 24 khettaras along the rivers of the Ait Aissa and Bouanane at up to midstream area, and the Guir river at the most downstream area of Zone B. Out of 24 khettaras, 20 are productive khettaras at present. Several khettaras along the Ait Aissa river, of which the most upstream of the khettara gallery is installed in the riverbed, have their discharge of more than 15 lit/sec. A collecting gallery has been constructed to effectively collect riverbed flow in Ain Chouater. (refer to Figure B.1.3)

3) <u>Zone C</u>: All khettaras in Zone C are productive by similar reasoning as Zone B. Khettaras are constructed in the inundated area of the Guir river composed of gravel and sand. (refer to Figure B.1.3)

4) <u>Zone D</u>: Most of the khettaras are located at the right side of the Gheris river in Zone D. In the

zone, khettaras are located roughly in parallel as shown on Figure B.1.4. Khettaras located in the northern area of Fezna and Jorf areas have dried up before 20 to 30 years due to excessive pumpage. Total 21 khettaras which is equivalent to about one third of total khettaras in the zone are productive at present. Productive khettaras are located from Jorf to Hannabou area. The discharge of the khettaras adjoining each other is different because of depth of the mother well, length of gallery, various permeability of aquifers, different longitudinal profiling, etc., however khettara flow is perennial in all khettaras. (refer to Figure B.1.4)

5) Zone E: All khettaras are located at the right side of the Gheris river in Zone E. Total 14 khettaras out of 25 total khettaras are productive at present. The khettaras are definitely divided into two groups by discharge according to their discharges, i.e., khettaras with adequate discharge of more than 10 lit/sec and those with minimal discharge of less than 2.0 lit/sec. It is assumed that difference of their own maintenance work causes a various discharge, especially in the sand dune area. (refer to Figure B.1.5)

6) Zone F: Most of khettaras have dried up except the khettara Haroun as shown on Figure B.1.6. Khettara Haroun also has little discharge and inhabitants in the village, thus depend on other water sources such as potable water supply by the ONEP. Groundwater obtained from shallow aquifers is not enough for irrigation, in addition saline groundwater from deeper aquifers is also unsuitable for irrigation.

   There are 8 khettaras in Taouz. These khettaras are so well maintained that perennial flow sustains daily life of inhabitants. (refer to Figure B.1.6)

7) Zone G: Zone G (Alnif area) is broadly divided into four areas, i.e., Timzaker - Ou Adil river area, Tinifit river area, Reg - Fezzou river area and Ahssia river area. There are 103 khettaras, however 37 khettaras are productive at present. As shown on Figure B.1.7, several khettaras downstream of the Reg river basin and almost all area of the Ahssia river basin have dried up at present. Khettara discharge is fluctuated due to a small watershed and rainfall amount, especially the khettaras located along the Reg river used to drying up during May to October. As an exception, khettara Aachich located at Hsia has adequate discharge of more than 10 lit/sec through the year because of suffucient riverbed flow is available at its yield area along the Ahssia river. (refer to Figure B.1.7)

B.2 Water Resources

B.2.1 General

The Tafilalet region is broadly composed of four (4) river basins, Ziz, Gheis, Guir and Maider. The Hassan Addakhil dam was solely constructed at the north of Errachidia in the Ziz river basin. Several diversion weirs were also constructed in each river basin to divert the flood water to the farmland.

B.2.2 Dam Facilities

The Hassan Addakhil dam was constructed in 1971 at the north of the Ziz river gorge with its effective impounding capacity of 346 Mm^3. Water from the Ziz river used to flow unimpeded into the Tafilalt basin and provided the primary source of water for irrigation. Storage records are shown on Figure B.2.1 and Table B.2.1 and B.2.2. Water released from the reservoir is conveyed through irrigation canals. Impounding water contributes to the irrigation of about 9,400 ha, more than 75 % of all arable land currently used in Erfoud and Rissani area in the Tafilalet plain.

Average storage capacity from 1971 to 2003 is estimated at about 72 Mm^3 and it is equivalent to 20 % of the effective storage capacity of the reservoir. Continuous drought from 1997 has reduced irrigable area in the Tafilalet plain at present.

B.2.3 Diversion Weirs

There exist several diversion weirs along the rivers and tributaries of the Ziz, Gheris and Guir rivers. These weirs aim at diverting flood water to the command areas located at downstream of the weirs. The largest weirs, the Mouley Brahim, Lahmida and Elbrouj weirs are located along the rivers Gheris and Ziz. Former two weirs divert flood water from the Gheris river basin to the Ziz river basin. The Elbouj weir is located at the north of Erfoud, and diverts the Ziz river water to the command area of Erfoud.

Diversion water volume of these three weirs are shown table below. Actual diversion volume through these three weirs are about 107 Mm^3, and diversion rate is 23 % in the climatic year of 2003 - 2004.

Diversion Volume from 3 Diversion Weirs (2003 - 2004)

Command area	Command area (ha)	Diversion volume (Mm^3)	Diversion rate (%)
Ziz river and settlement area	5,500	31	38
Tafilalet plain	22,400	76	15
Total	27,900	107	23

Source: Rapport de Gestion, ORMVA/TF

Diversion weirs in the basins of Guir, and Ziz - Gheris rivers are shown on Figure B.2.2 and B.2.3, respectively. In addition, major diversion weirs and their conveyance canals which divert flood water for irrigation in Goulmima, Tinejdad and Jorf areas are illustrated on the satellite image. (see Figure B.2.4 to B.2.6)

B.2.4 Pump Stations

(1) Communal pump stations

The ORMVA/TF owns 114 communal pump stations, while private pump stations exist about 6,700 sites in the Tafilalet regions at present according to the ORMVA/TF. Communal pump stations are under operation and maintenance responsibility by the cooperatives and associations. The list of the communal pump station is in Table B.2.3. The ORMVA/TF has commenced to install the pump stations since the beginning of 1970s, and highly promoted their construction since 1983 to cope with a drought started from 1981. Among the 114 communal pump stations, about 60 % stations are well operated and maintained, however remaining 40 % are not well operated due to poor maintenance work, for example shortage of spare parts, etc.

Figure B.2.7 shows location of the communal pump stations constructed under the PDRT (Rural Development Project in Tafilalet) funded by the IFAD, BID and local governments.

(2) Pump stations for potable water supply

Wells used for potable water supply are shown on Table B.2.4 (Study area for wells for potable supply is shown on Figure B.2.8), and their locations are plotted in Figure B.2.9.

B.3 Discharge Measurement of Khettaras

B.3.1 Objectives

The khettaras are scattered in the Tafilalet region, and situated in different natural conditions, e.g. meteoro-hydrological and geological conditions. As for meteorological condition, rain tends to fall on the north area (Zone B, C) because of its higher altitude of the zone location. Annual rainfall is recorded more than 176 mm in average at Amouguer in the High Atlas mountain range. On contrary to this, it is about 50 mm or less in Erfoud and Taouz which are located in the southern area of the Study area in the Tafilalet plain and adjacent to Algeria. From the point of hydro-geology, some khettaras are located in the aquifers in the previously inundated areas downstream of the large river basins, some are located in the rock foundation aiming at collecting fissure water, and some are in the river deposits for collecting riverbed water (subsoil water) through a collecting gallery across the river bed.

The discharge measurement was carried out for three (3) times in June and September 2003 and February 2004 to clarify a seasonal fluctuation of their discharges for selected 30 khettaras as shown on Figure B.3.1. In addition to a recording of seasonal discharge fluctuation of the khettara flow, measurement was conducted at three (3) or five (5) sections at most upstream, middle and most downstream of khettaras to investigate distribution of the khettara discharge along the gallery, e.g. extent of yield and leakage sections, leakage rate, etc.

B.3.2 Observation of Discharge Measurement

Results of the discharge measurement on 30 khettaras are tabulated in Table B.3.1, and their characteristics were studied in terms of 1) seasonal fluctuation, 2) yield and leakage sections and 3) leakage rate. The following are elucidated points through putting the measurement results in order.

(1) Seasonal fluctuation

Discharges observed in particular sections are plotted on Figure B.3.2. It is pluvial from October to February in the Study area, in this fact khettara discharge increased in February 2004 in the most sites. Meanwhile such a tendency was not found in the khettara in Alnif area (Zone G) because it rained few amount though the year in the southern area of the Study area. In Zone D, Jorf, Monkara, Bouya and Hannabou areas, the flow was almost constant through the year. It is assumed that groundwater level in largely spread aquifer was not so sensitive to seasonal fluctuation of rainfall and floods occurrence.

(2) Yield and leakage sections

In general, khettara gallery is divided into two sections i.e., yield section and leakage section except the section lined with previous materials such as concrete, mortar and clayey soil. Distribution of khettara dischrage is plotted on Figure B.3.3 (1) and (2). Figure B.3.3 (1) is on actual length in x-axis, and Figure B.3.3 (2) is on converted length to unit length of "1.0 (100%)" in x-axis in order to simply compare the rate of yield and leakage sections along each khettara gallery.

In due consideration of discharge fluctuation along the gallery, distribution pattern is categorized as follows:

1. Yield section is restricted in most upstream section .... (Category 1)
2. Yield section is in upstream to mid-stream sections................................ (Category 2)
3. Yield section is along all gallery section .... (Category 3)

Category 1: Yield section is located at most upstream of the gallery. In several khettaras, severe leakage causes water loss of the whole quantity. This pattern is observed in comparatively long khettaras located at Zones D and E (Jorf and Sifa area).

Category 2: About 20 khettaras belong to this category among 30 khettaras. Figure B.3.3 (2) indicates that a yield section is broadly located upstream 40 % length, and leakage is found along the downstream section of a gallery.

Category 3: The khettaras in Category 3 are located in small tributaries in the hilly area and constructed in the subsurface of the riverbed. As khettara gallery is longitudinally situated parallel with the riverbed surface, riverbed flow continuously flows into the gallery. Accordingly khettara discharge gradually increases in whole gallery extent.

Hydro-geological condition such as distribution of permeable layers, groundwater level, yield point of groundwater is the conceivable factors which influences a distribution pattern of khettara flow along a gallery.

(3) Leakage loss

Discharge data observed in June, September 2003 and February 2004 in Category 1 and 2 are available to estimate leakage loss. Leakage loss is summarized in Figure B.3.4 based on the result of the discharge measurement. As is obvious from the plots on Figure B.3.4, leakage data vary widely from high to low. It is however justly expected that larger discharge has longer "wetted perimeter" (The length of the wetted contact between a stream of flowing water and its containing channel), accordingly leakage loss should become large. In this assumption, observation data was screened and plotted by assigning discharge value as shown on Figure B.3.4. The following table indicates summary of the estimates.

Leakage Loss per Unit Length (km)

(unit : lit/sec/km)

Observation period	Whole data	10 lit/sec < Q	5 < Q <10 lit/sec	Q < 5 lit/sec
June 2003	1.5	1.9	1.4	1.0
September 2003	1.4	2.3	1.5	1.0
February 2004	1.8	1.8	3.3	2.9
Average	1.6	2.0	2.1	1.6
Applied leakage*	**---**	**2.5**	**2.0**	**1.5**

Note: * Leakage loss applied to cost - benefit analysis on khettara rehabilitation works

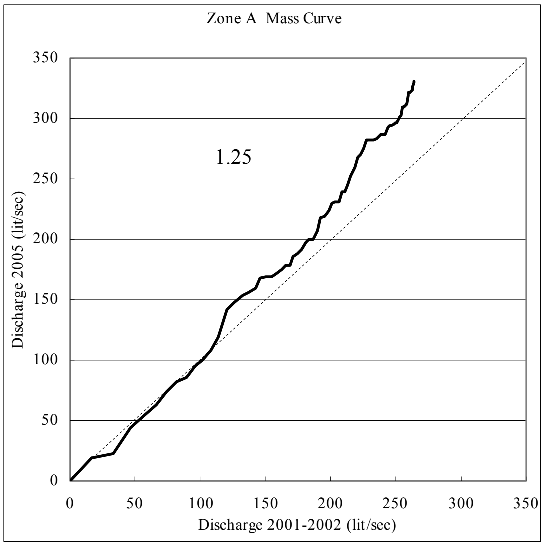
Base on the estimates in the table above, following assumtions have been additionally considered to estimate leakage loss (Applied leakage in the table above) which is referred to project benefit calculation by the rehabilitation of the khettara.

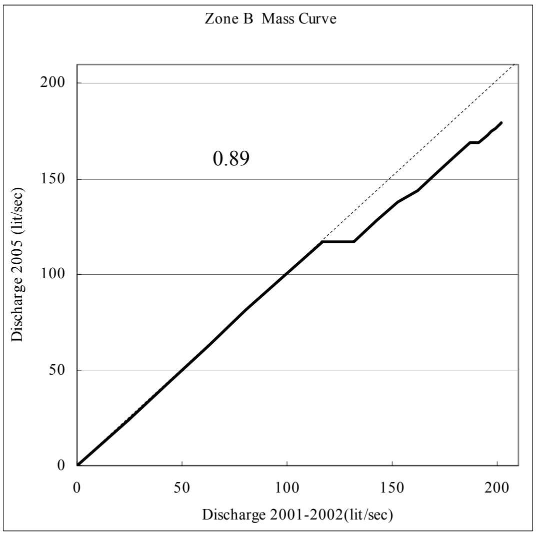
1) Khettara discharge observed in the year of 2003 to 2004 has declined due to continuous drought since 1997. When khettara discharge is recovered by ordinal rainfall, larger leakage may occur corresponding to the increase of the discharge. It is in other word, larger leakage loss should be applied to estimate project benefit originated from leakage reduction by the khettara rehabilitation work.

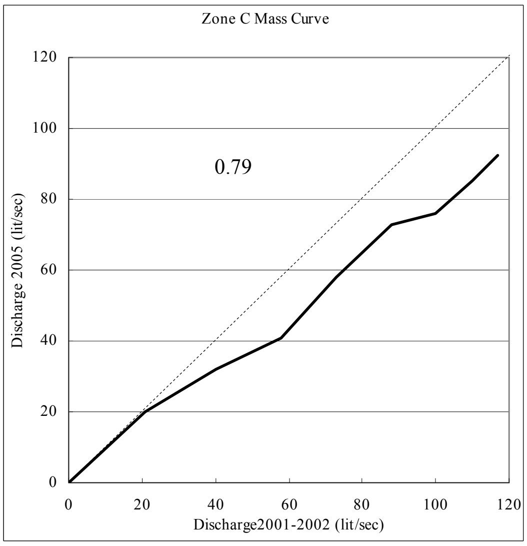
2) Leakage loss was not constant between the measurement sections, but fluctuated and concentrated in particular sections in the extent of several hundreds meters. Larger leakage loss but not average loss can be applied since khettara rehabilitation work is performed first at where severe leakage is observed to maximize project benefit.

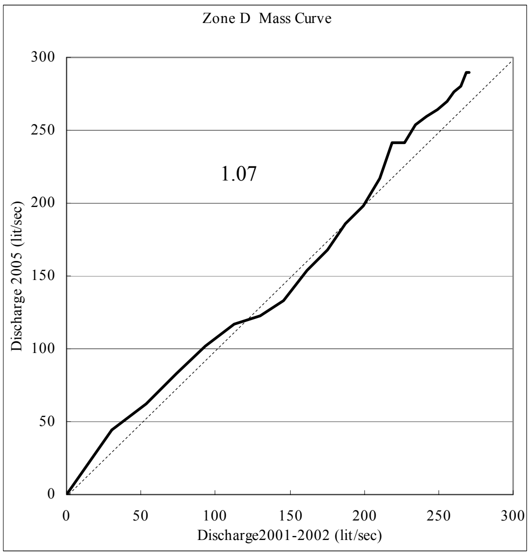
(4) Discharge fluctuation in longer period

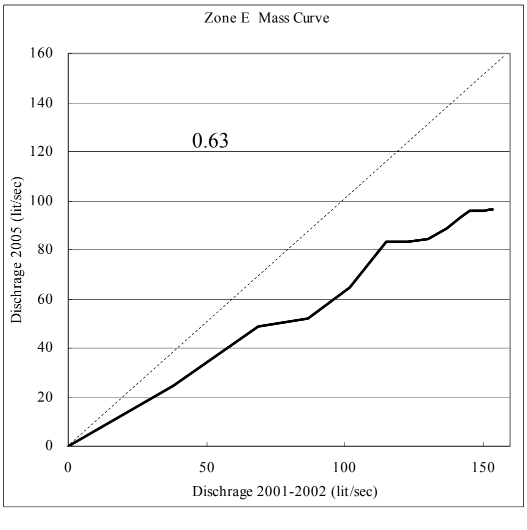
There is no reliable khettara discharge data for past decade. Khettara discharge data observed at the period of 2001 - 2002 and beginning 2005 are plotted by mass curve by zone as shown below.

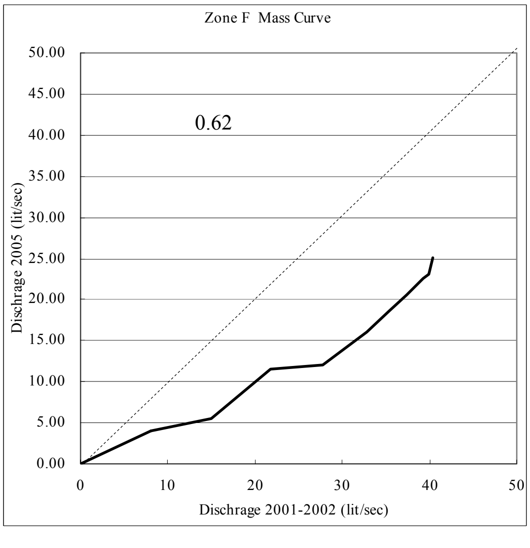

Zone A Mass Curve
1.25
Discharge 2005 (lit/sec)
Discharge 2001-2002 (lit/sec)
0
50
100
150
200
250
300
350


Zone B Mass Curve
0.89
Discharge 2005 (lit/sec)
Discharge 2001-2002(lit/sec)
0
50
100
150
200

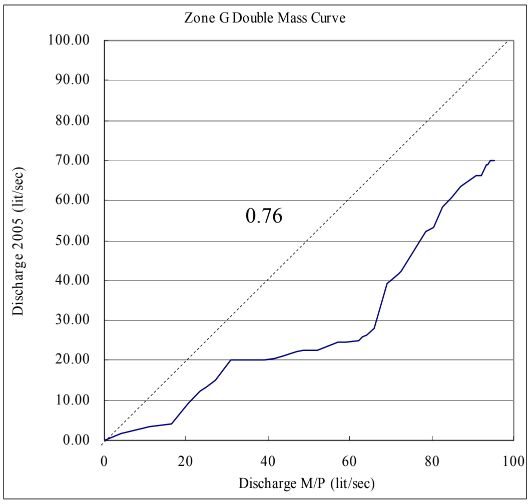

Zone C Mass Curve
0.79
Discharge 2005 (lit/sec)
Discharge2001-2002 (lit/sec)
0
20
40
60
80
100
120


Zone D Mass Curve
1.07
Discharge 2005 (lit/sec)
Discharge2001-2002 (lit/sec)
0
50
100
150
200
250
300


Zone E Mass Curve
0.63
Dischrage 2005 (lit/sec)
Dischrage 2001-2002 (lit/sec)
0
20
40
60
80
100
120
140
160
50
150


Zone F Mass Curve
0.62
Dischrage 2005 (lit/sec)
Dischrage 2001-2002 (lit/sec)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
0
10
20
30
40
50

Plotting in the mass curve is in descending order of discharge of entire khettaras. The mass curve indicates that total discharge of the khettaras observed in the beginning of 2005 has reduced to 88 % of that observed in the year of 2001 to 2002 due to large reduction of the khettaras in Zones E, F and G. Reduction rate reached 62 to 76 % since these zones are located at the southern part of the study area and it rains scarcely comparing with that in northern area, i.e. 50 to 80 mm per annum, and in addition smaller drainage area of tens km^2 also caused decrease of the khettara discharge due to a continuous drought between those observation period in 2001 to 2002 and at present. Other factors, for example social factor should not be neglected from the said decrease considering the fact that several khettaras have been abandoned due to their drying up caused by a financial difficulty of maintenance works.



(5) Discharge data applied to the project evaluation

It is fundamental policy in the Master plan to equally rehabilitate entire khettaras in physically and financially same level so as to give an equal opportunity to access to the rehabilitation works by the governmental agencies, but not give a higher priority to particular khettaras even though which may have economically higher relevance. In this regard, economical viability of the khettara rehabilitation works has examined on total of whole khettaras and communities. Project cost and benefit are evaluated as a total of each khettara rehabilitation works.

The following indicates discharge of whole khettaras observed in the year of 2001-2002 and 2005. The table shows that continuous drought since 1997 reduced khettara discharge year by year.

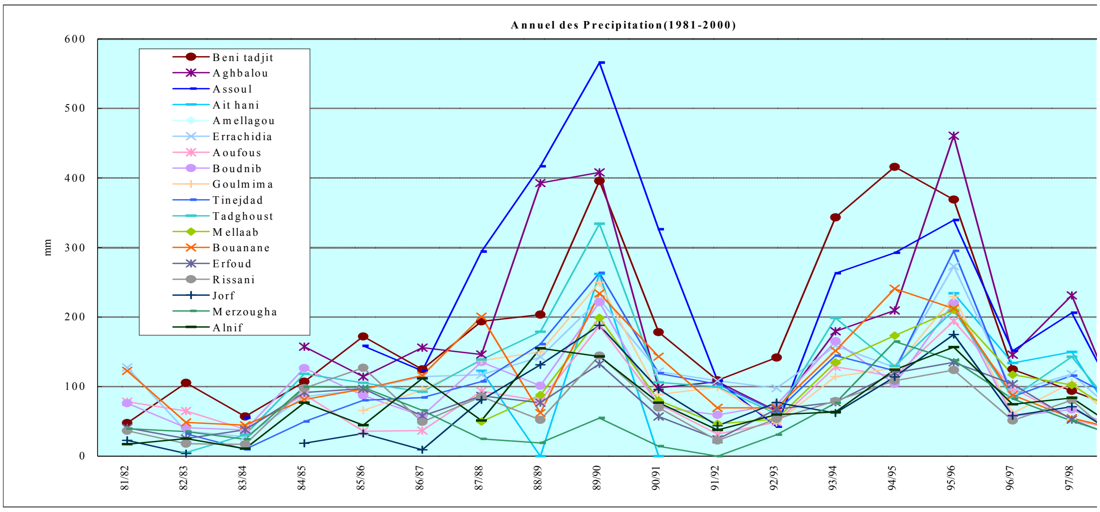
Total Discharge of Khettaras

Observation period	2001 - 2002	2005
Total discharge	1,277 lit/sec	1,124 lit/sec
Parcentage	100 %	88 %

With respect to this fact, total discharge of 1,277 lit/sec observed in 2001 to 2002 is applied to the economic analysis of the khettara rehabilitation works based on the discharge data of each khettara observed in 2005 in due consideration of the following facts that:

1) The drought years were recorded in 1981 to 1983, 1991 to 1992 and up to date since 1997 according to the recent 20 years observation. While groundwater level has used to be recovered to the previous level within one to two years after the drought years ended up. As the discharge

data observed in 2001-2002 seemed to be small because they were observed during the continuous drought year after 5 to 6 years since drought has started in 1997. So it is reasonable to apply the discharge in 2001-2002 to the economic analysis of the khettara rehabilitation works because normal discharge is larger than the discharge in 2001-2002, eventually those data give still safer side for the evaluation.



2) It is principle to periodically revise rehabilitation plan to meet an economic requirement or satisfy the project justification in accordance with monitoring and evaluation results during ten years rehabilitation period. As shown in table below, sensitive analysis indicates that EIRR is slightly lessened as the project cost escalates or expected benefit declines. In this fact, it is not necessary to immediately revise the original rehabilitation works plan as long as a fluctuation of the khettara discharge becomes un-negligibly large.

Sensitive Analysis

	EIRR
Proposed case	**12.2 %**
- 10 % reduction of agricultural productivity	10.9 %
- 10 % escalation of project cost	11.0 %
- Both of above 2 cases	9.7%

B.4 Rehabilitation Records

B.4.1 Achievement of Rehabilitation Works by ORMVA/TF

The ORMVA/TF has commenced khettara rehabilitation works mainly since the beginning of 1990s with financial support of local budget, IFAD, BID, etc. The following table summarized expenditure for the khettara rehabilitation works from 1995 to 2002.

Financial Data on Khettara Rehabilitation Works done by the ORMVA/TF

(unit : DH)

	1,995	1,996	1,997	1,998	1,999	2,000	2,001	2,002	TOTAL
Total budget Equipement	51,300,000	35,288,000	90,650,000	106,140,000	174,610,000	128,196,000	139,135,000	143,590,000	868,909,000
Khettaras Rehabilitation works (1)	**3,622,560**	**597,910**	**3,830,500**	**870,270**	**5,924,520**	**2,090,360**	**3,356,890**	**1,816,360**	**22,109,370**
Others	47,677,440	34,690,090	86,819,500	105,269,730	168,685,480	126,105,640	135,778,110	141,773,640	846,799,630
Financial support under PDRT (2)	3,032,560	297,910	3,380,500	555,270	924,520	90,360	956,890	416,360	9,654,370
FIDA	2,456,390	217,820	2,724,910	172,740	809,050	72,290	775,080	337,250	7,565,530
LF	576,170	80,090	655,590	382,530	115,470	18,070	181,810	79,110	2,088,840
BID	0	0	0	0	0	0	0	0	0

FIDA: International fonds for Agriculture Development
BID: Islamic Bank for Development
LF: Finance Maroccan Law
N.B: (1) = (2) + Budget of khettaras in ORMVA/TF usual program

The ORMVA/TF prepared budget of DH 22 million for the khettara rehabilitation works. Rehabilitation works under the PDRT financed by the IFAD and the BID are shown on Table B.4.1. Contents of the rehabilitation works are summarized in the table below, and detailed information is listed in Table B.4.2. Total number of khettaras were 200 khettaras within nine years. The rehabilitation cost is approximately estimated at DH110,000 for one khettara site, and rehabilitation length of 59,400 m is equivalent to about 4.5 % of whole khettara length of 1,312,000 m.

Contents of Rehabilitation Works

Rehabilitation works	Re-profiling of gallery (m)	Extension of gallery (m)	Protection of gallery (m)	Rehabilitaion of gallery (m)	Coverture of gallery (m)	Regulating basin (sites)
Scope of works	47,281	817	244	57,417	1,750	9

Source: ORMVA/TF

B.4.2 Small Scale Grant Aid Program

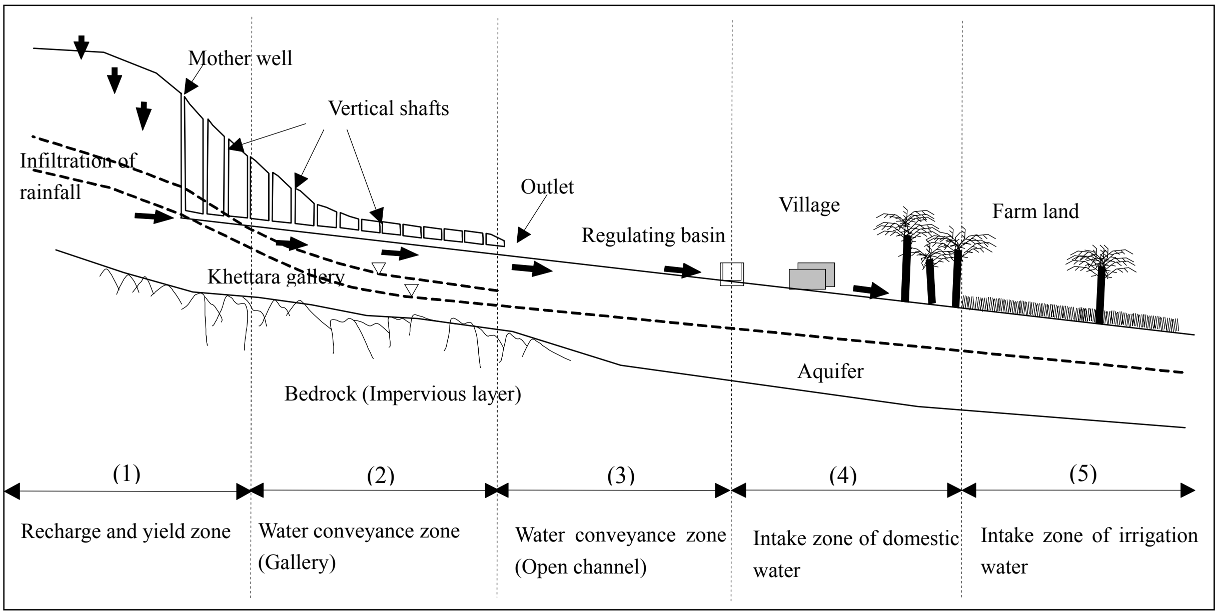
The khettara rehabilitation works were carried out under the small scale grant program by the Japanese Government. Location of the rehabilitation sites and work items are shown on Figure B.4.1 and Table B.4.3, respectively.

Total 12 khettaras and irrigation canal networks were rehabilitated with total rehabilitation cost of DH6.1 million.

B.5 Khettara Rehabilitation Works

B.5.1 Constraint on Existing Khettaras

Considering the extents of the khettara shown on Sub-Chapter B.1.1, constraints and damages of the khettara are described below:



Schematic Diagram of Khettara

1) Recharge and yield zone

   Sediment deposits in the gallery causes decline of water conveyance capacity of gallery canal. Sediments are mainly composed of sand and gravel, and these materials are originated from inflow of sand through the vertical shafts and collapse of the gallery wall. The former is observed mainly at the khettaras situated in the sand dune areas, e.g. Jorf, Taouz and Tinejdad areas. Collapse of the gallery wall is caused by a repetition of dry (shrinkage) and wet (swelling) inside of the gallery. It is effective to keep the vertical shafts open to continuously ventilate the gallery, on the other hand such a ventilation causes inflow of the sand through a opening of the vertical shafts. At the moment, the vertical shafts are closed for several hundreds meters at most of the khettaras because the amount of inflow of the sand dune is larger than those caused by collapse of the gallery wall.

In addition, flood flow causes damages of the gallery at where khettaras are located adjacent to the rivers (wadi), especially in Beni-Tadjid, Boudenib, Tinejdad and Alnif areas. Flood flow first erodes the shaft and gallery walls, and sand and gravel conveyed together with flood are consequently deposited and clogs the gallery canal.

2) Water conveyance zone (Gallery)

Since groundwater level is lower than the gallery base, huge amount of leakage loss is observed in this section in addition to the same problems detailed above. Leakage section is broadly estimated at about 60 % of the whole gallery length in accordance with dischrage measurement of several khettaras, it is therefore necessary to rehabilitate the section so as to miximize khettara flow.

Narrow gallery section also hinders daily maintenance works such as dregding of the sand deposits in the galley canal. The gallery width is limited to 0.3 to 0.4 m, and hight also so small about 0.8 to 1.2 m in several khettaras in accordance with the field investigation of the gallery during the Study. Widening of the inside section of the gallery is very laborious work especially when bringing out the excavated soil through the vertical shaft. In addition it is difficult to continuously maintain water flow for the irrigation use downstream of the khettara during th ework. As gallery become deeper so as to increase groundwater yield, earth work requires a great deal of expense and labor, and outcrop of rock foundation takes tremendous labor to re-profiling the gallery foundation.

3) Water conveyance zone (Open channel)

Most downstream section of the several galleries is composed of open channel because the gallery is located in the shallow portion, for example less than 3 m. Majority of khettaras have already rehabilitated with rock or concrete covers, however some khettaras are behind the rehabilitation, accordingly huge amount of the sand and gravel along the open channel goes into the channel.

4) Intake zone of domestic water

Khettara water is drawn according to the order of first potable water and domestic water such as washing and finally for irrigation use at the outlet of the khettara taking public health into account. Since the water tap area is closely located each other, some risks such as contamination by washing or contagion made by domestic animals cannot be avoided.

In addition the gallery constructed laid underground in the residential area has a risk of contamination by miscellaneous waste- water.

5) Intake zone of irrigation water

There observed large seepage loss along the irrigation canal except concrete lining canal.

B.5.2 Rehabilitation of Khettaras

(1) General consideration

Considering the constraints mentioned above, several rehabilitation methods are proposed for each specifies purpose as follows:

Proposed Rehabilitation Methods for Specifies Purpose

No.	Rehabilitation Purposes	Rehabilitation Works
1	Increase of khettara flow	1-1 Extension of galley 1-2 Protection of gallery wall
2	Mitigation of leakage loss through gallery canal	2-1 Lining of gallery canal
3	Lightening of maintenance works (dispensation with much labor and reduction of cost)	3-1 Protection of gallery 3-2 Protection of vertical shaft
4	Prevention of sand material from entering gallery	4-1 Extension of shaft toward higher elevation 4-2 Covering at top of vertical shaft
5	Mitigation of leakage loss through open channel and irrigation canal	5-1 Canal lining by concrete or mortar
6	Prevention of sand material from entering open channel and irrigation canal	6-1 Covering of canal by concrete plate (culvert)
7	Prevention flood after from entering into the gallery	7-1 Extension of vertical shaft 7-2 Protection of gallery and vertical shaft 7-3 Construction of flood protection dike
8	Public health control	8-1 Lining for khettara canal with concrete, mortar and masonry 8-2 Construction of washing place 8-3 Water proof culvert to prevent waste- water from entering into the gallery

In planning the khettara rehabilitation works, several rehabilitation methods are proposed, meanwhile it is also necessary to remark social and traditional restriction and other factor related to the technical and economical points, such as:

1) Technical points: It is difficult to anticipate increase amount of discharge by the gallery extension works when hydro-geological survey is insufficient. In this regard, it is essential to conduct hydro-geological survey such as boring, electric resistivity test, etc.

2) Economical points: It is necessary to implement the khettara rehabilitation works with allocated budget. In proposing rehabilitation works, there are several alternatives to proceed the rehabilitation works, for example to distribute the budget equally

to whole khettaras however rehabilitation length of each khettara may be limited, to first commence the rehabilitation works from the khettaras which are economically vital, etc. It is necessary to provide the best solution corresponding to the budget disbursement schedule.

3) Social points: In general, geo-hydrological condition in subsurface flow is unidentified without detailed geo-hydrological exploration. Because of this, certain khettara rehabilitation work may affect discharge of other khettaras adjacent that khettara. This fact therefore sometimes becomes constraint to smoothly implement the khettara rehabilitation works. In addition, rapid shifting to groundwater use by pumpage also becomes constraint to the khettara rehabilitation works because shifting to pumpage system has caused discord between khettara users.

(2) Rehabilitation works

The photograph explains rehabilitation methods proposed for specified purpose.

(a) Protection of gallery wall

(b) Lining of gallery canal

(c) Construction of flood protection dike

(d) Protection of vertical shaft

(e) Protection of gallery for sanitary control

(f) Applying pre-fabricated concrete

(a) Protection of gallery wall

Khettara Ait Ben Omar

View of ground surface

Gallery before rehabilitation work

Excavation works in the gallery

Inside of gallery after widening

⇨

Installation of reinforcing bar and water stop

Concrete placing

Top surface of concrete culvert

Inside of concrete culvert
Width: 0.6m, height: 1.5m

Opening for entering into the gallery at interval of 30 m

(b) Lining of gallery canal

Khettara Diba

Khettara Diba
Before rehabilitation. Gallery wall is composed of firm rock. 0.4m gallery width prevents smooth movement for maintenance works.

After enlargement of gallery section, concrete canal was placed. 0.6m wide canal (inside) make workers easy to carry out maintenance works.

Space between side wall and rock is filled with concrete.

Existing gallery was excavated from the ground, and covered with plane stone. Gallery is about 10 m below from the ground. Photo shows after removal of stone cover to secure the safety inside of the gallery.

Replacement of gallery cover by concrete slab.
(see from inside of the gallery)

(a) Protection of gallery wall

Khettara Lambarkia

View of ground surface before rehabilitation

Excavation by backhoe and giant beaker for rock excavation

Excavation to the gallery foundation
Concrete placing was commenced after open excavation works.

Concrete placing (gallery and vertical shafts)
Gallery and vertical shafts of its interval of 30m

Form assembly for the vertical shafts

After refilling

Vertical shaft about 5 m high from the foundation

Top of vertical shafts (0.9 m x 0.9 m inside)

(a) Protection of gallery wall

Khettara Oustania

View of ground surface before rehabilitation

Excavation works along the gallery

Concrete placing with chute

Concrete placing of top slab

Gallery and vertical shafts of interval 30 m
（Middle portion of total rehabilitation length of 300m

Gallery and vertical shafts of interval 30 m
（Downstream portion ）

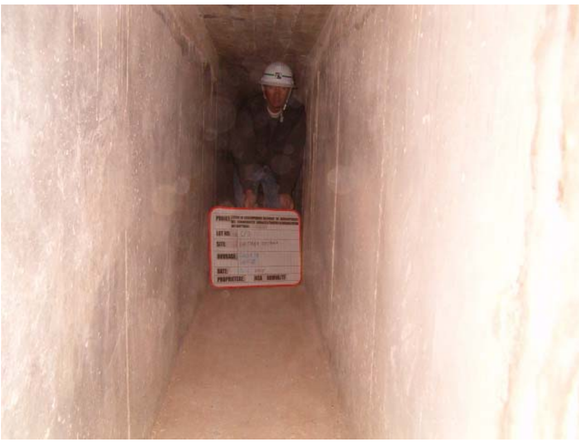
Inside of concrete culvert
Width: 0.6m, height: 1.5m

Khettara Oustania

Gallery and vertical shaft with its interval of 30 m

Reinforcing bar

Installation of pre-fabricated concrete



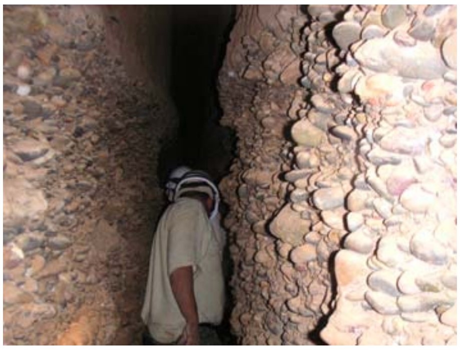
Inside of concrete culvert
Width: 0.6m, height: 1.5m

View of ground surface after refilling

(a) Protection of gallery wall (by PVC pipe)

Khettara Oustania

View of ground surface
Gallery exists about 18 m below from the surface

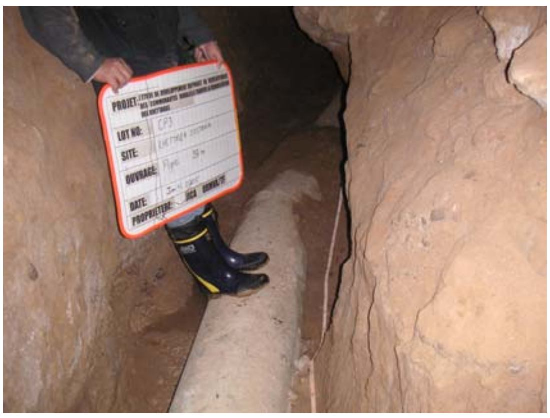


Inside of the gallery
Gallery width is about 0.4 to 0.5 m

PVC pipe (diameter 400mm) mitigates leakage loss through gravel layer.

Excavation works for PVC pipe installation. Gallery is located at 18 m below ground surface.

Openings are installed to remove sediments inside of the pipe.



PVC pipe installed along the gallery

Most upstream of PVC pipe
Pipe diameter has certain surplus flow capacity for increase of discharge in future.

Khettara Azag

Before rehabilitation works. Masonry wall of gallery was damaged by flood.

After rehabilitation works by masonry. (same location as photograph at left)

Galley section before rehabilitation works. Riverbed deposits caused leakage before construction.

PVC pipe installed in the gallery (diameter 200mm)

27m length was completely damaged by floods.

After rehabilitation works by masonry wall. PVC pipe was installed to prevent leakage.

Installation of air pipe

(c) Construction of flood protection dike

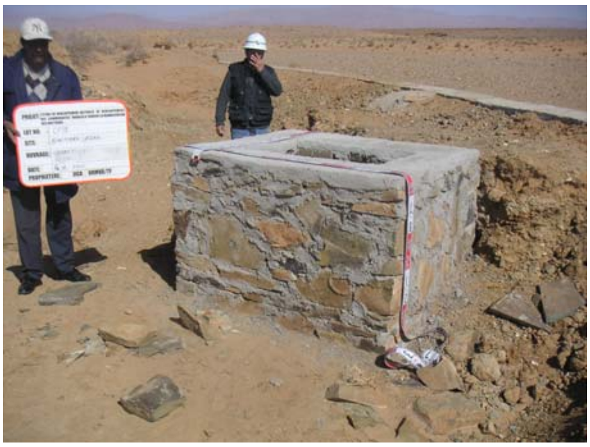
Khettara Azag

Round portion ◯ was subject to the rehabilitation works.

Masonry wall for flood protection (50m length)
Gallery is located along arrow mark in the photograph.

Bank erosion was developed to gallery. Water level was about 1.2 m from the river bed (Horizontal pole shows water level in the photograph)

Completion of flood protection wall (masonry)
Masonry wall has 3.5 m high from foundation or 2.75m from riverbed.



Additional shaft was constructed adjoining to flood protection wall.

Inside of vertical shaft
Shaft has its depth of 5.85m.

(d) Protection of vertical shafts

Khettara Agoumad

View of ground surface
Khettara is located along the river (wadi), so floods have damaged khettaras.

View of rehabilitation works

Flood protection dike is effective to prevent the gallery from collapse or erosion in the case a gallery is situated closely to the river.

⇩ Vertical shaft damaged by floods

⇩ Excavation for masonry protection

⇩ Placing masonry protection in the shaft

Top of masonry protection
Flood does not flow into the gallery.

(e) Protection of gallery for sanitary control

Khettara Bakassia

After excavation along the gallery

After refilling of the gallery

Downstream of the khettara is located in the residential area, so that waste water has caused contamination of the water for potable use.

Concrete is used to mitigate waste water inflow instead of existing masonry.
In addition, water stop along the joint of culvert is important for the same reason above.

(f) Applying pre-fabricated concrete

Pre-fabricated concrete for the shaft of khettara

Steel form for pre-fabricated concrete (for vertical shafts)

Left was assembled in Japan (0.6 m x 0.6 m x 0.3 m height) for reference, and right was assembled in Morocco (1.2 m x 1.2 m x 0.3 m height)

B.6 Data Collection for Recharge Facility Planning

B.6.1 General

Severe drought has continued in the Tafilalet region since 1997. The ORMVA/TF has implemented several irrigation projects to secure water sources for the agriculture, however the ORMVA/TF realizes again the necessity of project implementation for the preservation of groundwater resource including groundwater recharge which constantly supply water to the khettaras and existing pumping systems during the heavy drought years. For further groundwater use by khettaras and pumping wells, sufficient exploitation data, such as meteoro-hyrological data, water level records are required to realize the project implementation on groundwater preservation.

In this Chapter, necessary investigation in terms of exploitation, planning of the recharge facilities is explained.

B.6.2 Recharge Facility Plan

As explained in the main report, several methods are proposed for groundwater recharge.

Recharge Facility Plan

	Recharge Facilities			Recharge Methods
1)	Construction of diversion weir	⇨	i)	Impounding in natural depressed ground
			ii)	Construction of small scale recharge pond
			iii)	Construction of larger dam by earth or gravity type
			iv)	Diversion to farmland aiming at infiltration to the ground
2)	Construction of dam	⇨	i)	Release storage water to accerelate rechrage through riverbed
			ii)	Natural infiltration from reservoir
3)	Construction of flood dispersion weir (embankment)	⇨	i)	Enlargement of recharge area by dispersion weir to accerelate groundwater recharge
			ii)	Temporary storage of rainfall to effectively use rainfall for groundwater recharge

Taking account of topographical, hydro-geological conditions of watershed area of each khettara, suitable recharge method is taken to realize groundwater recharge. Meteorological and hydrological data are essential for the recharge facility planning.

B.6.3 Data Collection and Sorting

(1) Meteorological and hydrological data

All meteorological and hydrological stations and observed data are shown in Annex A. Among these data, rainfall, run-off and evapo-transpiration data are most important data for the recharge facility planning.

- **Rainfall (Monthly)**

- Temperature (Monthly average, maximum, minimum)
- Humidity (Monthly average, maximum, minimum)
- Wind velocity
- **Evaporation (Daily average)**
- **Run-off data (Monthly)**

It is proposed to continuously collect a daily rainfall data and run-off data to precisely establish a water balance calculation.

(2) Groundwater level

In addition to the meteoro-hydrological data, groundwater level data are also important for facility planning as well as project evaluation. The DRH and the ORMVA/TF are observing groundwater level in several sites as shown in Annex A.

During the study, groundwater observation has been newly commenced at the observation wells located at surrounding Jorf area aiming at collecting necessary data for recharge facility planning as a trial. Locations of groundwater observation sites and observed groundwater level are shown on Figure B.6.1. The following are clarified through observation data analysis.

1) Groundwater level data indicate that groundwater along the Ghris river were considerably influenced by floods of the river. Such a fact can be explained as follows:
    - groundwater levels observed at Bouya (Well No. 1029/57) and Hannabou (Well No. 1048/57) which were located far from the Gheris river were almost stable, while those observed at Jorf area (Well No. 1028/57, 3628/57, 3630/57) which were located close to the river were rapidly fluctuated together with flood occurrence.
    - groundwater observed at Jorf area clearly fluctuated in proportion to rainfall amount during drought years from 1981 to 1988, 1993 to 1995, and pluvial years 1991 to 1993 and 1996 to 1997, etc.
2) Groundwater level has gradually declined since 1980. Annual drawing down of the groundwater level is estimated at about 0.15 m according o the observation data at Bouya and Hannabou. (see Figure B.6.2) (In ganeral, it is said to be a precaution situation when draing down rate reaches 0.3 m per annum.)

It is notified that groundwater level observation takes a substantial role in geo-hydrological investigation.

(3) Khettara discharge

Khettara flow is susceptible to changing with seasonal or annual periodicity due to fluctuation of rainfall, continuation of drought year and occurrence of floods as well as geo-hydrological factors, e.g., water storage potential in aquifers. Since khettara discharge is various between several adjacent khettaras due to intricate geological structure, it is therefore essential to investigate each khettara discharge to effectively and efficiently establish a recharge facility planning.

For this purpose, following 33 khettaras are selected for the discharge measurement in a daily basis.

Selected Khettaras for Daily Discharge Measurement

No.	Zone	Zone No.	ID No.	Khettara	Commun Rural	Recharge Source	Discharge (l/s) December 1, 2005
1	A	A 1	A-74	Taghia	Ferkla Ooulia	Toughache	6.2
2		A 2	A-65	Ait M'hamed	Ferkla Ooulia	Toughache	1.34
3		A 3	A-67	Tighfert	Ferkla Soufla	Tangarfa	9.06
4		A 4	A-59	Ait Ben Omar	Ferkla Soufla	Tangarfa	7.22
5		A 5	A-58	Diba	Ferkla Soufla	Tangarfa	1.3
6		A 6	A-49	Ait my Lmamoun	Ferkla Soufla	Gheris	4.5
7		A 7	A-41	Bakassia	Ferkla Soufla	Gheris	11.32
8		A 8	A-15	Aghroud	Mellaab	Gheris	9.35
9		A 9	A-8	Ighrane	Mellaab	N'chari	5.98
10		A 10	A-12	Oukhit	Mellaab	Oukhit	8.9
11	D	D 1	D-44	Lambarkia	Jorf	Batha	13.53
12		D 2	A-35	Aissaouia	Jorf	Batha	-
13		D 3	D-47	Lahloua	Jorf	Batha	11.88
14		D 4	D-55	Kdima Bouya	Jorf	Hnich	16.46
15		D 5	D-54	Jdida Bouya	Jorf	Hnich	17.31
16		D 6	D-60	Fougania	Jorf	Hnich	29.67
17		D 7	D-61	Ouastania	Jorf	Hnich	-
18		D 8	D-55	Krair Kdima	Jorf	Hnich	7.6
19		D 9	D-56	Krair Jdida	Jorf	Hnich	6.02
20	E	E 1	E-8	Lakdima Siffa	Siffa	Hnich	22.58
21		E 2	E-14	Haj Allal	Siffa	Hnich	21.79
22		E 3	E-16	Charchmia	Siffa	Hnich	-
23		E 4	E-7	Ramlia	Siffa	Hnich	10.91
24	G	G 1	G-60	Taomart Jdida	Alnif	Tomart	-
25		G 2	G-59	Taomart Lkdima	Alnif	Tomart	-
26		G 3	G-19	Tizi Lajiar	Alnif	Amssaad	-
27		G 4	G-18	Tizi Lakdima	Alnif	Amssaad	3.68
28		G 5	G-15	Alnif	Alnif	Amssaad	-
29		G 6	G-17	Ait Lahbib	Alnif	Amssaad	-
30		G 7	G-78	Tighourdine	Alnif	Talitat	6.78
31		G 8	G-64	Timarzite	Alnif	Timarzit	-
32		G 9	G-14	Agoumad	M'cisi	Ichichen	-
33		G 10	G-13	Taghrout	M'cisi	Ichichen	-

Locations and observed discharge are shown on Figure B.6.3. Discharge fluctuation graphically represented on Figure B.6.4 indicates that:

1) Zone A Discharge increases in February to March, however it decreases little by little after this season. It is assumed that recharge is markedly increased from November to February, and its effect appears after a few months. Since the watershed of each khettara is not so extensive and aquifers have smaller capacity, khettara discharge continuously and

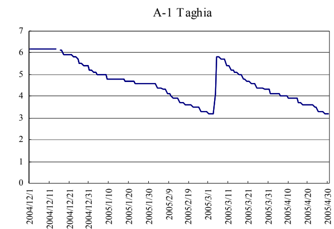
gradually decreases until next rainfall season comes.

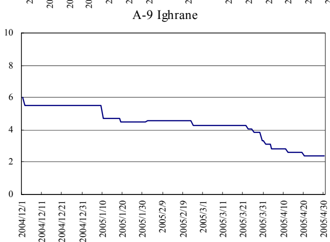
2) Zone D, E Discharge is almost constant through the year. It is assumed that in Zone D and E, recharge effect is observed after six months or more after floods flow down the Gheris river according to the experiences of the inhabitants.

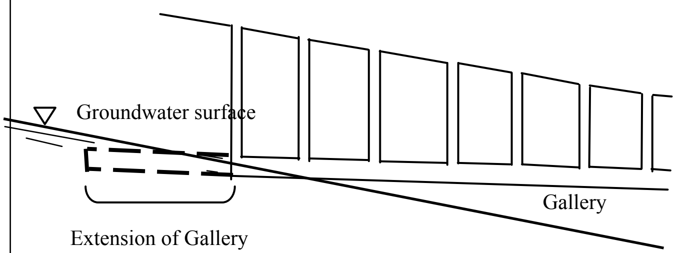
3) Zone G Most of khettaras located along the Reg river dries up in May to June because riverbed water (subsoil water) decreases due to shortage of rainfall. The farming practice is not carried out in this period except minimal farmland by pumpage. It is possible to increase khettara flow if the khettara galleries are dug down below the water level of riverbed flow. It is also remarkable that the khettara flow located along the tributaries rapidly increases just after flooding, and slowly decreases when supplemental flood does not occur.

Following remedy are proposed aiming at increase of the khettara on the basis of the above study:

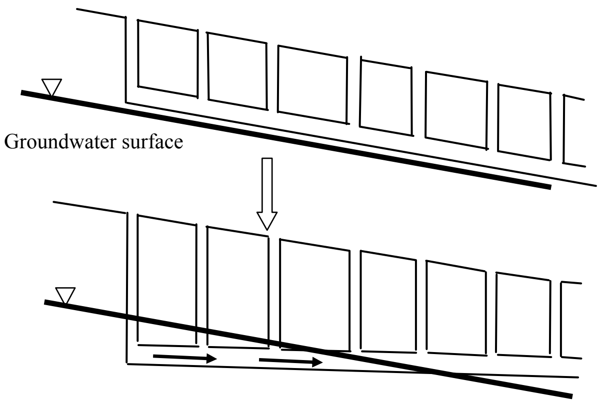
Discharge fluctuation	Remedial works
Discharge gradually decreases after April to May ⇨	Extension of khettara gallery







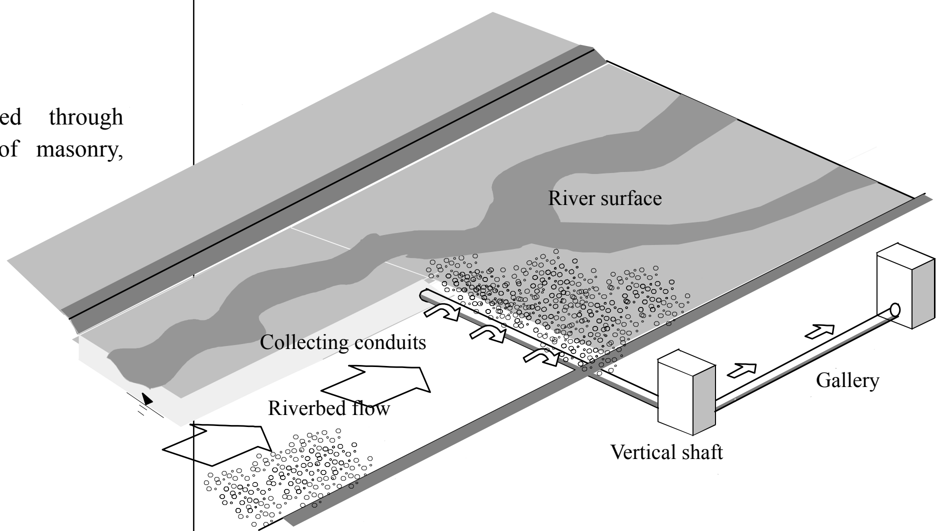
Discharge fluctuation	Remedial works
Discharge gradually decreases after April to May ⇨	Degradation of gallery base



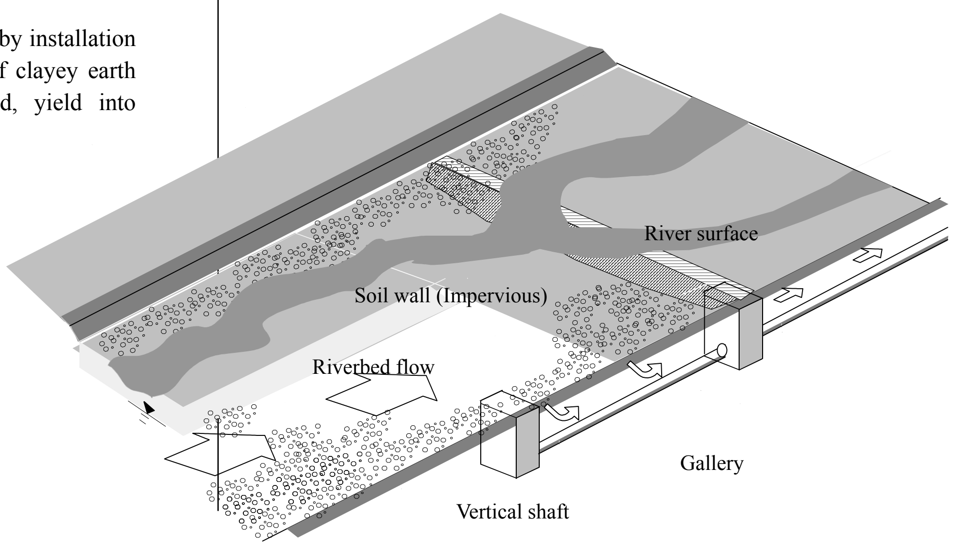
Gallery situates under groundwater surface, and yield increases

⇨ Collecting riverbed flow through collecting conduits

Riverbed flow is diverted through collecting conduits made of masonry, concrete pipe, PVC pipe, etc.



Riverbed flow surface rises by installation of impervious wall made of clayey earth material. By this method, yield into gallery increases.

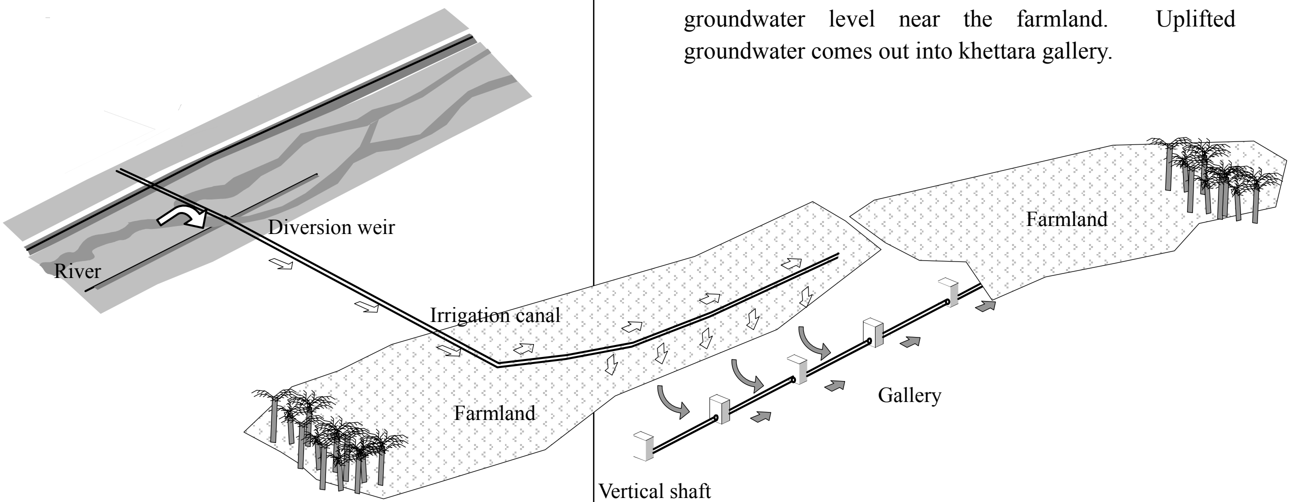


Discharge fluctuation	Remedial works

Since khettara is located far from the river, recharge through riverbed is minimal.

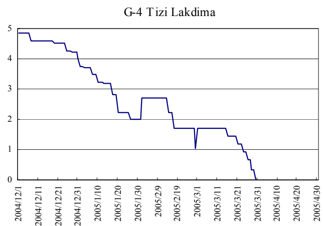
⇨ Diversion of floods through irrigation canal

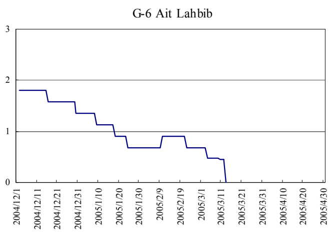
Surplus water diverted from a weir aiming at irrigation use infiltrates into ground, and contributes to rise groundwater level near the farmland. Uplifted groundwater comes out into khettara gallery.



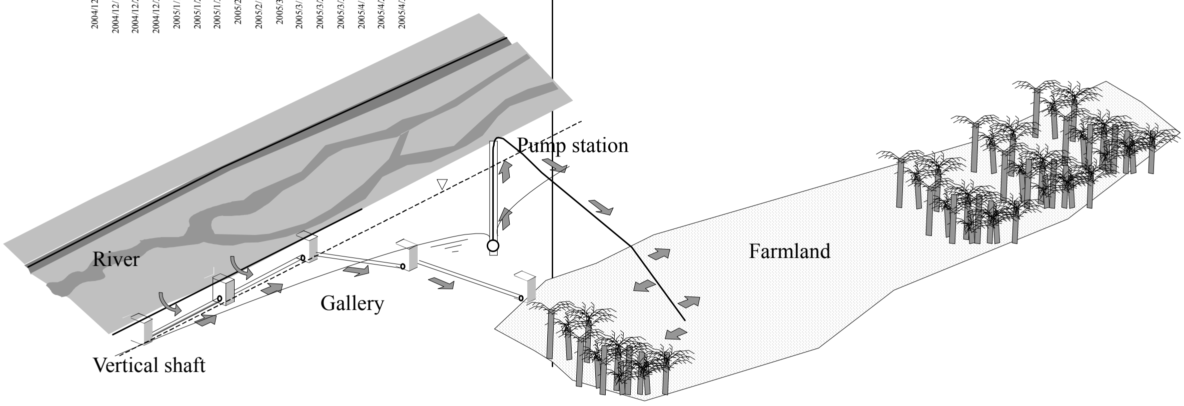
Riverbed flow becomes minimal after May or June, accordingly khettara water is dried up during this season.

⇨ Pumpage is available as a supplemental water source for irrigation.





Due to decline of riverbed flow surface, khettara is dried up, especially after April to June. Beside degradation of the khettara gallery, pumpage is useful to supplementary supply water for irrigation use.



Discharge fluctuation	Remedial works
Since khettara is located far from the river, recharge through riverbed is minimal. ⇒	Construction of recharge dam or storage dam

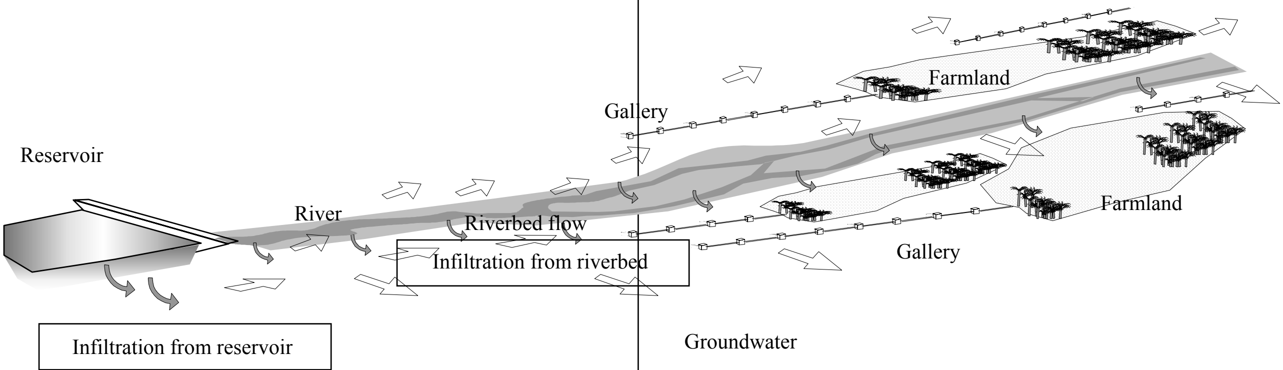
Dam water contributes to recharge though seepage through reservoir foundation, or
released water infiltrates into riverbed and consequently recharges groundwater.

Dam is categorized into two types by construction purpose.
One aims at surface water storage and directly convey the water to the farmland by open channel, etc. Recharge is indirectly expected by seepage through reservoir foundation or riverbed.

Other aims at only recharge purpose. This type directly contributes to groundwater recharge through reservoir foundation or riverbed.

Since huge amount of sand and gravel has been accumulated in the river, special attention shall be paid for sediment removal from the reservoir. With respect to this matter, following countermeasures are proposed:

1) Divert water from river to reservoir when sediment flow is minimal. When flood flows down, bed loads become smaller after peak flood occurs during a flood event.
2) Secure sufficient dead capacity for sediment accumulation.
3) Install sediment pocket (small pond or a series of bands) to prevent sediment from flowing into a reservoir.



(4) Pump station

Location of pump station for potable water use is shown on Figure B.2.9. These pump stations are located sufficiently away from the khettaras so as not to affect khettara discharge. Many khettaras are located near the khettaras in Alnif area, however most of pump stations have been constructed at downstream of khettaras, and their aquifers is deeper than 30 m, which are different aquifers from those for khettaras.

Figure B.6.5 indicates observed data for electric conductivity of each pump stations above. Figure includes plots of khettara locations of their discharge of 5.0 lit/sec or less. As explained in previous Sub-Chapter, groundwater use by pumpage is proposed to supplementary provide irrigation water for the khettara which yield is minimal or fluctuates in season. Higher electric conductivity is observed at Mellaab in Zone A, Rissani in Zone F and southern area of Alnif (Zone G). When electric conductivity is higher than 2,000 dS/cm, it is not suitable to irrigation use, otherwise special treatment against injury from salt is required according to the USDA (United States Department of Agriculture). With respect to this, groundwater pumped up from deeper aquifers at the areas mentioned above is difficulty to use for irrigation (see Table B.2.4). For the use of groundwater, aquifer, river deposits or shallow well are available for irrigation purpose.

B.6.4 Field Investigation for Recharge Purpose Dams

(1) General

There exist three proposed dam sites in the Study area, i.e, Tanguerfa, Fezzou and Ahassia dams. Geological features of these dam sites are summarized below. Dam features, such as catchment area, run-off volume, storage capacity, recharge potential are described in the main report in accordance with existing study reports.

(2) Geological features

(a) Alnif area (Fezzou, Ahassia sites)

1) Geology

- Alternation of strata of sandstone and shale is distributed in Fezzou and Ahassia sites. Bedding plane is obviously recognized in the alternation of strata. Fissure runs on the surface with relatively wider interval of several meters. After an observation of block field at foot of inclined plane, it is similar to a metamorphic rock by regional metamorphism.
- Volcanic rock (effusive rock: basalt) is distributed in the Fezzou site. In the same manner as an alternation of strata of sandstone and slate, it was interacted by regional metamorphism.
- Riverbed deposit is obserbed in the riverbed of the Fezzou and Ahassia sites. Riverbed deposits are mainly composed of sand and gravel. Its thickness depends on the location, and it is assumed about 20 to 30 m in maximum from topographical feature of both abutments. Round stone of its diameter of 30 cm in maximum is deposited in the riverbed. Gravel

deposits are rigid and mainly composed of volcanic rock, sandstone and shale. Sand material is unconsolidated.

- Talus deposits also observed in the Fezzou and Ahassia sites. Talus deposits are comprised of an angular gravel originated by collapse of a rock spine. Talus deposits are in stable and slope gradient is in angle of repose.
- Bearing strength: Firm rock foundation is enough to sustain dam body. There is less possibility of slide on the surface of fissure originated from a depositional surface, accordingly detailed investigation is necessary, especially for the foundation of a gravity dam in terms of presence of fissure, its extent and shearing strength along the fissure.

2) Dam type and scale

Both dam sites are composed of firm rock foundation and abutments. In this fact, a gravity type dam is proposed bacause of less excavation volume for spillway construction which is required for a fill type dam. As to dam height, maximum height is roughly estimated at about 20 and 30 m for the sites of Fessou and Ahassia, respectively taking topographic conditions of both sites into account.

3) Groundwater level

It is anticipated that groundwater level is in riverdbed deposits in both sites.

4) Permeability of foundation

It is proposed to investigate permeability along fissures. Most of fissures have developed horizontally originated by depositional surface and those perpendicularly to the horizontal one. Continuation of these fissures from up to downstream of dam may form a path of percolation. When either abutment is thin, special attention shall be paid for a possibility of percolation induced by shorter pass of percolation.

5) Grouting

Ordinary grouting is available to improve permeability for rocks with fissures. In case abutment is thin, it is necessary to put grouting into practice with certainty.

(b) Tanguerfa site

1) Geology

- Alternation of strata of sandstone and shale is distributed in the Tanguerfa site. Sandstone is predominant rather than shale (e.g. sandstone : shale = 9 : 1). Bedding plane is obviously recognized in the alternation of strata. Fissure runs on the surface with narrow interval of 10 cm. Strike is about ENE - WSW with dip of 10^{o}. The right abutment of dam body forms dip slope structure and other side forms negative dip slope structure. Accordingly, abutments of both sides form unsymmetrical configuration, the right side forms gentle slope configuration and the left side forms relatively steep slope configuration. After an observation of block field at foot of inclined plane, it is similar to a metamorphic rock by regional metamorphism.

- Riverbed deposit is observed in the riverbed. Riverbed deposits are mainly composed of sand and gravel. Its thickness is assumed about 20 m in maximum, and it is thin at the right side abutment. Round stone of its diameter of 50 cm in maximum is deposited in the riverbed. Gravel deposits are mainly composed of limestone, sandstone and shale. Sand material is unconsolidated.

- Bearing strength: There exists firm rock at both sides of the abutment and weathered rock layer is not laid, accordingly foundation is enough to sustain dam body. There is a possibility of slide on the surface of fissure originated from a depositional surface, which is inclined from right upstream to right downstream. Therefore, there is a touch of uneasiness in asserting the dam safety when a gravity type dam is proposed. It is therefore necessary to investigate in detail especially for the foundation for a gravity dam in terms of presence of fissure, its extent and shearing strength along the fissure. In the case fill type dam is proposed, such a fissure does not lower dam stability.

2) Dam type and scale

Both dam abutments are composed of outcrop of firm rock. Since crest length may become longer, fill type dam is not preferable as a dam type because a large quantity of excavation is necessary either abutment for a spillway construction. It is therefore gravity type dam is proposed. As to dam height, maximum height is roughly estimated at about 10 m taking account of topographic conditions of upstream of reservoir area.

3) Groundwater level

Groundwater level of 14 m from the ground surface is observed in the well located at the reservoir area, several hundreds meters from the dam axis. It is anticipated that groundwater level at dam site ranges 10 to 20 m.

4) Permeability of foundation

It is proposed to investigate permeability along fissures. Most of fissures have developed horizontally originated by depositional surface and those perpendicularly to the horizontal one. Continuation of these fissures from up to downstream of dam may form a path of percolation.

5) Grouting

Ordinary grouting is available to improve permeability for rocks with fissures. In case abutment is thin, it is necessary to put grouting into practice with certainty.

Topographical and hydro-geological features of each dam site are summarized in Table B.6.1.

B.6.4 Field Investigation for Recharge Pond

With respect to the small scale recharge pond proposed in the area of Jorf to Hannabou, location and its presence of water of each mother well are investigated. Location and other information are shown in Table B.6.2 and Figure B.6.6, respectively.

In accordance with the proposed plan, it is located at upstream of the Hinich river (wadi). Field investigation, especialy on mother well location is useful for further study for this recharge facility.

Ahassia dam site (Alnif)

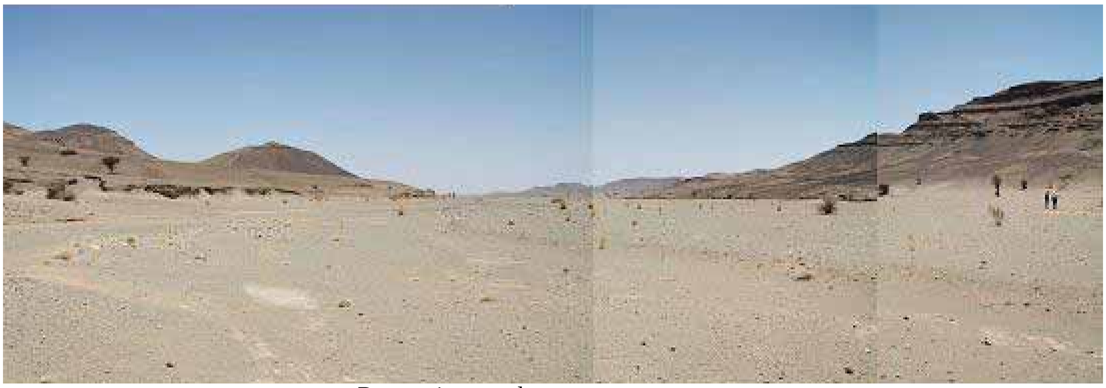
Left bank

Right bank

Proposed dam axis toward downstream

Right bank

Left bank



Reservoir toward upstream
An auxiliary dam is constructed to increase storage capacity along the right side bank.

Most upstream of the right bank ridge located at about 1 km upstream from the dam axis

When dam height is larger than 30 to 40 m, an auxiliary dam is required.

River deposits in the riverbed surface

(Sand and gravel)

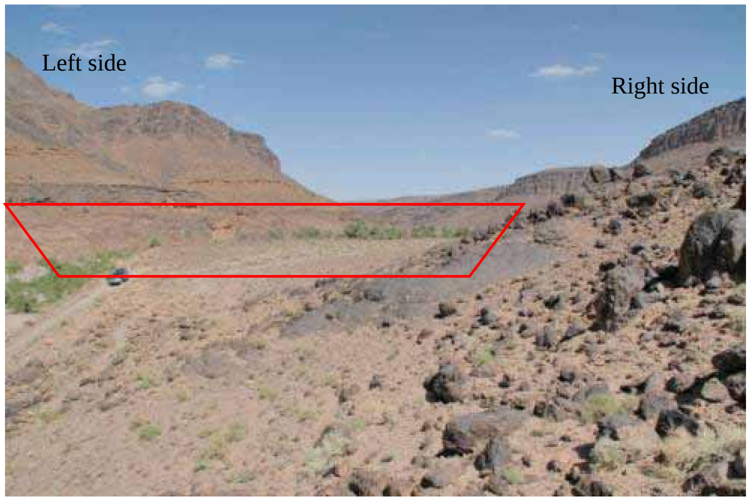
Fezzou dam site (Most upstream site)　(Alnif)

Proposed dam axis (left side of photograph) and reservoir seeing from the left side of reservoir

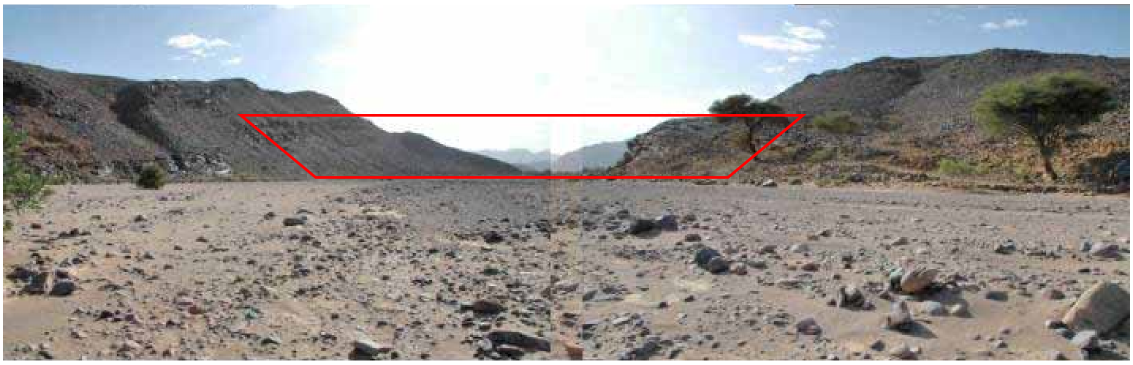
Larger tributariy merges immediately upstream of the dam from the right side bank.　A few families live in the reservoir area (center of photograph)

Reservoir toward upstream

Proposed dam site seeing from left side downstream of the dam

	Fezzou dam site (Midstream site)　(Alnif)
	Proposed dam axis seeing from upstream of the right side bank 
	Reservoir seeing from downstream Large amount of talus deposits has accumulated in the reservoir. 
	Outcrop of sand stone (The right side of dam abutment) 

	Fezzou dam site (Most upstream site)　(Alnif)	
	Photograph of the reservoir seeing toward downstream	
	Dam axis seeing toward downstream The ridge at the right side abutment is thin and its height also low, about 20 m.	
	Photograph shows the right side abutment The abutment is only 10 m wide, and well developed fissures may cause seepage route from up to downstream of the reservoir.	

	Fezzou dam site (Most downstream site) (Alnif) Left bank Right bank  Proposed dam axis (seeing toward upstream) Right side abutment is composed of thin ridge, and its elevation also not so high.
	Riverbed of the reservoir area River deposits are accumulated mainly composed of sand and gravel. Right side Left side 
	 Right side abutment An intrusive rock exists in the right side abutment crossing sandstone and shale alternation of strata. Enlarged photo further for the details of an intrusive rock shown on the left photograph 

Tanguerfa dam site (Ferkla Soufla)

Proposed dam axis (left side of photograph) and reservoir seeing from the right side of reservoir

Several rivers (wadi) are situated upstream of the reservoir area

Outcrop of the left side dam abutment

Abutment is composed of firm sandstone and shale alternation of strata. Low angle bedding with fissures may become seepage route in the case fissures continues to downstream of the dam body.

River deposits shown in the reservoir.

Riverbed material is composed of mainly sand and gravel. Its thickness is assumed at about 20 m referring to the groundwater level observed in the well near the dam site.