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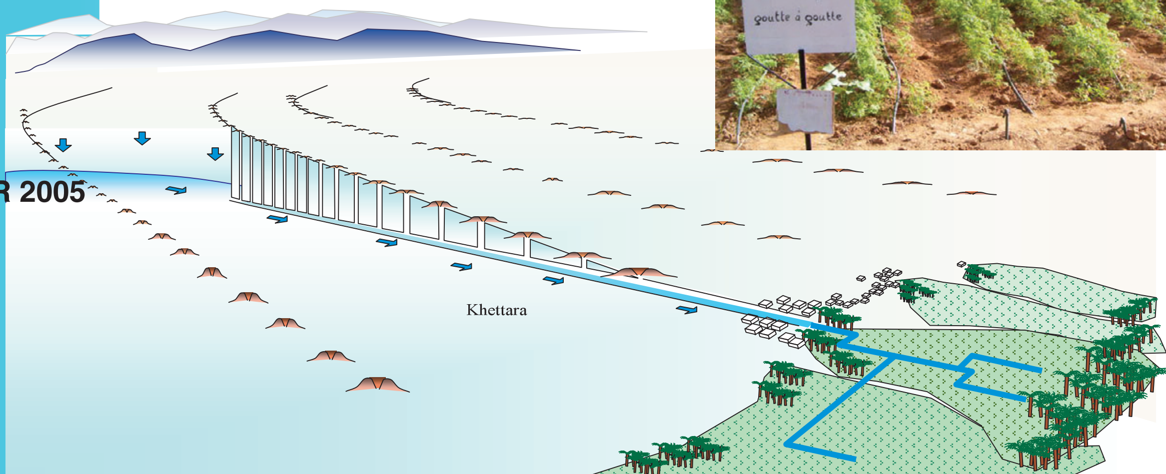
NO.

MINISTRY OF AGRICULTURE, RURAL DEVELOPMENT AND SEA FISHERIES
REGIONAL AGENCY FOR RURAL DEVELOPMENT OF THE TAFILALET
THE KINGDOM OF MOROCCO

THE DEVELOPMENT STUDY ON RURAL COMMUNITY DEVELOPMENT PROJECT IN SEMI-ARID EAST ATLAS REGIONS WITH KHETTARA REHABILITATION IN THE KINGDOM OF MOROCCO

MANUAL FOR KHETTARA WATER USE



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1. General Description

1.1 Objective of the Manual

Frequent drought and exponential increase of diesel-pumped wells results in the falling of groundwater level and decreasing of khettara water discharge in Tafilalet area.

There is no doubt that the rehabilitation of khettara itself is the most effective measures to increase directly khettara water discharge, but not sufficient to achieve sustainable development of agricultural activities and rural communities relying upon khettara.

In this manual, water saving is described as a critical measure for effective use of khettara water.

Under the present situation, the constraints for effective use of khettara water can be pointed out on the irrigation canal level and farming practice level That is to say; loss caused by filtration from the unpaved irrigation canals is widely observed and basin irrigation method with low efficiency is adopted so far on irrigation plots without exception.

Therefore, main objectives of this manual are to propose various ways to accelerate effective use of Khettera water.

For this manual, adequate modification and update should be made based on the further information in future since this is formulated in accordance with the available information at present.

1.2 Present situation of khettara water use

Groundwater collected by khettara is conveyed with open canal by gravity to the residential and irrigation area, and khettara water is used for drinking, washing, cooking, washing, water for domestic animals, and irrigation water so on.

Concerning on drinking, washing, cooking, washing, local population in Tafilalet area depends on various water resources such as khettara water, water supplied by ONEP and PAGER project, local communities, or others.

In recent years, ONEP has been extending the service to rural area, and it accounts for 82% of potential service area as of 2003. Besides, ONEP formulates five years terms extension plan which schedules to cover 97% of potential service area by 2007.

However, some people in local villages where public fountains are already equipped utilize khettara water for domestic use because it is free of charge.

Daily water consumption for drinking, cooking, washing, bashing is 10 litter per one person based on the water demand survey conducted by ONEP.

Besides, daily water consumption for livestock can be obtained on the assumption of 50 litter per day for one cattle, 10litter per day for one sheep or goat. And one household owns three cattle, eight sheep, and ten goats in average in accordance with socio economic survey for rural community conducted by this study.

Percentage of each amount on water consumption was estimated in this study based on irrigation area, population, and number of households belonging to individual khettara.

The result of the estimation revealed on the whole that 93% of total khettara water amount is consumed for irrigation purpose and remaining 7% is consumed for others.

This means that water saving on irrigation water is significantly important.

To grasp actual situation of water balance of demand and supply in khettara area, irrigation water requirement was calculated in this study based on the following data.

1) Reference evapotranspiration ETo; obtained with Blaney-Criddle method.

2) Crop coefficiency; data provided Ministry of Agriculture and Rural Development.

3) Cropping pattern; data obtained by land use survey in typical seven khettara irrigation areas

Irrigation water requirement is in the range of 0.31 to o.52lit/sec/ha and averagely 0.4lit/sec/ha at the peak according to the calculation result.

On the contrary, water supply from khettaras is not sufficient as shown in Figure 2.2.1. Water supply in 58% of the khettaras is less than irrigation water requirement 0.4lit/sec/ha, and 37% of that is less than 0.2lit/sec/ha. In other words, only half of khettaras satisfy the water amount required in khettara irrigation area, and only one-third of khettaras satisfies half amount of water requirement.

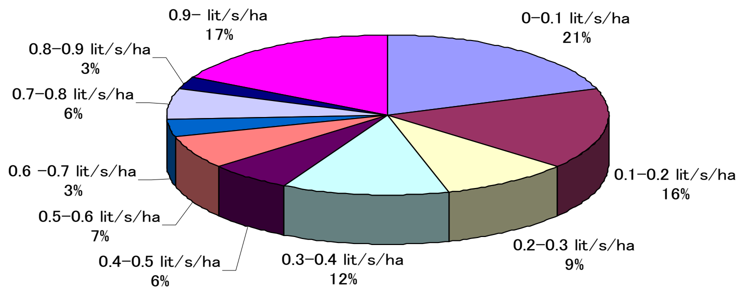


Figure 2.2.1 Water Supply Volume from Khettaras

Note: This figure is made based on the data of khettara inventory survey carried out in 2003.

Water amount of khettara is recognized to be a critical factor for the stable agriculture production in oasis. Needless to say, it is important to keep or increase water discharge with khettara rehabilitation in order to response the decreasing water amount.

In addition to this, it is indispensable to use khettara water effectively at most through improving traditional irrigation method and facilities which have been hindered effective use of water in khettara irrigation system.

2. Water saving in khettara irrigation area

2.1 Water balance of khettara irrigation system

Figure 2.2.2 shows the concept of water balance in khettara irrigation area.

Some of khettara water amount is lost by conveyance loss, water management loss, and water surface evaporation during flowing on the irrigation canal.

However, all of the irrigation water that reaches the farmlands is not available for crop growth.

Because, on farm level, some of irrigation water amount is lost by soil surface evaporation and soil deep percolation.

Only soil water amount between pF2.0 (Field capacity) and pF4.2 (Permanent wilting point) stored in available soil layer can be consumed for the crop growth.

Therefore, reducing the wasted water part is regarded to be the main target in order to supply irrigation water to available soil layer as much as possible, which leads to make the most of the limited khettara water.

Hereby, concrete approach each on irrigation canal level and on-farm level will be discussed.

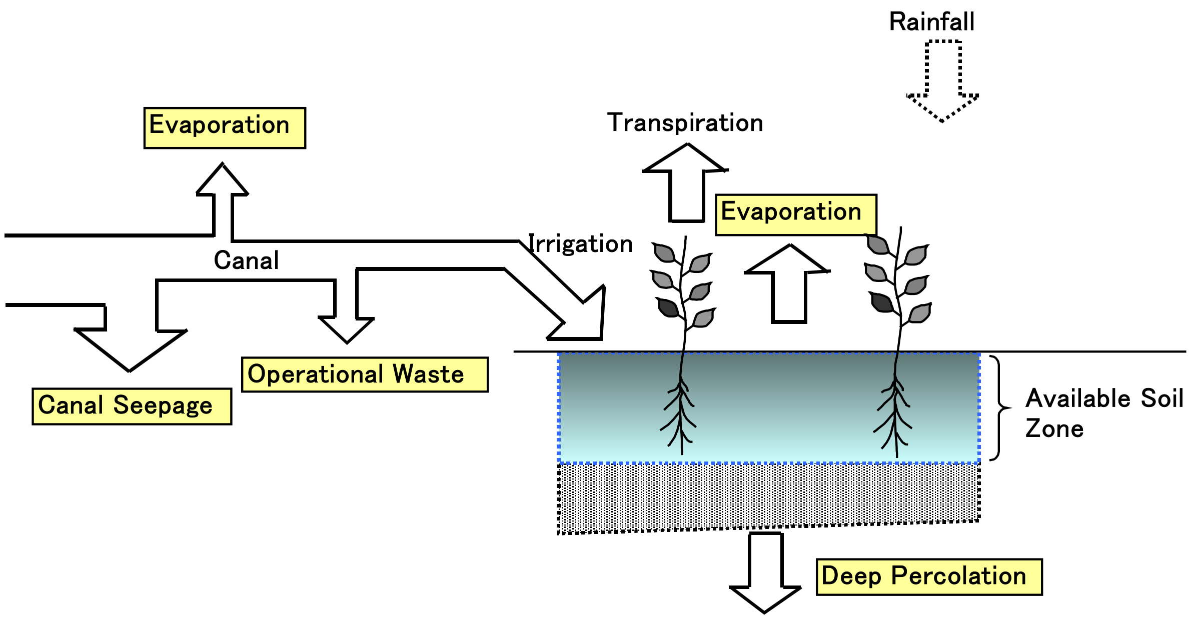


Figure 2.2.2 Water Balance on Irrigation Field

2.2 Water Saving Aproach

2.2.1 Irrigation canal level

Irrigation canal network has been formulated to distribute khettara water to all of the farmlands at every khettara irrigation areas

Since most part of irrigation canals is made with earth, not paved with concrete, filtration loss is estimated to be 18 to 22% at the verification study.

Earthen canal accounts for 73% of main and secondary canal and almost 100% of on-farm canal in length according to khettara inventory survey.

Therefore, drastic reduction of filtration loss can be realized by concrete lining of these earthen canals.

Besides, no facility is equipped at the distribution points along the irrigation canals.

It is a common practice that water users fill these distribution points with soil to divert water flow of the canal. Seepage loss at the distribution points is also estimated to be 11 to 14% at the verification study.

The amount of this seepage water is not negligible because there are plenty of distribution points along the irrigation canal.

Improvement of distribution outlets is necessary in terms of not only saving water but also saving labor for water management.

2.2.2 On-farm level

Basin irrigation method has been applied without any exception in oases, which is the traditional method to impound irrigation water into the divided small farm plots by turns.

Basin irrigation is noted to be one of the constrains against effective water use, because formulated wet zone over whole irrigation plots increases water surface evaporation, and time lag and unequal impounding depth leads to the filtration loss.

Therefore, water saving irrigation techniques such as furrow irrigation and drip irrigation is needed to apply in oases area in order to accelerate effective water use.

3 Water saving on irrigation canal level

3.1 Classification of Irrigation Canal

Figure 3.2.1 illustrates the canal network in khettara irrigation area, which conveys and distributes irrigation water from the exit of the khettara to the individual farmlands

Irrigation canals are classified into three categories, main canal, secondary canal, and on-farm canal in terms of system.

Principal canal is defined as main canal that conveys irrigation water from the exit of the khettara to the secondary canal.

Secondary canal is defined as the canal branched off from main canal to distribute irrigation water to individual farmlands.

On-farm canal is defined as end canal that distributes irrigation water to each irrigation plot in the farmlands.

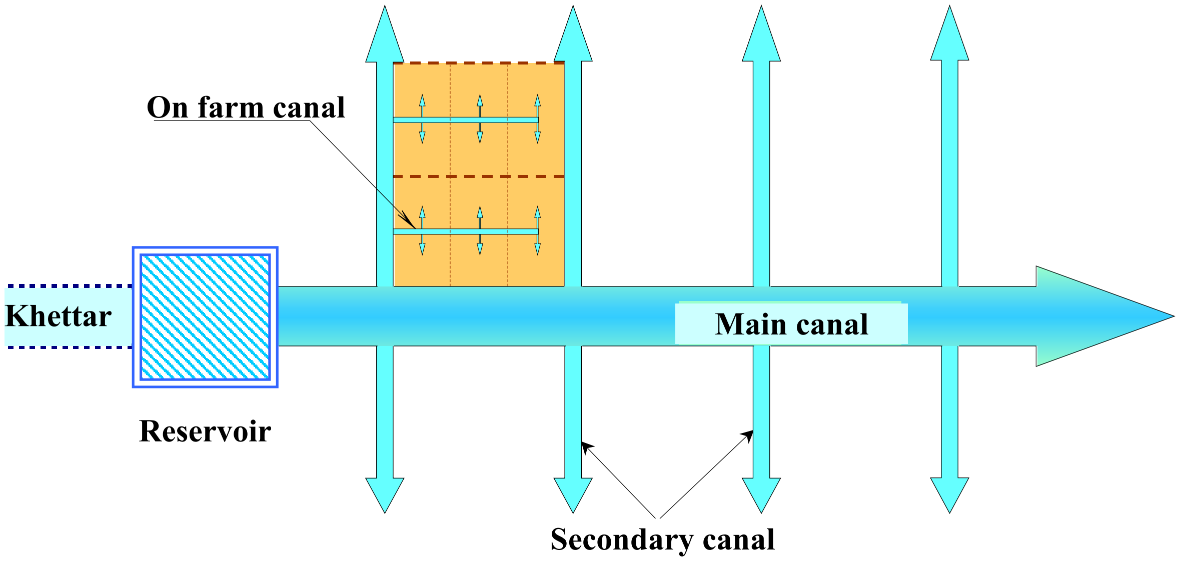


Figure 3.2.1 Schematic Diagram of Irrigation Canal Network

3.2 Canal rehabilitation plan

3.2.1 Investigation and design procedure

Rehabilitation works for irrigation canals shall be proposed taking account of water saving, economy and safety, proper operation and management, etc. Besides, harmonization with environmental and socio-economic conditions related to the khettara irrigation area must be considered in canal rehabilitation plan.

Prior to the investigation and design for formulating canal rehabilitation plan, following schematic diagram should be made based on field reconnaissance to grasp the outline of the proposed irrigation area.

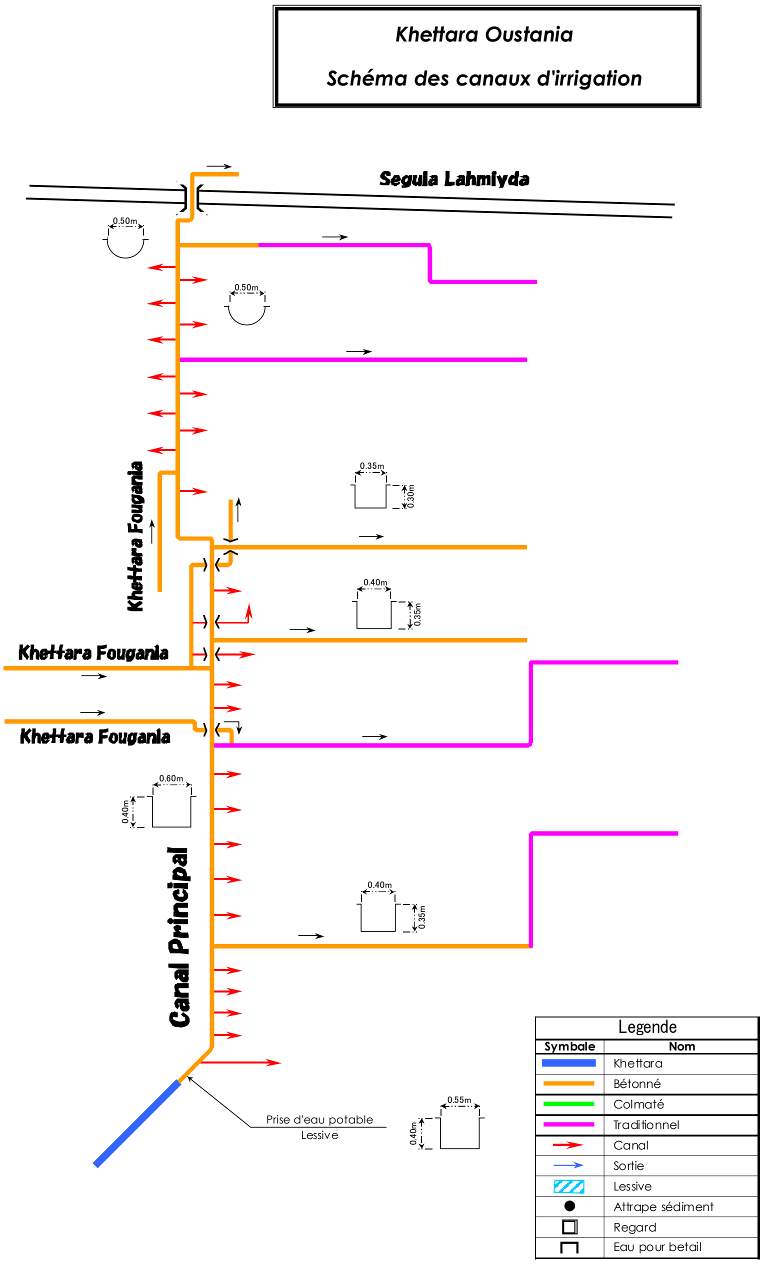


Figure 3.2.2 Schematic Diagram of Canal Irrigation System on Khettara Oustania

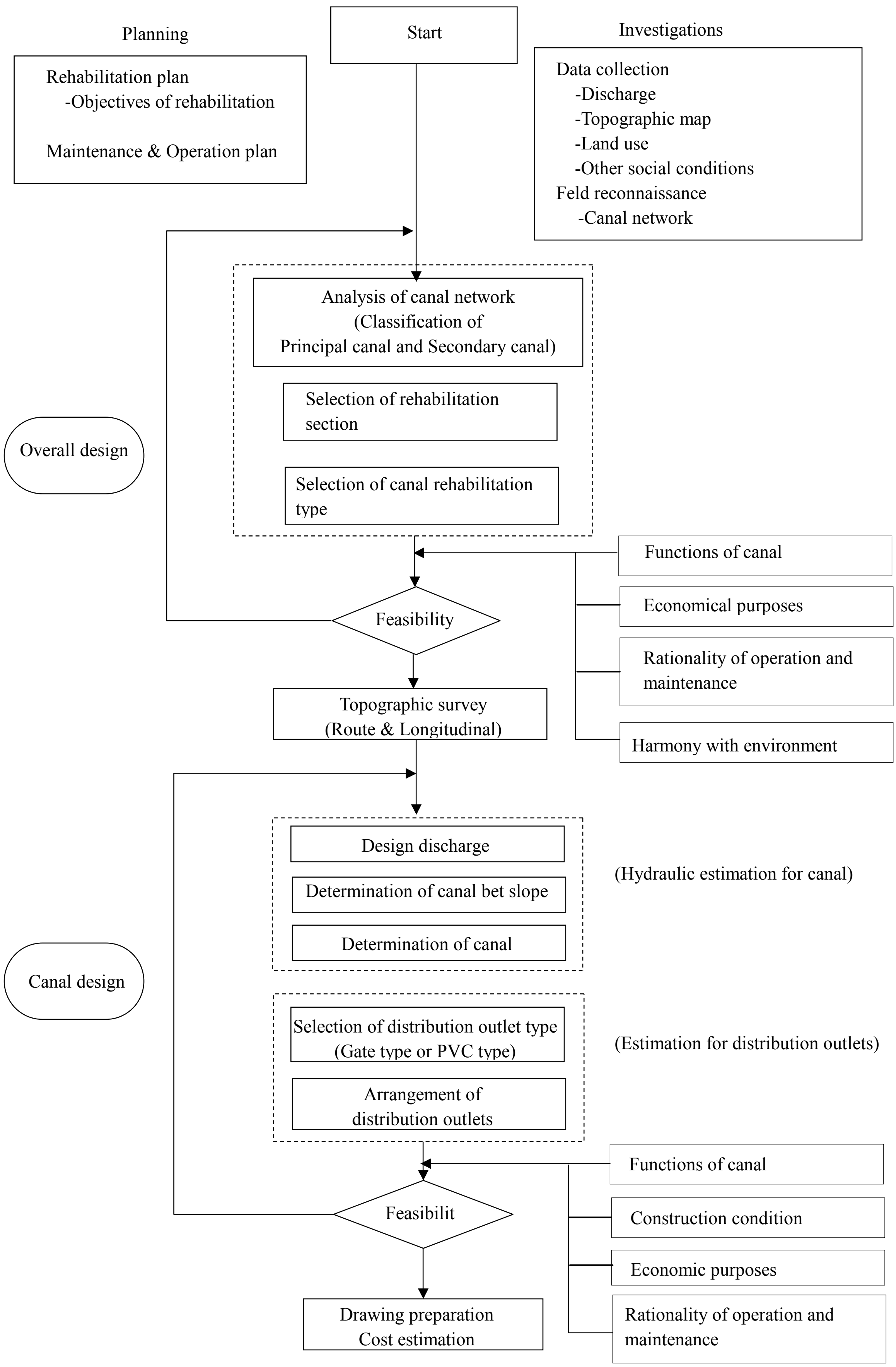


Figure 3.2.3 Flow Chart of Investigation and Design for Canal Rehabilitation

3.2.2 Canal rehabilitation

(1) Design Discharge

khettara discharge varies by 1) seasonal fluctuation of rainfall, 2) consecutive drought, 3) flood occurrence, and in addition, influence by excessive pumping at the area surrounding to the khettara.

With consideration of these factors, design discharge shall be properly determined canal dimensions and canal bed slope.

In this manual, the design discharge is defined to be the maximum value among the discharge measured throughout the year.

(2) Selection of Canal Type

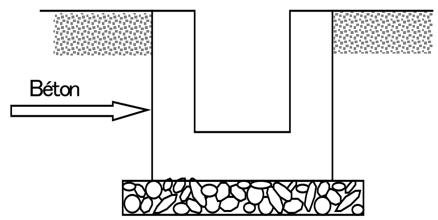
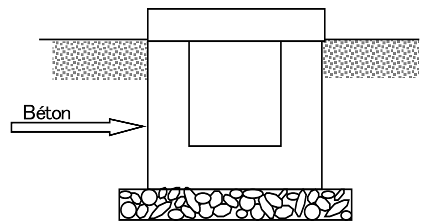
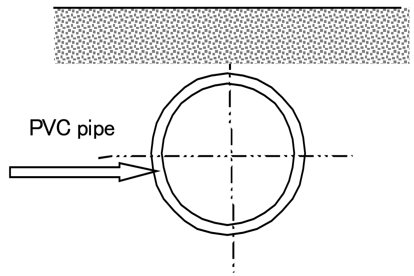
The selection of the canal type shall be examined carefully, since it significantly affects the construction costs and future maintenance.

The canal type must be determined taking into consideration of several factors such as design discharge, construction cost, natural and social conditions, and operation and maintenance.

In general, the canal type in the khettara irrigation area can be divided into three types, flume without cover, flume with cover, and pipeline type.

The characteristics of each canal type are shown in Table 3.2.1 attached with standard section and photo.

Table 3.2.1 Characteristics of Canal Types

Canal type	Descriptions	Figure	Photo
Flume without Cover type	- Easy construction and repair. - Easy maintenance. - Lower cost than other type. - Difficult to control the quality. - Difficult to prevent soil or others from going into the canal.		
Flume with Cover type	- Cover prevents soil or others from going into canal. - Higher cost than flume without cover type. - Difficult to control the quality. - The cover must be removed in case of maintenance.		
Pipeline type	- Pipeline can prevent soil or others from going into canal. - Settling basin is necessary to prevent intrusion of floating materials. - High quality of material can be kept.		

(3) Selection of Canal Route

This manual deals with the rehabilitation works of existing earthen canal, therefore the criteria for route selection is summarized as follows.

1) Proposed route is basically same place as existing one.

2) The route must be decide not to cut thoughtlessly date trees planted along the existing canals because those are one of farmer's valuable income resources.

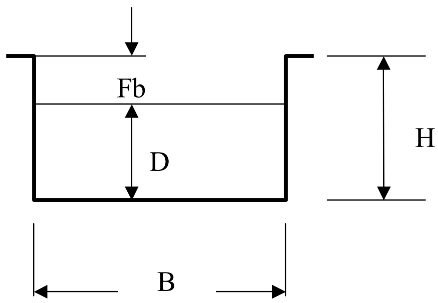
3) The route for pipeline shall be confirmed as straight and short as possible to minimize the construction cost. However, approval of land-owners for new route must be gained before finalizing.

(4) Hydraulic Design

Dimensions of cross section for the rehabilitation canal are determined based on the design discharge.

The capacity of the canal is calculated with following equation:

$Q=A\times V$



Where, Q; discharge (m^3/sec)

A; cross section area (m^2) $A=B\times D$

B; canal width (m)

D; water depth (m)

V; mean velocity (m/sec)

Manning's formula shall be applied to the calculation of water flow velocity of the canal.

$V=1/n\times R^{2/3}\times I^{1/2}$

Where, I; hydraulic gradient (canal bed gradient)

R; hydraulic radius (m) $R=A/P$

P; wetted perimeter (m) $P=2\times D+B$

n; coefficient of roughness (Standard value is applied)

Materials	Coefficient of roughness; n		
	Minimum	Standard	Maximum
Concrete (cast in place)	0.012	0.015	0.016
Concrete pipe	0.011	0.013	0.014
PVC pipe	-	0.012	-

(5) Dimension of canal

1) Proposed canal bed gradient

Proposed canal bed gradient shall be determined in principal same as existing canal bed. Difference of canal bed in elevation between proposed canal and existing canal must be kept in the range of less than around 10cm to secure steady divert of irrigation water at the inlets.

2) Freeboard

For determining the height of the canal, some allowance called "freeboard" must be added above water level of the design discharge flow.

$$H = D + Fb$$

$$Fb = 0.05 \times D + Hv + 0.05$$

Where, H; height of the canal (m)

Fb; freeboard (m); Minimum value=0.10m

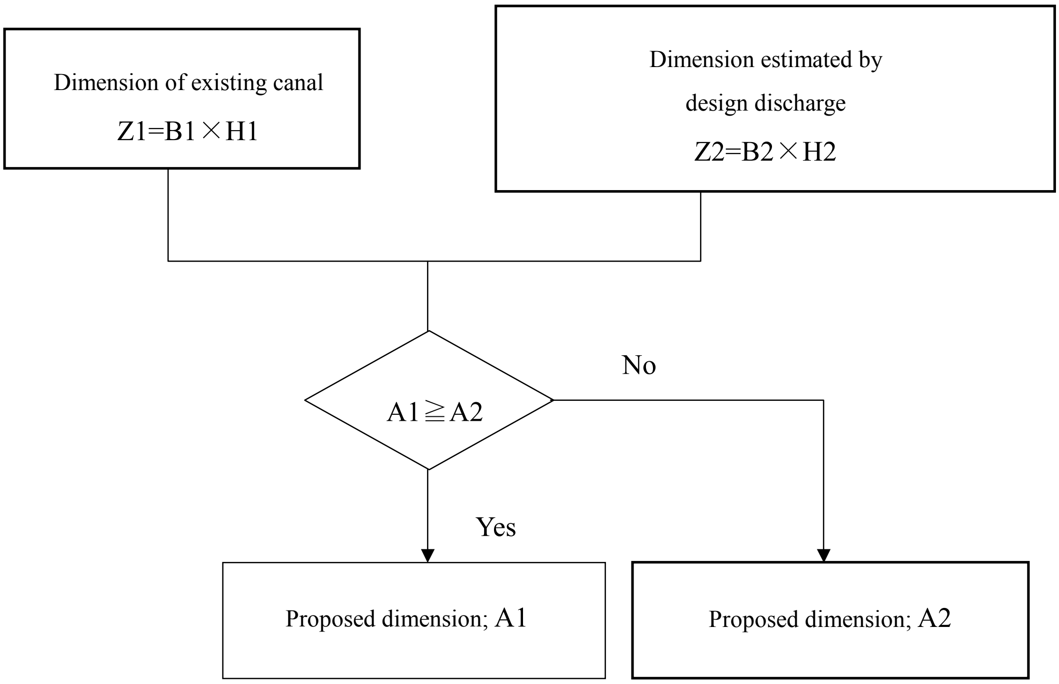
D; water depth (m)

Hv; velocity head=$V^2/19.6$

3) Dimension of cross section

Dimension of proposed canal cross section should be decided according to following procedure.

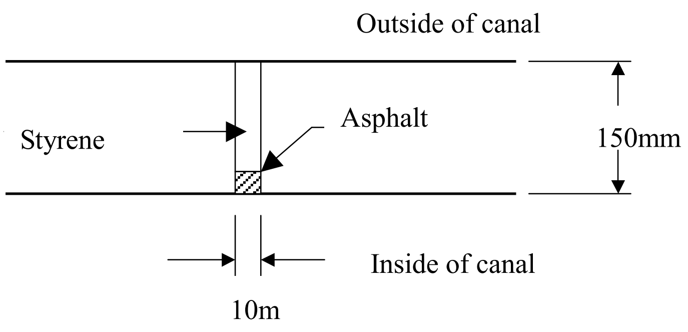
If the size of existing canal is bigger than the dimension estimated by design discharge, the existing dimension must be adopted to the proposed cross section. In almost all cases, the proposed cross section will be determined by the dimension of the existing canal because in recent years water discharge of khettara has been decreasing in the Tafilalet regions.



(6) Canal Appurtenant Facilities

1) Joint

Sectional joints should be constructed within six (6) m intervals. Styrene foam and asphalt must be placed at all of the construction joints as follows.



2) Sand trap

Most of the irrigation canal is open canal without cover; therefore it is impossible to avoid the soil coming into the canal. To make maintenance easy, sand trap should be constructed along the canal in 100m in intervals, the diameter of which is 1.0m length and 0.2 to 0.3 m depth.

3) Road crossing

Main farming roads cross over the canal here and there in the khettara irrigation area. Following canal type reinforced with steel bars is proposed to construct for these crossing points.

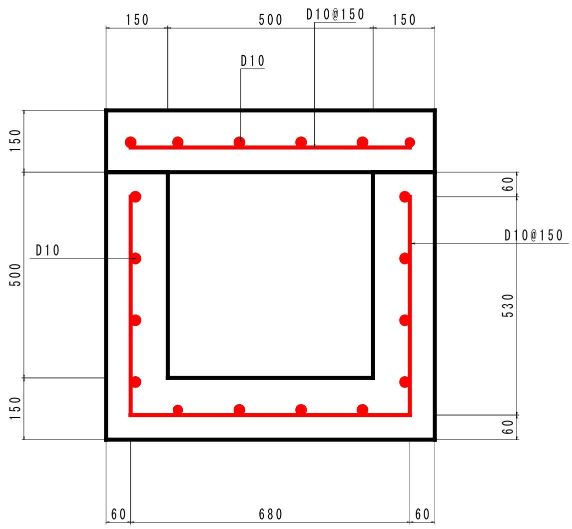


Figure 3.2.4 Road Crossing Section in Khettara Lambarkia

(7) Pipeline

1) Manhole

Manholes combined with sand trap must be constructed in less than 30m intervals to make soil accumulate and clean up the inside of pipes.

2) Screen

Wire mesh or bar screen must be also installed at the entrance of the first manhole to prevent floating garbage from going into the pipeline.

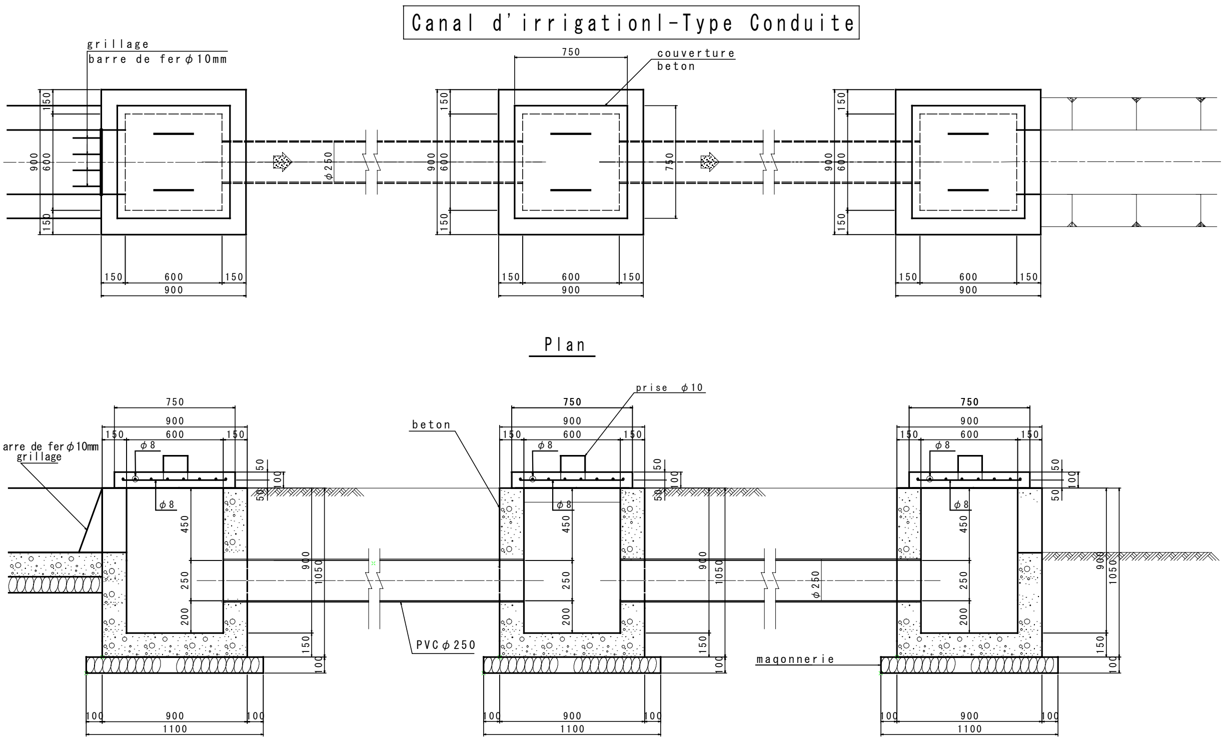


Figure 3.2.5 Irrigation Canal Conduit

3.2.3 Distribution outlet improvement

Users have been diverted water flow with earth filling on the canal to intake irrigation water into individual farmlands in accordance with their water right schedule. This traditional method leads to the seepage and operation loss at the all of the distribution outlets.

Following two improvement types are proposed to minimize water loss of the distribution outlets depending on the water discharge.

Table 3.2.2 Improved Distribution Outlets

Items	Simple gate type	PVC pipe type
Condition	This type shall be applied to the irrigation canal with bigger amount of water discharge of more than 5lit/sec.	This type shall be applied to the irrigation canal with smaller amount of water discharge of less than 5lit/sec.
Remarks	The size of steel gate shall be adjusted to the proposed canal dimension. One steel gate is provided at each distribution outlet. Chain is recommended to tie to steel gate for security.	The diameter of PVC pipe should be arranged based on water discharge. (PVC pipes of 160mm in diameter were installed at the main canal in the khettara Taoumart.) One PVC cap with screw is provided at each distribution outlet. Sand pit is recommended to construct in front of the distribution outlet to prevent entrapping soil.
Photo		

3.3 Water saving effect of canal rehabilitation

Rehabilitation works consisting of canal lining (for existing earthen canal) and inlet improvement (installation of steel gate or PVC pipe with cap) were implemented in the verification study, targeting on the main canal in three khettara irrigation areas. Through this study, it was confirmed that water conveyance loss decreases from 11-22 % without rehabilitation works to 5-10% with rehabilitation as shown in Table 3.2.3. This result reveals that such rehabilitation works are admired to be a reliable and quick acting way for water saving.

Water discharge of end point is 78-82 % of beginning point, 20% more or less of water amount is lost by the infiltration on the earthen canals. After lining the earthen canals with concrete or PVC pipe, water discharge of end point is 90-95 %of beginning point, namely loss decreases to 5-10%. As a result of examining water loss on irrigation canal, it might be said that concrete lining of main canal leads to about 12% increase of irrigation water amount.

Under the traditional water diversion method using soil, water discharge of end point is 86-89 % of beginning point, 11-14% more or less is lost by the infiltration of inlets. On the contrary, after improving the inlets with steel gate or PVC orifice type, water discharge of end point is 94 % of beginning point, namely loss decreases to 6%. It means that the inlet improvement of main canal leads to about 7% increase of irrigation water amount.

Besides, the outcome of rehabilitation works with PVC pipe at the downstream of main canal "Seguia Jdida" in Ait Ben Omar, suggests that main canal rehabilitation and/or extension have great potential of restoring the devastated irrigation area and expanding irrigable farmland.

Concerning on the inlet improvement, it was verified that PVC orifice inlet type has a reliable effect for water saving due to high waterproof, and also has an adoptability for the irrigation canal with water discharge of less than 10 lit/sec. In addition to that, easy handling and low cost gives a possibility of extending to other khettara irrigation canals.

Table 3.2.3 Water Saving Effect of Canal Rehabilitation

Khettara	Canal name	Discharge without rehabilitation (lit/sec)			Discharge with rehabilitation (lit/sec)		
		Beginning point	End point	End point / Beginning point	Beginning point	End point	End point / Beginning point
Ait Ben Omar	Seguia Harch	7.8	6.4	82% (18%)	7.3	6.6	90% (10%)
	Seguia Jdida	7.8	6.7	86% (14%)	5.4	5.1	94% (6%)
Lambarkia	Seguia Gauche	16.6	12.9	78% (22%)	19.9	18.5	95% (5%)
	Seguia Droite	17.4	14.3	82% (18%)	18.5	17.4	94% (6%)
Taoumart	Principal-1	2.8	2.5	89% (11%)	1.8	1.7	94% (6%)

Remarks; Percentage in parentheses indicates the rate of water conveyance loss obtained by following equation.

Rate of water conveyance loss=(Qb－Qe)/Qb×100 (%)

Qb: Water discarge at the beginning point of the irrigation canal (lit/sec)
Qe: Water discarge at the end point of the irrigation canal (lit/sec)

3.4 Maintenance & Operation

(1) Maintenance

Irrigation facilities of Kettara have been managed based on traditional water right by water user's group. This group is responsible for the maintenance of the main canal improved with the rehabilitation projects as well.

Monitoring activities should be kept on the function of the canals that convey and distribute khettara water to all benefited irrigation area for 24 hours in every day.

Following periodically maintenance activities shall be required.

1) To remove the soil accumulated at the sand traps equipped in certain intervals.

2) To inspect water-tightness at the joints of the canals.

3) To check the handling and water-tightness on the distribution outlets.

(2) Operation (Water Management)

In most khettaras, irrigation schedule for water users is rigidly settled taking into consideration of time lag between exit of khettara and individual plots. Canal rehabilitation with concrete lining leads to shorten the time lag due to the increase of water flow velocity; therefore readjustment of irrigation schedule might be required among water user's group.

4 Water saving on on-farm level

4.1 Water saving measures on on-farm level

4.1.1 Water saving approach

Water saving measure is divided into three categories 1) restrain of evaporation, 2) restrain of infiltration, and 3) minimization of operation loss. To realize water saving on actual farm sites, following approaches are proposed.

Table 4.1.1 Water Saving Approaches

Item	Measure	Contents	Decrease of evaporation	Decrease of infiltration	Minimization of operation loss
Restrain of evaporation	Shelter belt	Blocking wind	○		
	Multi cropping	Blocking sunshine	○		
	Mulching	Depressing evaporation from soil surface	○		
Irrigation method	Sprinkler	Equalizing watering amount		○	○
	Furrow	Partial irrigation	○	○	
	Drip	Partial irrigation	○	○	○
Cultivation technique	Selection of crops	Crops with small amount of consumptive water	○		
Soil improvement	Retaining admixture	Retaining soil moisture		○	

(1) Restrain of evaporation

Crop consumption consists of evaporation from soil surface and transpiration trough leaf surface.

We can not restrict the transpiration because it is dispensable factor for crop growth, but evaporation can be controlled with various measures to lead to water saving.

Shelter-belt has an effect of restraining the evaporation from soil surface through blocking the wind, one of factors determine the amount of evaporation, therefore the earthen fences are constructed here and there at the boundary of farmlands in oases.

More than half number of khettara irrigation areas are affected by desertification according to khettara inventory survey conducted in this study.

Combining with the conservation of farmlands in khettara irrigation area, the shelter-belt which is made of trees or soil is regarded to be effective as water saving measure.

Multi cropping is widely applied in this area, two layer cropping (olive+cereal, feed crops) in the mountain area, three layer cropping (date+olive+ cereal, feed crops, beans, vegetable, etc.) in middle, and three layer cropping (date+olive+ cereal, feed crops, vegetable, etc.) in the plains.

Considering that mulching contributes to not only restraining evaporation from soil surface but also retaining soil moisture, this measure is proposed to apply by using natural material which is available in this area.

(2) Irrigation methods

Sprinkler irrigation technique requires high water pressure (standard pressure: 20-30Bar) for operating sprinkler itself with regularity.

Adaptability of this method is considered to be low in arid area with high temperature because some part of water amount irrigated by sprinklers is lost with evaporation of water-drops entrapped into the leaves of crops.

Furrow irrigation is regarded to be more water saving technique than traditional basin irrigation because the former is partial area irrigation in contrast to whole area irrigation like the latter.

Drip irrigation is defined as the slow watering as discrete or continuous drops. Since water is applied directly to the root zoon through emitters placed on the soil surface, drip irrigation is the most water saving method.

(3) Cultivation technique

The varieties of cultivation crop should be carefully selected as well as irrigation techniques to utilize the limited water effectively,

However, the crops such as date or alfalfa which have been cultivated in this area are characterized with small water consumption and high durability against draught.

(4) Soil characteristic improvement

Although various admixtures have been developed for improvement of soil characteristics, it is difficult to extend the application of the retaining admixtures over a wide area owning to the problems on disposal and high cost.

4.1.2 Proposed water saving measures

For khettara irrigation area, following measures are promising among various water saving approaches mentioned above.

(1) Extension of water saving irrigation techniques (furrow irrigation, drip irrigation)

Instead of basin irrigation with low irrigation coefficient which has been applied in this area over a long period, water saving irrigation techniques such as furrow irrigation and/or drip irrigation should be extended in order to improve the efficiency of water use.

It was proved by this verification study that both techniques undoubtedly reduce water consumption of the crops.

The result of 1st stage (from October to January) in demonstration farms revealed that water amount consumed in furrow irrigation is 65 to 80 % of basin irrigation, and water amount consumed in drip irrigation is only 17 to 30 % of basin irrigation.

Furthermore, the practice of demonstration farms shows not only water saving effect but also several effects on other aspects on furrow and drip irrigation.

For example, furrow irrigation contributes yield increase of the crops through improving soil hardness, and drip irrigation leads to improving crop quality through appropriate soil moisture control and minimizing operation burden as well.

Furrow irrigation

Drip irrigation

Khettara	Furrow irrigation		Drip irrigation / Basin irrigation
	With reservoir / Basin irrigation	Without reservoir / Basin irrigation	
Ait Ben Omar	65%	66%	30%
Lambarkia	80%	68%	17%

Note; Above water consumption rate is obtained based on the 1st stage result of the verification study in demonstration farms.

Figure 4.1.1 Water Saving Measures

For the extension of drip irrigation, Morocco government has established financial supporting scheme to subsidize 40% of the initial investment for drip irrigation. Some farmers in this area already implemented small drip irrigation projects under this scheme with technical assistance of ORMVA/TF.

(2) Installation of on farm reservoir

Irrigation schedule regulated by hours and interval days under traditional water right and hydraulic system under the control of supply side is formulated from the exit of khettara to the end of its irrigation area.

Since irrigation hours and interval days are settled, it is difficult to control watering timing and amount taking the growth stage of crops into consideration. Excessive or less irrigation is widely observed in khettara irrigation area.

Installation of small reservoir on farm is indispensable to achieve appropriate watering and application of drip irrigation.

4.2 Water saving irrigation plan

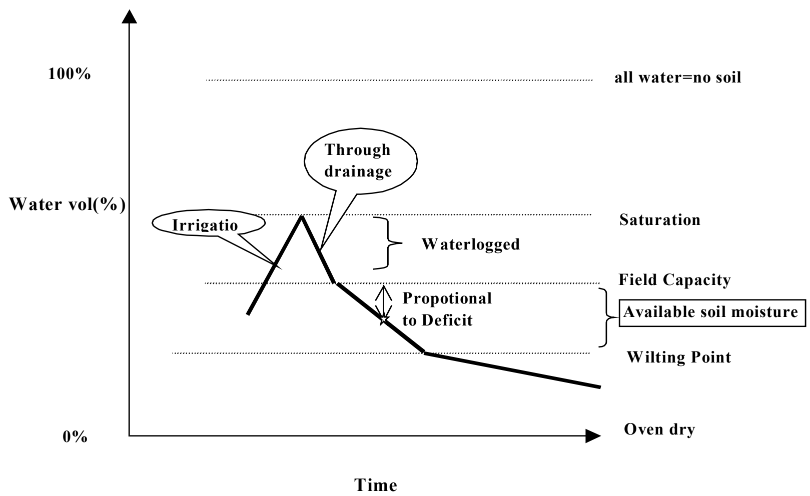
4.2.1 Readily available soil moisture (RFU)

Readily available moisture (RFU) is defined as moisture content in the effective soil layer readily consumable under the conditions where normal growing of crops is expected. It means the upper limit of irrigation amount at once, therefore irrigation water amount must be applied not to exceed readily available moisture (RFU).

Readily available moisture (RFU) is estimated based on Moroccan irrigation planning standard which is applied same procedure as "*Applications of Climatic Data for Effective Irrigation Planning and Management* "published in 1991 by FAO.

Field capacity (SFC) is the moisture content, being held by soil matrix against the gravitational forces. It is defined as the moisture content obtained after one or two days of fully irrigation, equivalent to the suction of around pF2.0 for sandy soil, pF2.5 for clay or loamy.

The moisture content that plants have permanently wilted is called as permanent wilting point (SWP). This is taken to correspond to the suction of pF4.2. Beyond permanent wilting point, watering is no longer available to the plants.



Notes: The suction is expressed as the height of water column (cm) that would rise from the water table against the force of gravity under influence of the force exercised by the soil matrix and is given as the negative logarithm (pF) of the soil moisture tension.

Figure 4.2.1 Readily Available Soil Moisture (RFU)

Water content up to permanent wilting point (SWP) is theoretically available; however the experience indicates that the growth reduction of the crops start before water content reaches this point. Irrigation should be scheduled earlier to maintain the optimum growth of crops.

Readily available soil moisture (RFU) is obtained by the following equation, multiplying total available soil moisture (RU) by the fraction coefficient (P).

$$RFU = RU \times P$$

$$RU = SA \times D/10 = (SFC - SWP) \times D/10$$

RFU; readily available soil moisture (mm)

RU; total available soil moisture (mm)

P; fraction coefficient, P=2/3 (Moroccan standard)

SA; available moisture (vol%)

D; root depth (cm), D=45cm (vegetable)

SFC；field capacity (vol%)

SWL；permanent wilting point (vol%)

The magnitude of available moisture (SA) is very important for the irrigation planning. A low value of SA suggests the possibilities of early crops wilting and the necessity of high irrigation frequency to keep soil moisture on acceptable level.

It depends on soil texture. In general, coarse textured soil (sandy soil) has lower SA than fine textured soil (clay), and loam is intermediate.

The table below shows the magnitude of RFU estimated based on the soil analysis result of three demonstration farms.

The RFU in the range of 20 mm to 29 mm indicates that the capacity of holding soil moisture is slightly low and soil moisture range available for crop growth is limited.

Table 4.2.1 RFU of three demonstration farms

Demonstration farm	Soil type	Field capacity PF2.5 SFC(vol%)	Permanent wilting point PF4.2 SWP(vol%)	Available soil moisture SA=SFC-SWP (vol%)	Total available soil moisture RU (mm)	Readily available soil moisture RFU (mm)
Ait Ben Omar	Sandy clay loam	24.2	14.7	9.5	43	29
Lambarkia	clay loam	28.3	21.8	6.5	29	20
Taoumart	Sandy clay loam	21.9	13.5	8.4	38	25

4.2.2 Water consumption (WC)

Water consumption can be obtained with evapotranspiration and crop coefficient by following equation.

$$WC = ETo \times Kc$$

WC; water consumption (mm/day)

ETo; evapotranspiration (mm/day)

Kc; crop coefficient

(1) Evapotranspiration (ETo)

Various methods are proposed for the estimation of evapotranspiration (ETo).

Blaney-Criddle method is commonly applied because ETo can be obtained by only temperature data, and Penman-Monteith equation will be used in case that four sorts of data such as temperature, wind speed, humidity, and sun shine hours are available.

In this study, monthly ETo was estimated by both methods based on the meteorological data of Errachidia from 1980 to 2002. There is no remarkable difference among both methods, but the result of Blaney Criddle method shows slightly bigger than that of FAO Penman Monteith method.

In this manual, Blaney Crridle method is applied owning to safety reason.

Table 4.2.2 Evapotranspiration (ETo; mm/day)

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Blaney Criddle	4.9	3.4	2.3	1.5	1.5	2.0	3.0	4.0	5.0	6.3	6.7	6.3
FAO Penman Monteith	4.1	2.5	1.4	1.0	1.1	1.7	2.9	4.1	5.1	5.6	6.1	5.1

Notes; Above ETo is estimated based on the meteorological data of Errachidia from 1980 to 2002.

(2) Crop coefficient (Kc)

Ministry agriculture shows the reference value on crop coefficient for the vegetables as follows.

Table 4.2.3 Reference Value on Crop Coefficient for Vegetables

Végétale	Pourcentage de la période de croissance et de développement(%)									
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Betterave	0.45	0.50	0.70	0.90	1.00	1.00	1.00	1.00	1.00	0.90
Cotonnier	0.45	0.45	0.45	0.60	0.90	1.00	1.00	0.90	0.70	0.60
Maïs grain	0.45	0.55	0.65	0.80	1.00	1.00	1.00	1.00	0.90	0.80
Maïs fourrager	0.45	0.55	0.65	0.70	0.90	1.00	1.00	1.00	1.00	0.90
Tournesol	0.45	0.50	0.55	0.80	0.80	1.00	1.00	1.00	0.80	0.60
Haricot,Soja	0.50	0.65	0.80	1.00	1.00	1.00	1.00	0.95	0.80	0.70
Fève	0.50	0.60	0.70	0.80	0.90	0.95	1.00	1.00	0.90	0.70
Maraîchage	0.45	0.50	0.60	0.70	0.90	1.00	1.00	1.00	0.90	0.80
Tomato	0.45	0.45	0.50	0.65	0.85	1.00	1.00	0.95	0.85	0.75
Pomme de terre	0.45	0.45	0.60	0.85	1.00	1.00	1.00	1.00	1.00	0.90
Melon, Pastèque	0.45	0.50	0.60	0.70	0.80	0.80	0.80	0.80	0.75	0.70

Note ;Valeurs du coefficient cultural Kc en fonction du stade de croissance; selon BLANEY-CRIDDLE,légérement modifié par M.A.R.D)

(3) Water consumption (WC)

Water consumption of the vegetables planted at the demonstration farm is estimated as Table 4.2.4.

Table 4.2.4 Water Consumption of Vegetables Planted at the Demonstration Farm

1st Stage

Month		Sep		Oct		Nov		Dec		Jan	
ETo(mm/day)		4.9		3.4		2.3		1.5		1.5	
	%	Kc	WC	Kc	WC	Kc	WC	Kc	WC	Kc	WC
Carrots	50	0.5	2.5	0.7	2.4	1.0	2.3	1.0	1.5	0.9	1.4
Turnip	50	0.5	2.5	0.7	2.4	1.0	2.3	1.0	1.5	0.9	1.4
Average			2.5		2.4		2.3		1.5		1.4

2nd Stage

Month		Mar		Apr		May		Jun		July	
ETo(mm/day)		3.0		4.0		5.0		6.3		6.7	
	%	Kc	WC	Kc	WC	Kc	WC	Kc	WC	Kc	WC
Melon	25	0.5	1.5	0.7	2.8	0.8	4.0	0.8	5.0	0.7	4.7
Gumbo	25	0.5	1.5	0.7	2.8	1.0	5.0	1.0	6.3	0.9	6.0
Water melon	25	0.5	1.5	0.7	2.8	0.8	4.0	0.8	5.0	0.7	4.7
Tomato	25	0.5	1.5	0.6	2.4	0.9	4.5	1.0	6.3	0.8	5.4
Average			1.5		2.7		4.4		5.7		5.2

4.2.3 Irrigation interval days

Irrigation interval days are obtained with readily available soil moisture (RFU) and water consumption (WC) by following equation.

Irrigation interval days= RFU × WC (omit decimates)

RFU; readily available soil moisture (mm)

WC; water consumption (mm/day)

On the other hand, water use interval is settled at 13days in Ait Ben Omar, 15 days in Lambarkia, and 9 days in Taoumart in accordance with traditional water right.

If irrigation practice is performed for the months at same interval as water use interval days which are longer than the irrigation interval days estimated by above equation, soil moisture falls to the level below the permanent wilting point.

For keeping on the soil moisture in the adequate range, the installation of on farm reservoir is definitely needed to shorten watering interval. Watering should be made within the maximum irrigation interval days, using some of irrigation amount stored into on farm reservoir at water use days.

Table 4.2.5 Estimated Irrigation Interval Days at Each Demonstration Farm

Cultivation stage			1st stage						2nd stage			
			Sep	Oct	Nov	Dec	Jan	Mar	Apr	May	Jun	July
Water consumption WC (mm/day)			2.5	2.4	2.3	1.5	1.4	1.5	2.7	4.4	5.7	5.2
Ait Ben Omar	Water use interval **13**days	RFU 29mm	**11**	**12**	**12**	19	20	19	**10**	**6**	**5**	**5**
Lambarkia	Water use interval **15**days	RFU 20mm	**8**	**8**	**8**	**13**	**14**	**13**	**7**	**4**	**3**	**3**
Taoumart	Water use interval **9**days	RFU 25mm	10	10	10	16	17	16	9	**5**	**4**	**4**

4.3 Furrow irrigation

It was proved that furrow irrigation has an advantage on water saving over basin irrigation through the verification study. Furrow irrigation does not require any investment but only making furrows in the field, therefore this is regarded to be a promising measure as one of water saving techniques from economic reason. The dimension of furrow irrigation is determined based on the technical guideline mentioned below.

(1) Furrow length

It is recommended to make furrow length as longer as possible for minimizing labor for water distribution, but it is required to decide optimum length for rising application coefficient on irrigation referring to Table 4.3.1 which gives the information on maximum furrow length according to the soil type.

Table 4.3.1 Maximum furrow length according to the soil type

Soil type	Root zone depth (cm)	One-time Irrigation volume (mm)	Maximum furrow length (m)	Remarks
Sand	40	16	4	Gradient of furrow: 10%
Volcanic ash soil	40	44	29	
Sandy-loam	40	34	36	
Loam	40	38	99	
Clay	40	44	121	

Note; Engineering Manual for Irrigation & Drainage, Upland irrigation, 1990, The Japanese Institute of Irrigation and Drainage

(2) Furrow width

Diffusion of the irrigation water infiltrated into the soil is important items to be carefully examined. In this sense, optimum furrow width should be determined for wet zone formulated by furrow irrigation to cover the root zone effectively. Figure 4.3.1 indicates the maximum furrow width for each soil type such as clay-loam, loam, sandy-loam, and sand.

For the soil type, clay-loam which is widely observed in this area, furrow width in 80 cm is recommended for the vegetables with 45cm root depth.

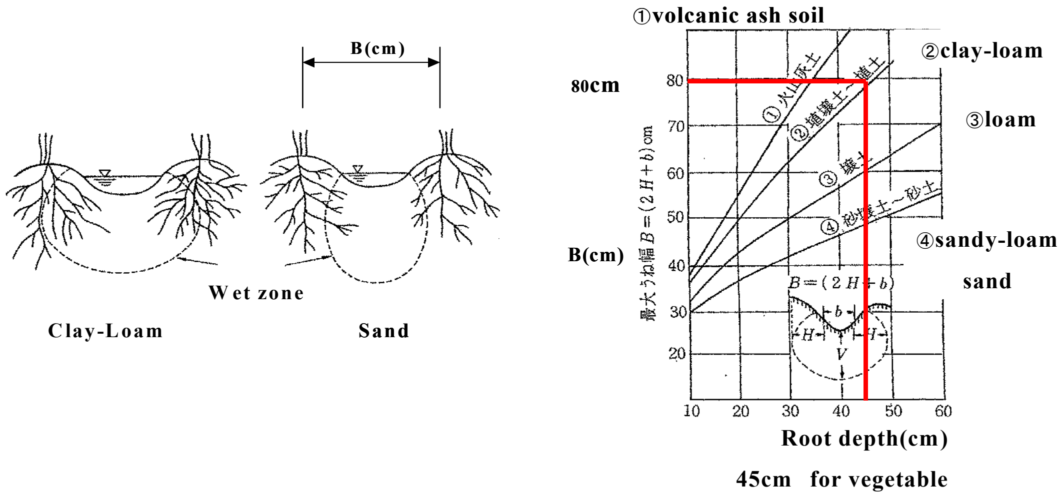


Figure 4.3.1 Maximum Furrow Width for Each Soil Type

4.4 Drip irrigation

4.4.1 Classification of drip irrigation

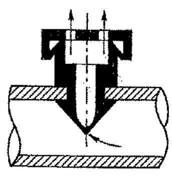
Drip irrigation is classified as follows;

- Drip irrigation
  - Drip irrigation
    - Drip emitter
    - Drip tube
  - Perforated pipe irrigation
    - Perforated pipe
    - Flexible perforated hose

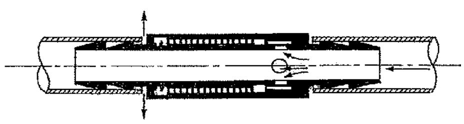
Type	Pressure (bar)	Discharge (lit/hr/m)	Wet zone width (m)
Drip irrigation	～1.0	～10	0.3～1.0
Perforated pipe irrigation	0.05～0.4	6～50	0.3～5.0

1) Drip emitter

Several kinds of water pressure control device are developed as drip emitter such as orifice type and spiral type as illustrated below. In this area, orifice type emitter is applied for date trees, olive trees, and other fruit trees.



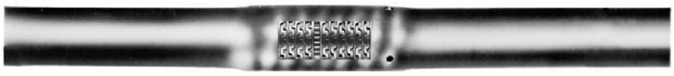
Orifice type



Spiral type

2) Drip tube

Irrigation water drips through drip holes after reducing water pressure in dual-chamber tube as shown in below photo. Since wetting circles being formulated around drip holes overlap each other, drip tube can be applied to the vegetables planted in line or densely.



3) Perforated pipe

Perforated pipe is the hard pipe made of PVC, polyethylene, or aluminum with many holes on upper section, which sprays irrigation water to both sides of the pipes.

The perforated pipe is detachable, lightweight, and portable; therefore the perforated pipes are connected with joints to expand the irrigation area.

4) Flexible perforated tube

Perforated tube made of high molecular materials has many advantages in the handling, easy expansion, and low cost. Irrigation water is sprayed to both sides with small holes placed on the perforated tubes.

Taking following specified conditions in this area into consideration, drip tube is applicable to the vegetable fields and drip emitter is recommended to apply to date trees as well.

1) Heat-resistant material should be applied because temperature is extremely high during daytime in summer season.
2) Sunshine-resistant material is required because sunshine hours are long through the year.
3) Easy maintenance for clogging is required because some irrigation water shows high salinity.

4.4.2 Irrigation dimension

Irrigation dimension should be determined based on the meteorological and soil physical data collected at each site. Hereby, the procedure for determining irrigation dimension is described using the data of the demonstration farm in this study.

1) Crop: Vegetable

2) Water consumption

Stage	1st stage (Winter season)					2nd stage (Summer season)				
Month	Sept	Oct	Nov	Dec	Jan	Mar	Apr	May	Jun	July
Evapotranspiration (ETo) (mm/day)	4.9	3.4	2.3	1.5	1.5	3.0	4.0	5.0	6.3	6.7
Crop coefficient (Kc)	0.5	0.7	1.0	1.0	0.9	0.5	0.6-0.7	0.8-1.0	0.8-1.0	0.7-0.9
Water consumption (WC) (mm/day)	2.5	2.4	2.3	1.5	1.4	1.5	2.7	4.4	**5.7**	5.2

3) Readily available soil moisture (RFU)

Readily available moisture（RAM）is assumed to be 25mm in average based on the soil analysis result of the demonstration farm.

4) Irrigation interval days

$$\text{Irrigation interval days} = \frac{\text{Readily AvailableMoisture(RAM)}}{WaterConsumption} = \frac{25}{5.7} = 4.4days \rightarrow 5days$$

5) Gross irrigation amount

$$\text{Gross irrigation amount} = \frac{WaterConsumption \times IntervalDays}{ApplicationEfficiency} = \frac{5.7mm/day \times 5days}{0.95} = 30mm$$

6) Irrigation intensive rate (P)

Discharge Q=2-4lit/hr/drip hole, Interval of drip holes=0.4m

→ Average q = 7.5 lit /hr/m (0.125lit /min/m)

Tube diameter 13×16mm

Water pressure 1.0bar (10m)

Wet zone width 0.65m

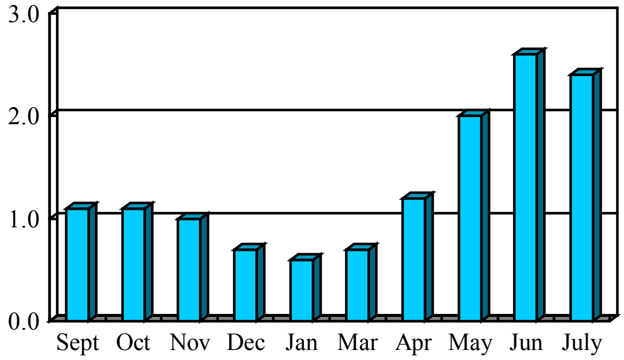
$$P = \frac{0.125\lambda/\min/m \times 60\min/hr}{0.65m} = 11.5m/hr$$

7) Irrigation hour

$$\text{Irrigation hour (Maximum)} = \frac{GrossAmoun\ tForEachIr\ rigation}{Irrigation\ IntensiveR\ ate} = \frac{30mm}{11.5mm/hr} = 2.6hr$$

Term	1st stage (Winter season)					2nd stage (Summer season)				
	Sept	Oct	Nov	Dec	Jan	Mar	Apr	May	Jun	July
Water consumption (WC) (mm/day)	2.5	2.4	2.3	1.5	1.4	1.5	2.7	4.4	5.7	5.2
Irrigation hour (hr)	1.1	1.1	1.0	0.7	0.6	0.7	1.2	2.0	2.6	2.4

Irrigation Hour (hr)



8) Irrigation times per day

$$\text{Irrigation times per day} = \frac{Irrigation\ HoursPerDa\ y}{EachIrriga\ tionHours} = \frac{12\ hr}{2.6hr} = 4.6 \rightarrow 4times$$

9) Rotation Block

Standard one (1) drip block=0.15ha（50m×30m）

One (1) rotation block＝One (1) drip block×irrigation times per day×irrigation interval days

＝0.15ha×4times×5days＝3.0ha

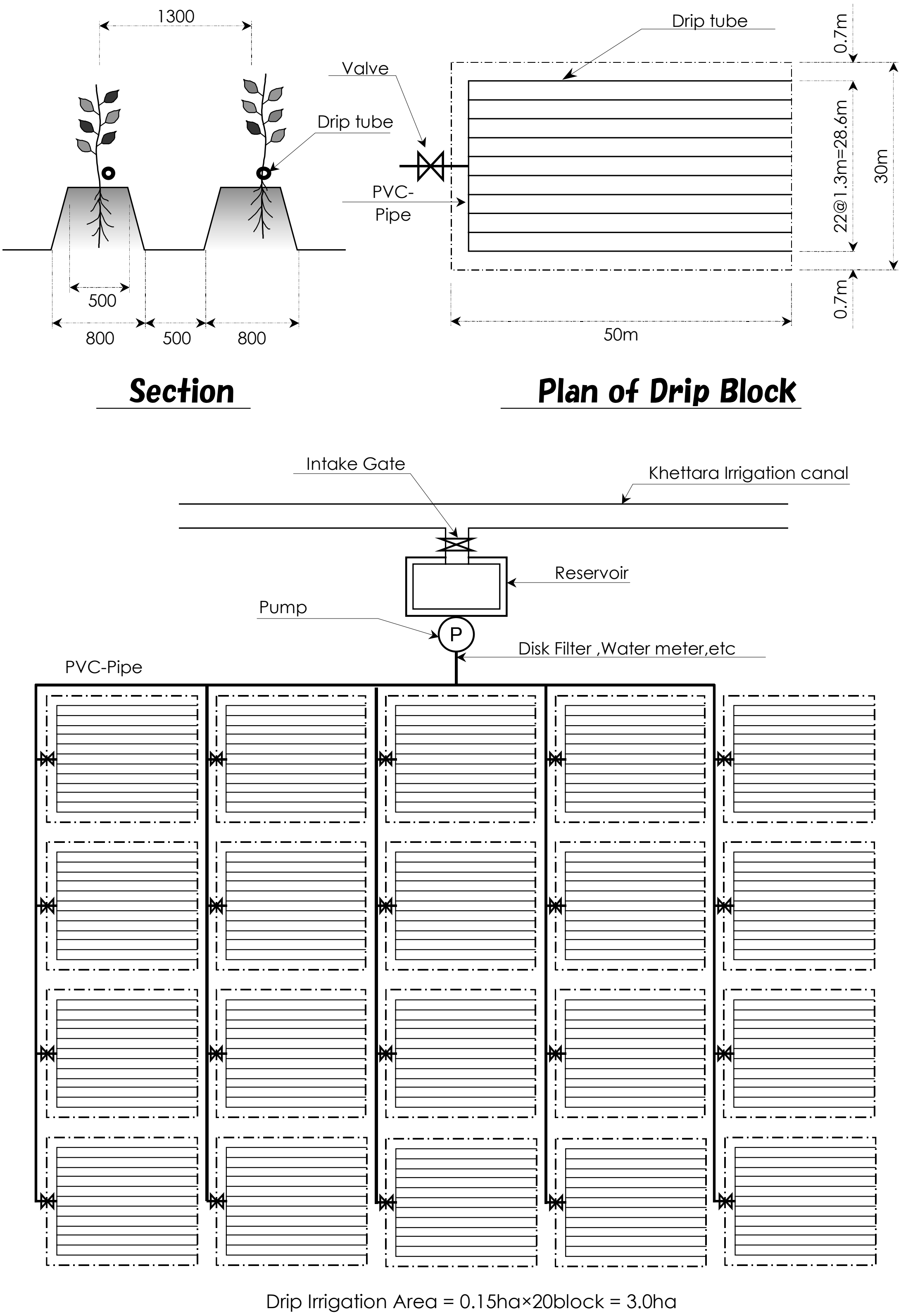


Figure 4.4.1 Plan of Drip Irrigation

Reference; Drip irrigation for date tree

Site; Experiment farm in SEMVA

Number of date trees; 204trees/ha (7m×7m→10,000m^2÷49m^2=204trees/ha)

Irrigation water amount per tree＝drip capacity×numbers×irrigation hours

＝24lit/hr×4emitters×6hrs/time＝576lit/time/tree

Irrigation times; 48times/year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigation times	3	3	4	4	4	5	6	5	4	4	3	3

Irrigation water amount per ha per year;

576 lit/time/tree×204 trees/ha×48 times = 5,640 m^3/ha/year (564mm/year=1.54mm/day)

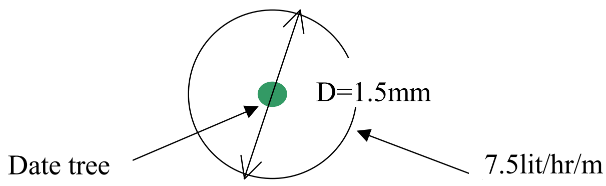
Remarks;

In case date trees are planted mixed with vegetables, drip tubes are utilized for not only vegetables but also date trees.

One date tree requires 96lit (24lit/hr×4 emitters) of irrigation water amount at one time according to the experiment result.

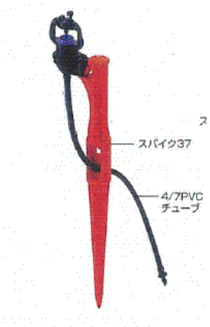
In case that the capacity of drip tubes for vegetable is specified to be 7.5 lit/hr/m, 12.8m in length is theoretically needed for one date tree.

D=1.5m→3rounds



Specification of Micro sprinkler

Water pressure	1 – 3 bar
Water discharge	18 – 95 lit/hr
Diameter of spray circle	3.0 – 6.5 m



4.4.3 Equipment

(1) Pipeline

The pipeline system for drip irrigation is composed of water-distribution pipeline, water-supply pipeline, and drip tubes as shown in following figure.

Water-distribution pipeline is laid underground for protection, which conveyes water from the water source (on-farm reservoir) to the water-supply pipeline. PVC pipes are generally used as water-distribution pipeline.

Water-supply pipeline is laid underground or on the ground, which distributes water from the water-distribution pipeline to the drip tubes. Either PVC pipes or hard polyethylene pipes are aplied to the water-supply pipeline.

For cleaning the inside of the drip tubes, simple water stopper should be equipped at the downstream end of the drip tube. After the harvest of crops, drip tubes must be removed and stored in warehouse for the preparation of next planting.

PVC valve is installed at the junction of the water-distribution pipeline and water-supply pipeline to control water distribution.

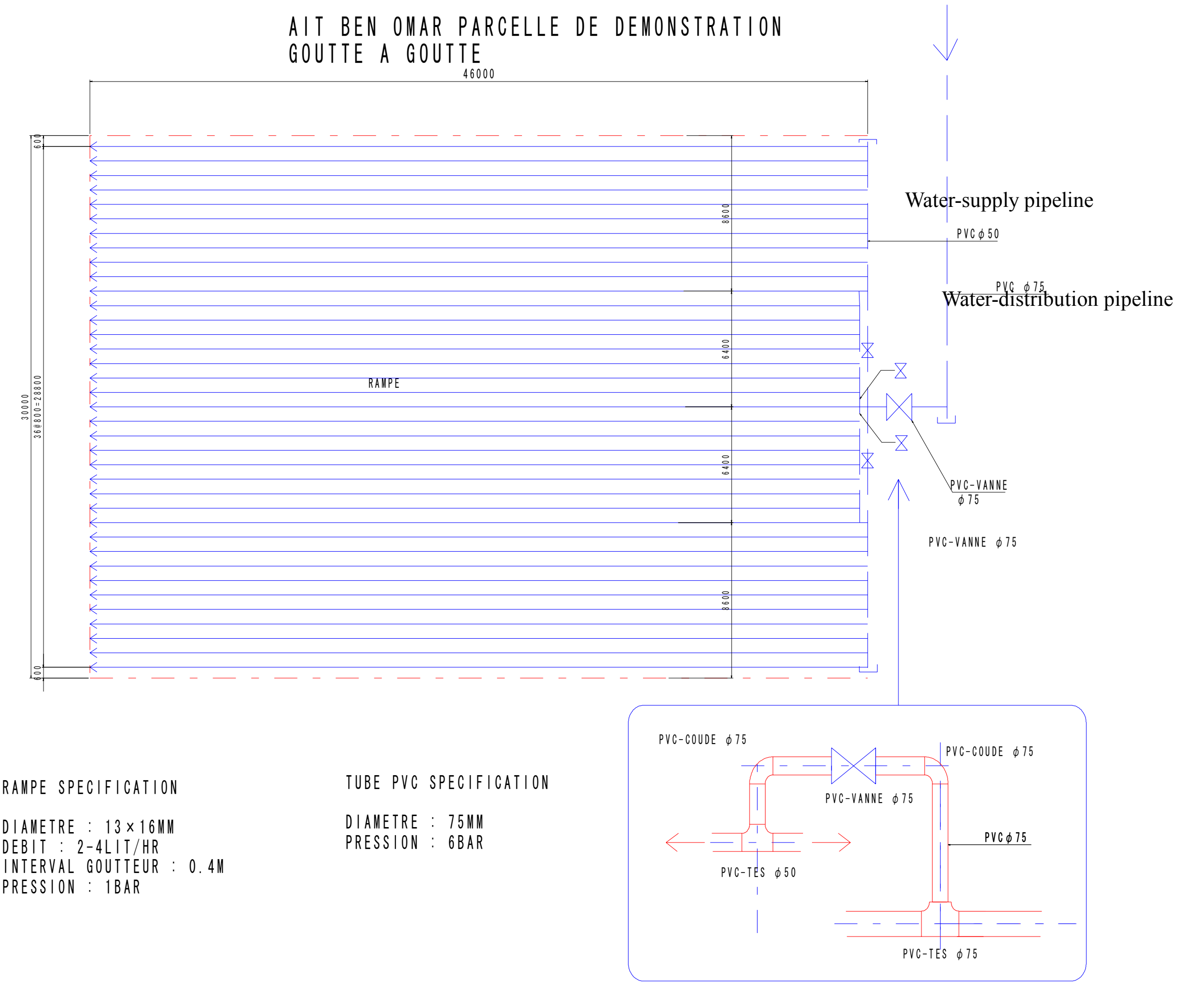


Figure 4.4.2 Layout of Pipeline System for Drip Irrigation

(2) Control device

Control device is composed of various kinds of equipment to control water pressure and discharge, and eliminate the sand and/or rubbish being contained in the irrigation water.

1) Pump

A certain water pressure should be given to convey water through the pipeline system and keep the uniformity of water drops along drip tubes. Therefore, diesel pump or electric motor pump is installed at the on-farm reservoir which reserves khettara water for adjusting supply and demand.

Pump capacity is determined based on the hydraulic calculation as stated below.

Hereby, the procedure of hydraulic calculation is described as one example of drip irrigation plot (50m× 30m).

Pump discharge; Qp

$$Qp = 0.125\lambda/\min/m \times 50m \times 23 lines = 142.8\lambda/\min = 2.4\lambda/\sec(0.144 m^3/\min, 8.64 m^3/hr)$$

Pumping head; Hp

Required water pressure for drip tube

ho=10m(1.0 bar)

Head loss for valve, filter and others

h1= 5m

Head loss for pipe

Length of water-distribution pipeline is assumed to be 300m.

$$h2 = F1 \times \left\{ 6.287 \times 10^6 \times \left(\frac{Q}{C}\right)^{1.85} \times \frac{L}{D^{4.87}} \right\} = 3.97 \times 10^{-1} \times \{6.287 \times 10^6 \times (\frac{71.4}{140})^{1.85} \times \frac{15}{50^{4.87}}\} = 0.06m$$

$$h3 = 6.287 \times 10^6 \times (\frac{Q}{C})^{1.85} \times \frac{L}{D^{4.87}} = 6.287 \times 10^6 \times (\frac{142.8}{140})^{1.85} \times \frac{5}{75^{4.87}} = 0.02m$$

$$h4 = 6.287 \times 10^6 \times (\frac{Q}{C})^{1.85} \times \frac{L}{D^{4.87}} = 6.287 \times 10^6 \times (\frac{142.8}{140})^{1.85} \times \frac{300}{75^{4.87}} = 1.45m$$

(*Note; Micro irrigation Planning Guide, 1994, The Ministry of Agriculture, Forestry and Fisheries of Japan)*

Total head loss=ho+h1+(h2+h3+h4)×1.1

=10.0+5.0+(0.06+0.02+1.45)×1.1=16.7m

Pumping head Hp=Head loss16.7m+Suction head3.0=20m

Horsepower;

$$P = 0.222 \times \frac{Q \times H}{\eta} \times (1+R) = 0.222 \times \frac{0.144 \times 20}{0.5} \times (1+0.2) \geqq 1.5 ps$$

Portable pump

2) Rubbish remover

The mechanism of the rubbish remover is based on the principal of a centrifugal force or whirlpool force, in which floating substances are separated from water, accumulated and removed together with small amount of water.

3) Filter

The filter is the screening device to trap the sand at the meshes made of fiber, plastic or wire meshes. The required size of meshes shall be determined by the diameter of the drip holes.

Table 4.4.1 Filter for Each Soil Type

Name	Grain size		Number of meshes
	(mm)	(μ)	
Conglomerate	2.00-1.00	2,000-1,000	10-18
Coarse sand	1.00-0.50	1,000-500	18-35
Medium sand	0.50-0.25	500-250	35-60
Fine sand	0.25-0.10	250-100	60-160
Very fine sand	0.10-0.05	100-50	160-270
Silt	0.05-0.002	50-2	270-400
Clay	0.002 or less	2 or less	

Rubbish remover

Filter

4) Check valve

In case drip irrigation system is applied to multi-purpose, check valve shall be equipped to prevent reverse flow mixed with fertilizer and/or agriculture chemicals back to the water source.

5) Air valve

Air valve shall be installed to blow off the entrapped air to maintain smooth water flow of the pipeline.

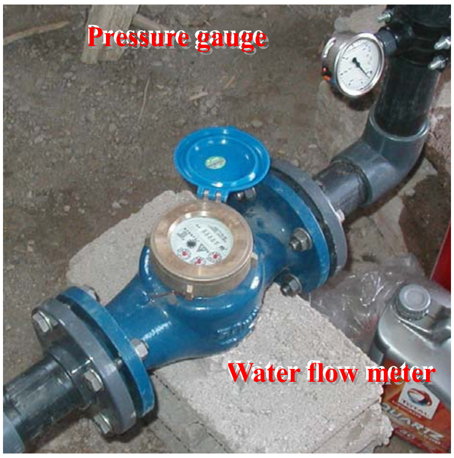
6) Water flow meter

Water discharge and total water amount can be measured by water flow meter.

7) Pressure gauge

Two pressure gages are installed at the upstream of rubbish remover and the downstream of filter.

Extreme pressure decline indicates the possibility of the leakage from the pipeline, and big deference of two pressure gauges shows the clogging at the filter.



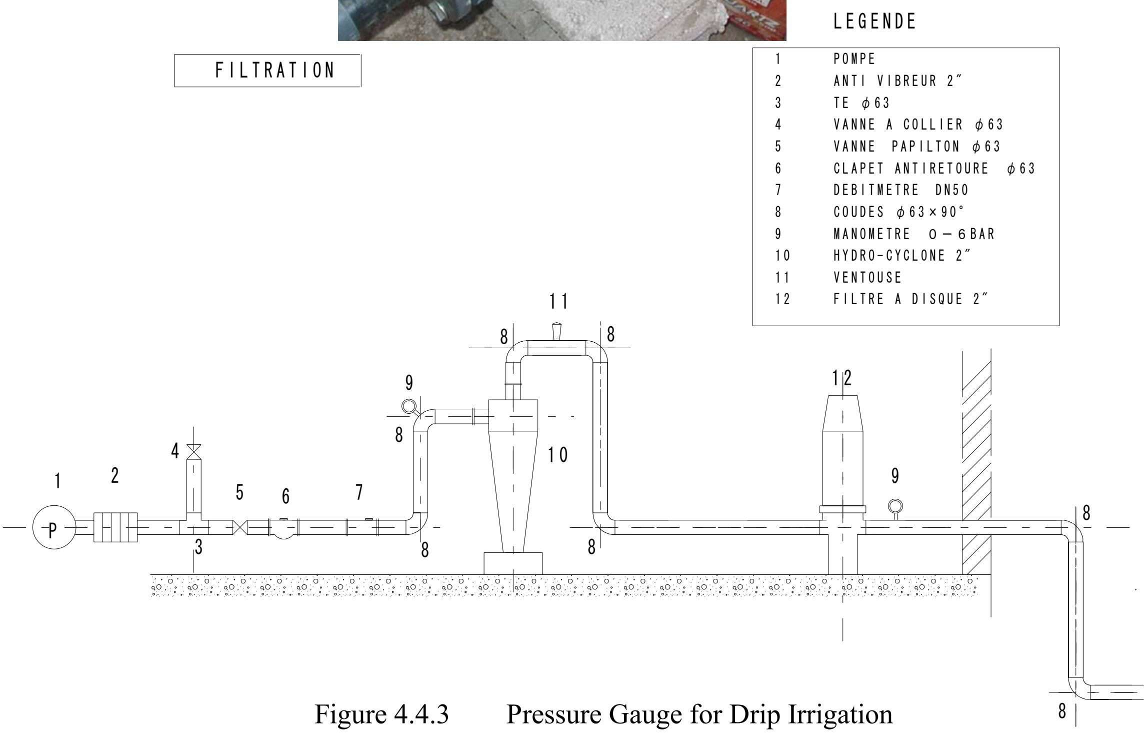


Figure 4.4.3 Pressure Gauge for Drip Irrigation

4.4.4 Reservoir capacity

Water balance on farm level is expressed by supply from khettara and demand in farmland. Water supply to the farmland is subject to the traditional water right and water demand is subject to the irrigation in farmland.

In case of basin irrigation, farmers irrigate to their farmlands when water use turn come to them, therefore there is no need to regulate between supply and demand on farm level.

Although water use schedule is settled based on the traditional water right, farmers sometimes adjust to meet crop water demand through exchanging and/or dividing their irrigation hours.

However, it is actually impossible to reduce the irrigation interval days not to exceed the lower limit of soil moisture (permanent wilting point) and to adopt drip irrigation technique that irrigates in one to two days interval to keep the soil moisture content constant.

In this regard, the construction of on-farm reservoir is indispensable to apply drip irrigation in khettara irrigation area.

Capacity of on-farm reservoir can be obtained by following equation.

$V = WD \times DAY$

V; Capacity of on-farm reservoir (m^3)

WD; Water demand (m^3/day)

DAY; Supply interval day (days)

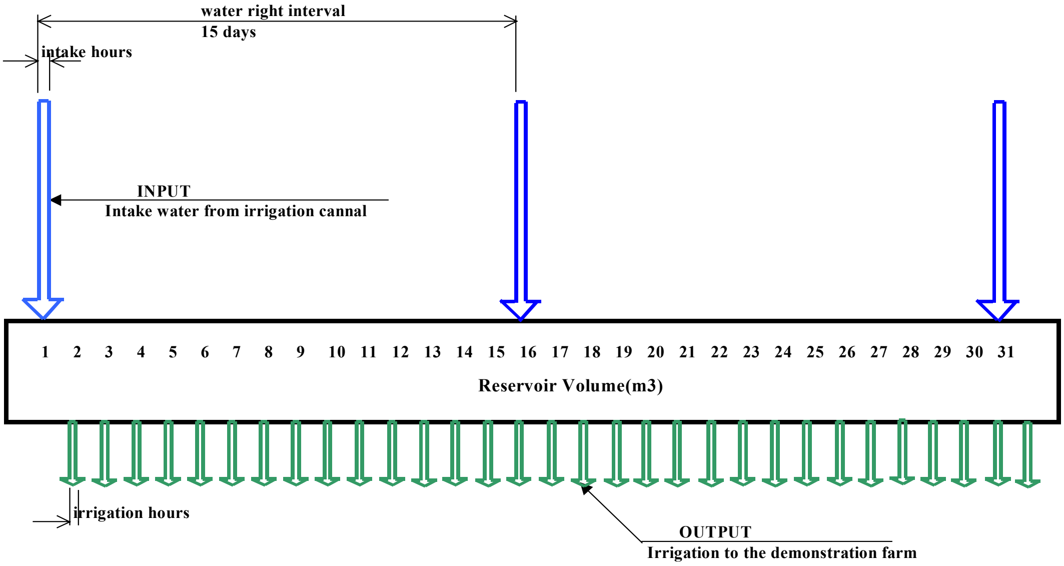


Figure 4.4.4 Reservoir for Drip Irrigation

Table 4.4.2 Capacity of Reservoir by Irrigation Interval

Irrigation method		Basin	Furrow irrigation	Drip irrigation	Remarks
Watering are (ha)		A=0.15	2/3・A=0.10	1/2・A=0.075	Irrigation area A=0.15ha
Application efficiency Ec		0.70	0.85	0.95	
Water consumption WC (mm/day)		5.7	5.7	5.7	Maximum (in June)
Water demand WD (m^3/day)		12.2	6.7	4.5	WD=WC×A×10/E c
Reservoir capacity V (m^3)	Supply interval day =1day	12.2	6.7	4.5	V=WD×DAY
	2days	24.4	13.4	9.0	
	3days	36.6	20.1	13.5	
	4days	48.8	26.8	18.0	
	5days	61.0	33.5	22.5	
	6days	73.2	40.2	27.0	
	7days	85.4	46.7	31.5	

4.4.5 Design procedure

The procedures of the canal design are shown in Figure 4.4.5.

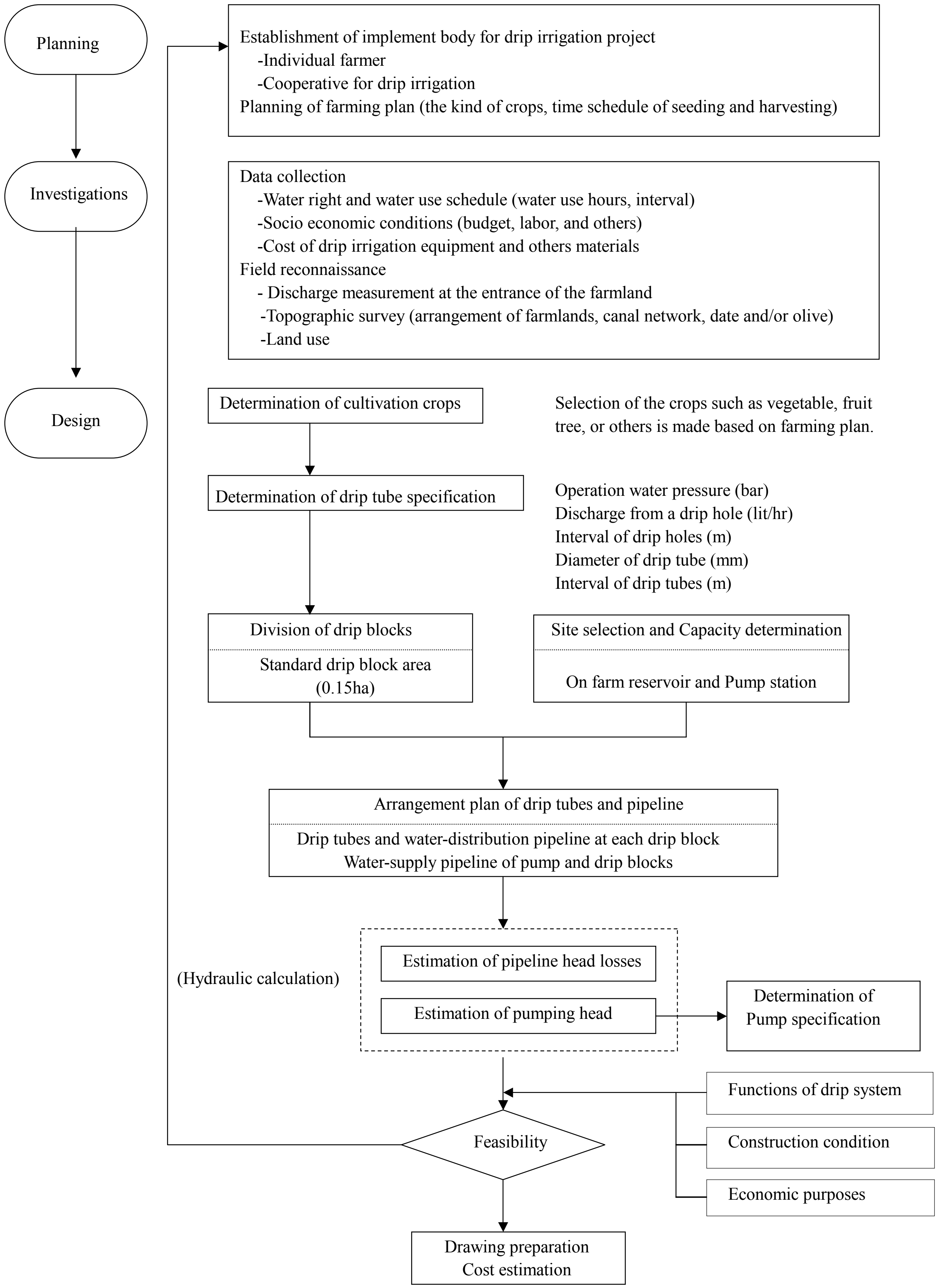


Figure 4.4.5 Flow Chart of Procedure of the Canal Design for Drip Irrigation

4.4.6 Maintenance

Drip irrigation system is composed of many facilities and equipments as shown in the table below.

Following activities on maintenance are recommended to make at a certain frequency for the individual facilities and equipments to keep the function of drip irrigation system well.

Table 4.4.3 Maintenance of Facilities and Equipments for Drip Irrigation

Classification	Facilities and equipments	Maintenance	
		Activities	Frequency
Water resource	Reservoir	The soil accumulated on the bottom should be removed to keep the reservoir capacity and to avoid the suction by pumping. Water depth must be carefully monitored without the operation of pump to find the leakage from the reservoir.	At the termination of irrigation period In case of big leakage, prompt repair will be needed.
Control devices	Pump	Pump operation should be carefully monitored with pressure gauge and water flow meter installed at the downstream of pump. Whenever any abnormality is observed, pump must be immediately stopped and checked the concerned equipments to trace the cause.	Every day
	Rubbish remover and Filter	The substances suspended in the irrigation water are intercepted and deposited through the screening devices. Periodically cleaning should be made to keep the functioning of these devices. Since the clogging of the rubbish remover and filter results in the difference in pressure between upstream gauge and downstream gauge, the timing of cleaning can be noticed with the pressure difference of the pressure gauges.	At lease once a irrigation period At the time when the pressure difference of both gauges reaches a certain value.
	Valves	The functioning of the valves such as air valve, check valve, and cut off valves are carefully monitored. Whenever remarkable leakage is observed, the valve must be immediately replaced.	Every day
	Water flow meter and Pressure gauge	In case that the indicator is not properly functioning, the devices must be repaired or replaced.	Every day

Pipeline	Drip tube	During irrigation period, the equality of the wetting zones at each drip hole should be carefully monitored to find any clogging of drip tubes. Farming operation should be carefully performed not to damage the drip tubes placed on the ground. (Spare parts must be always in stock for the replacement caused by any damages.)	Every day
		At the termination of irrigation period, drip tubes should be washed with running water and properly removed and stored in manner of winder preventing any twist or breakage in the warehouse.	At the termination of irrigation period
	Water-distribution and water-supply pipeline	Before the start of irrigation, the entrapped air of water-distribution and water-supply pipeline must be blew off from the top of vertical pipe connected at the horizontal pipeline buried in the ground.	At the beginning of irrigation period