Ministry of Agriculture

The Republic of Zambia

TECHNICAL COOPERATION PROJECT ON COMMUNITY-BASED SMALLHOLDER IRRIGATION (T-COBSI) IN THE REPUBLIC OF ZAMBIA

APPENDIX

June 2017

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

SANYU CONSULTANTS INC.

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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
MINISTRY OF AGRICULTURE AND LIVESTOCK (MAL), REPUBLIC OF ZAMBIA

TECHNICAL COOPERATION PROJECT ON COMMUNITY-BASED SMALLHOLDER IRRIGATION (T-COBSI)

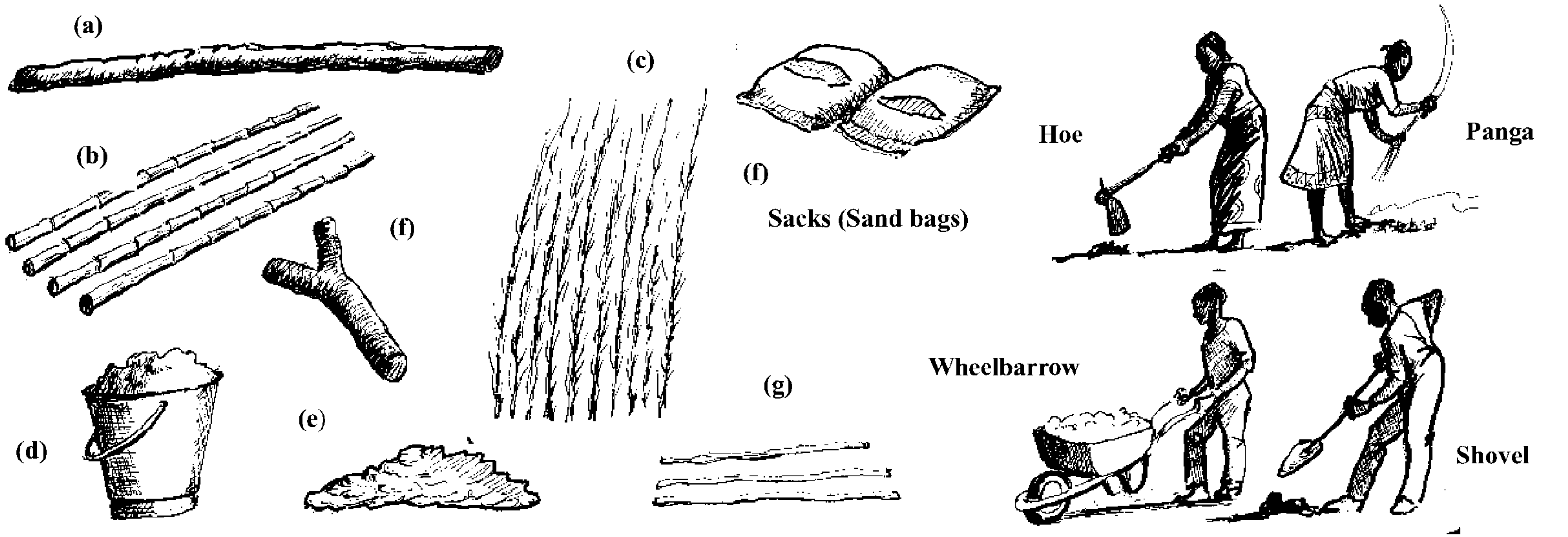
TECHNICAL MANUAL
(Simple Weir Construction and Canal Alignment)

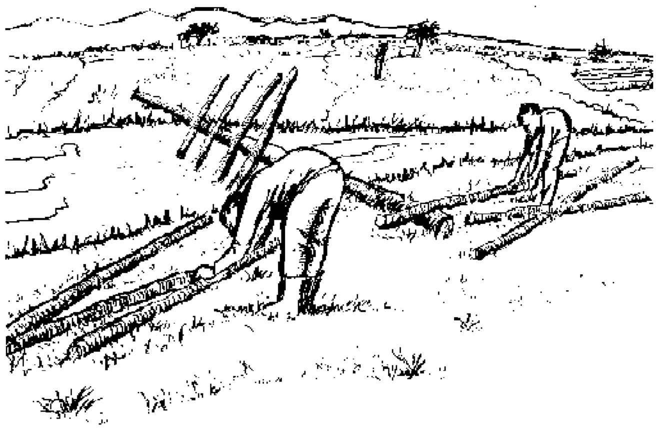
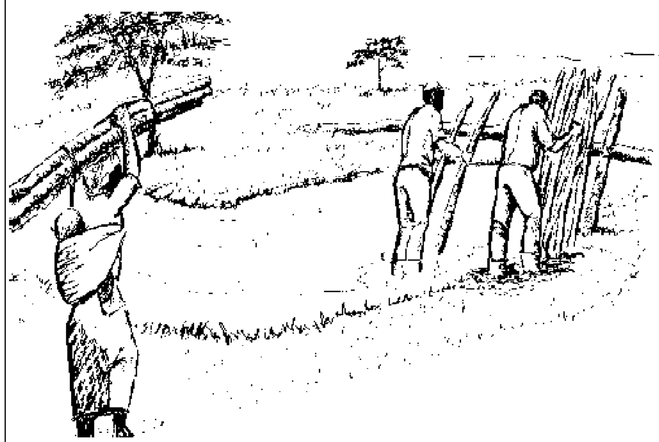
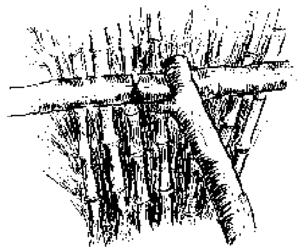
MAY 2015

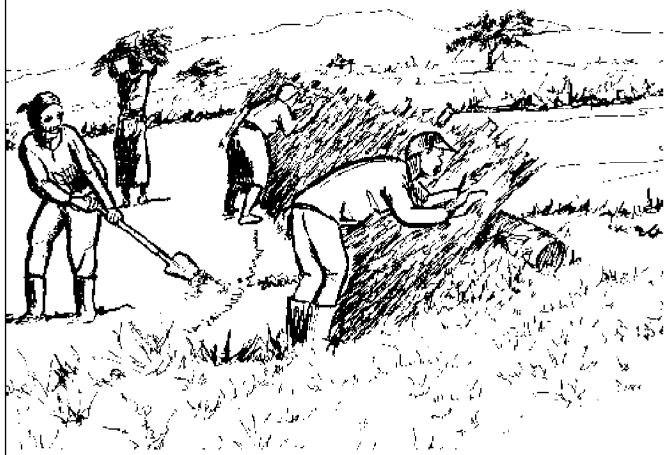
SANYU CONSULTANTS INC., TOKYO, JAPAN

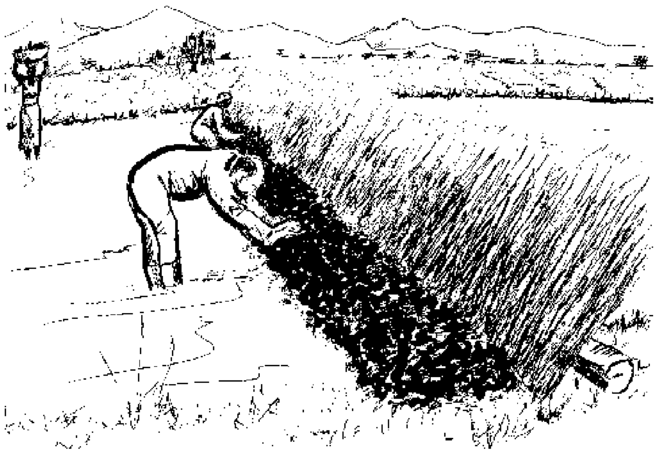
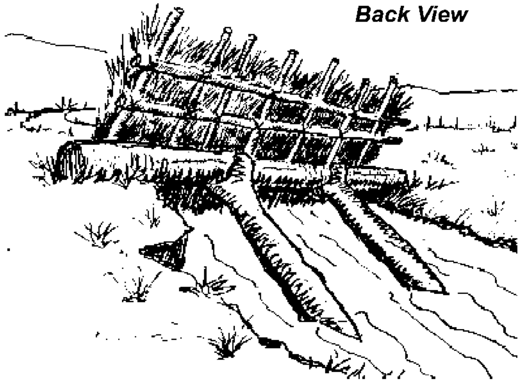
PROCESS DESCRIPTION MANUALS

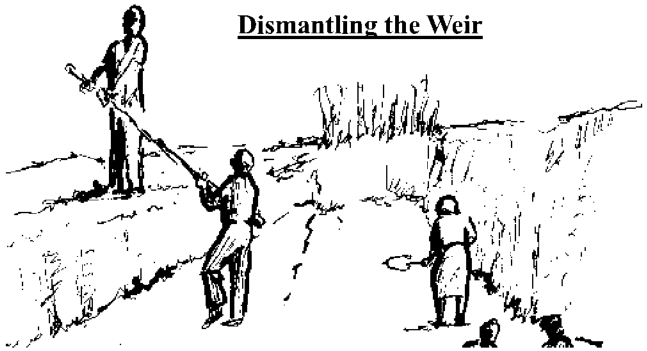
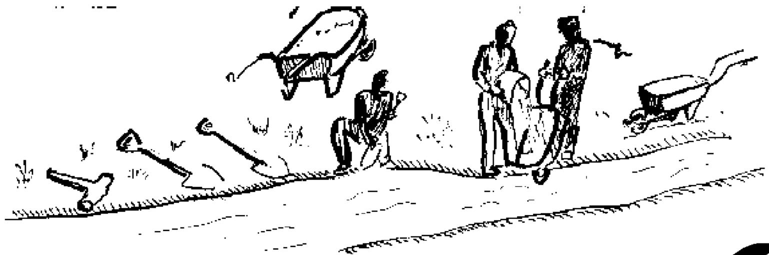
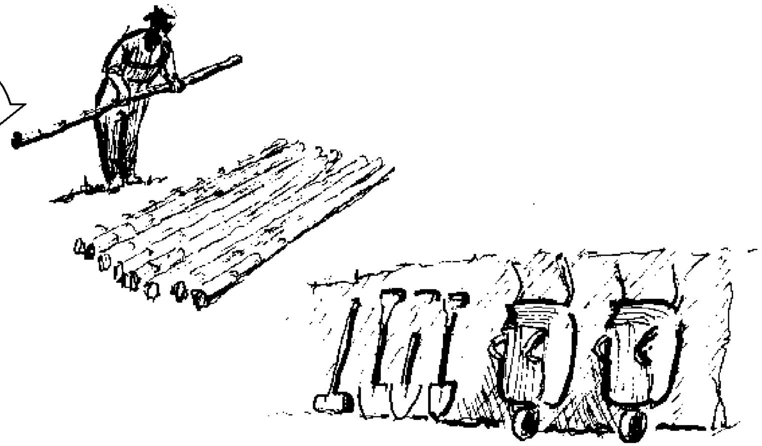
1. Construction of A Temporary Weir: Inclined Wall Type (best suited at narrower streams)

Step	Materials to be collected
0	**Collect all the following materials (refer to the illustration below);** (a) A log: to be put horizontally on the stream bank across the diversion point (Quantity: 1 nos., Refer to Step-1) (b) Bamboo/Twigs: to stand in front of the horizontal log (Quantity: 8 – 10 nos. per 1 meter width of the dam, Refer to Step-2) (c) Grasses (Elephant grass): to be put in front of vertical members (Quantity: depend on the size of the dam, Refer to Step-3) (d) Clay soil: to patch on the grasses. And, if necessary, the clay soil is put in the streambed to replace the sand foundation (Quantity: depend on the size of the dam, Refer to Step-5) (e) Ordinary soil: to patch on the clay soil patched on the grass (Quantity: depend on the size of the dam, Refer to Step-6) (f) Log: to support the brush dam (Quantity: depend on the size of the dam) (g) Creeper: to fix the bamboo/twigs to the horizontal log (Refer to Step-2) **Implements;** Hoe, Shovel, Panga knife, Wheelbarrow, Watering can, Sacks (Quantity of these implements depends on the number of participants for construction of the Dam).
	

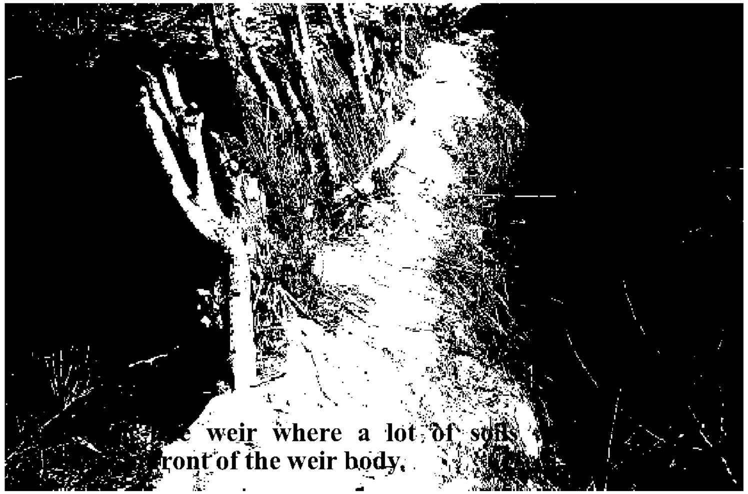
Step	Process	Description	Remarks
1		**<u>Put A Log Horizontally;</u>** Put a horizontal supporting log at the diversion point across the stream. It is advisable that the horizontal log is put on a place where there are tree stump/rock for support of the log. If there are no objects for support, put something such as stone to keep the log from moving by water pressure and weight of the brush dam itself. Length of the log is selected depending on the site condition such as width of the stream.	In case of such site where the material of stream bed is composed of thick sand layer, there is a need to replace the sand layer with imported clay soil. To make replacement work easy, a cofferdam may be constructed using sandbags. If the sacks are not available at the site, banking (soil filling) can be applied.
2		**<u>Stand the Vertical Members;</u>** The vertical members composed of bamboo/twigs are put in front of the horizontal supporting log as seen in the illustration.	To put grasses and soil easily, the vertical members such as bamboo/twigs should be put as close as possible together. These vertical members are placed into the foundation, which in cases has been replaced by clay soil, and again connected to horizontal support log at the top, using materials such as runner (see below). 

Step	Process	Description	Remarks
3		**<u>Placing the Grasses;</u>** Grasses are placed or fixed in front of the vertical members.	To prevent swelling out of grasses, the grasses are bound by horizontal members such as bamboo and tied together with the vertical members as shown in the illustration. 
4		**<u>Pile the Grasses</u>**; Grasses are piled horizontally on vertical standing grasses. See the illustration at the left.	To make the structure less porous to water, the horizontal layers of grass are placed in front of vertical layers of grasses in a criss-crossing way. This pattern helps in making the weir very much water tight. To prevent swelling out of grasses, the grasses may be bound by a vertical member (bamboo) once again.

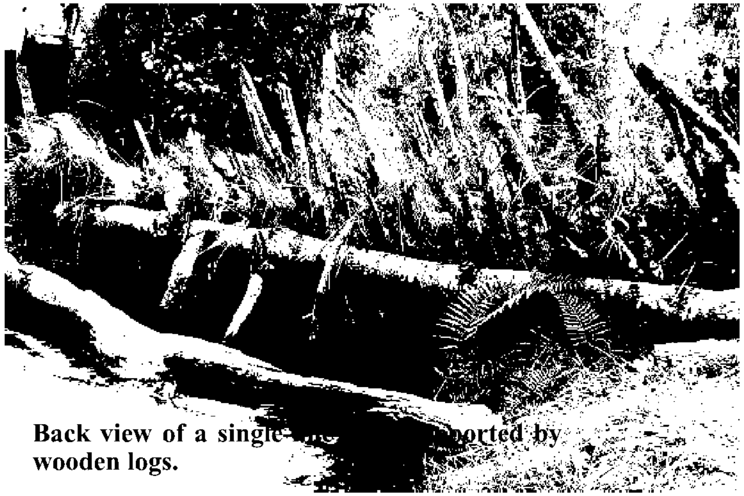
Step	Process	Description	Remarks
5		**<u>Patch the Clay Soil;</u>** The clay soil is patched on the grasses as shown on the illustration in the left hand. Furthermore, to significantly prevent water leakage, the layer of clay soil constructed may be covered by soil existing around the brush dam.	To prevent water leakage, clay soil is patched tightly on the grasses. The clay soil is put not only on grasses as a part of dam but also on the stream banks in contact with the weir to minimize water leakage passing through banks.
6	 ***Front View***	**<u>Completion of Construction;</u>** The weir is then completed. See the illustrations in the left hand and below. ***Back View*** 	**<u>Note; Maintaining the Weir</u>** During operation of the irrigated farming, the diversion weir should be maintained carefully. For instance, if a hole is found at the weir, immediately stop it by sealing with clay soil. This process will restore the weir its former good shape, as the hole will be a source of weakness whereby the structure can fail.

Step	Process	Description
7	**Dismantling the Weir**  **Washing the Tools**  **Transporting Materials and Tools to the village** 	**Note; Dismantling the Weir and Set Aside the Main Materials** These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. **Setting aside the Materials & Tools** 

Examples of Inclined Weir (Kawambwa District, Luapula Provicne)

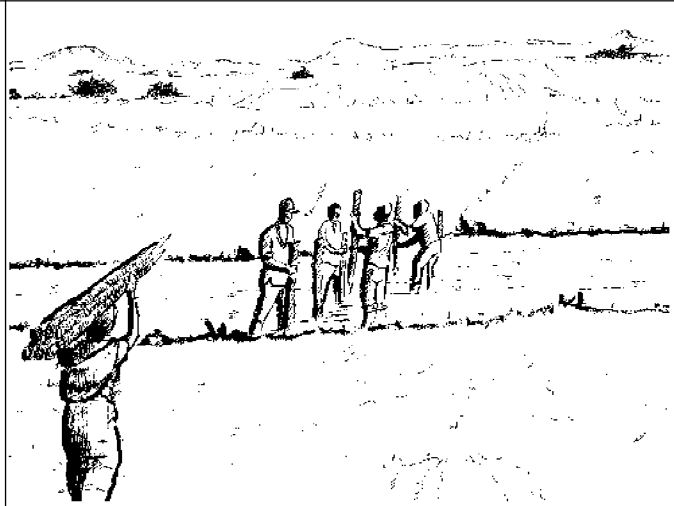
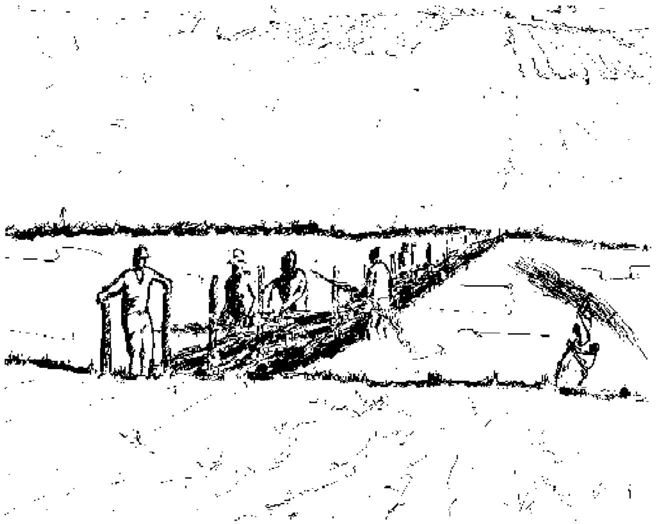
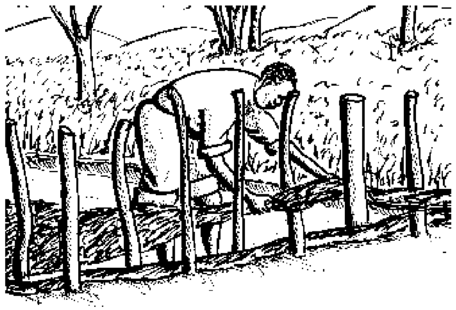


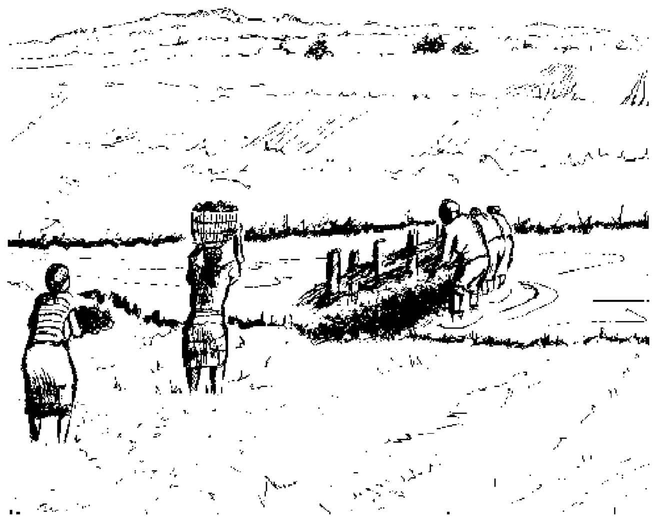
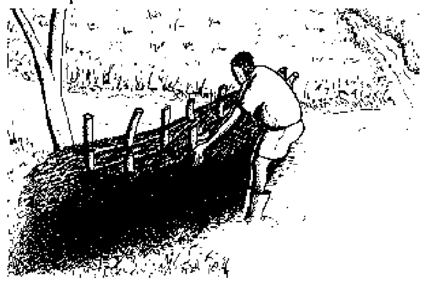
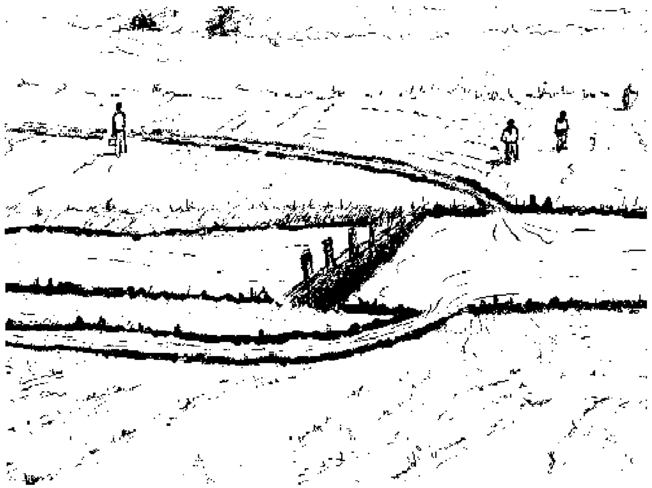
… weir where a lot of soils … ront of the weir body.

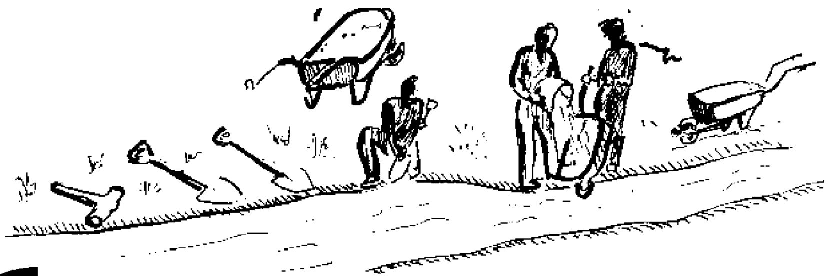
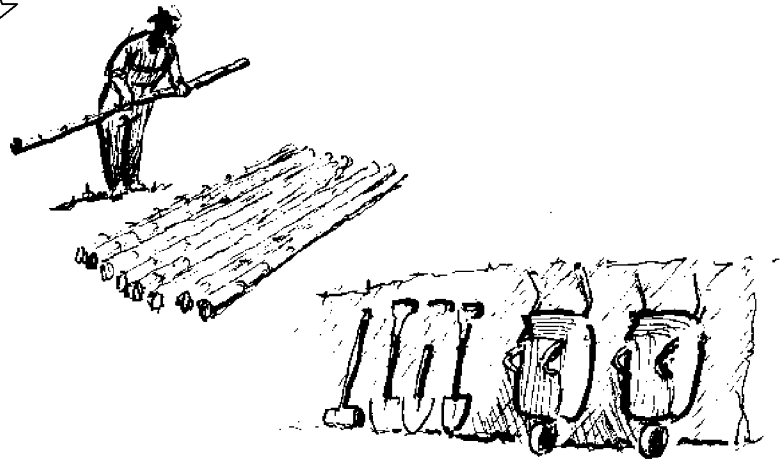


Back view of a single … orted by wooden logs.

2. Construction of A Temporary Weir: Single-line Wall Type (best suited at wider streams whose foundations are not rock)

Step	Process	Description	Remarks
1		<u>**Position the Wooden Poles;**</u> Position the wooden poles at the diversion point across the stream with an interval of 20 – 30 cm. In short, there should be 3 to 5 numbers of wooden poles per one meter. The poles are driven into the ground at a depth of more than 0.3m, below soft foundation if any. Length of the pole depends on the site condition, more especially in relation to the design tapping water level.	In case of a certain site in Kasama District, width of the stream at diversion point was about 6m. About 20 wooden poles were piled with 0.2 - 0.3m of interval. Good straight poles with a sizable diameter should be the ones to be used in this step. The hammering of the poles into 0.3 m below the bed level should be done in order to overpass sand foundation if any, which would be prone to scouring effect if placed above 0.3m.
2		<u>**Weave the Grasses through the Poles;**</u> To tap the stream flow, grasses (elephant grass etc.) are woven horizontally through the poles. See the illustration in the left hand. 	A good chunk of grasses is taken, and then is twisted and finally it is woven between the poles. The bundled woven grasses are treaded layer by layer as they are put criss-crossing on upright logs. This kind of compaction is required in order to achieve water tight situation. When the bundle has reached the end, the next bundle should not start at the very end of the last bundle, but rather, it should start at midway in order to minimize gaps.

Step	Process	Description	Remarks
3		**<u>Put the clay soil on the Grass Fence;</u>** Put the clay soil on the grass fence. To prevent water leakage from the grass fence and boiling due to sand bed material of the stream, clay soils are put on the grass fence and the bottom of the stream up to certain level. 	It may not be effective to use sandbags as a measure of preventing leakage by boiling/piping on the bottom of the stream. Rather using clay and ordinary soil to seal the gaps in the grass fence and the bottom of stream is effective because the gaps would be clogged with particles of clay and soil. After putting the clay soil on the grass fence and the bottom of stream, soils (stream bed material where appropriate) are thrown to the grass fence.
4		**<u>Completion of Construction;</u>** The weir is completed after following all the steps above.	During operation of the irrigated farming, the diversion weir should be maintained carefully. For instance, if a hole at the weir is found, it should be immediately sealed with clay/ordinary soil. This process will restore the weir its former good shape.

Step	Process	Description
5	**Dismantling the Weir** **Washing the Tools**  **Transporting Materials & Tools to the village** 	**Note; Dismantling the Weir and Set Aside the Main Materials** These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. **Setting aside the Materials & Tools** 

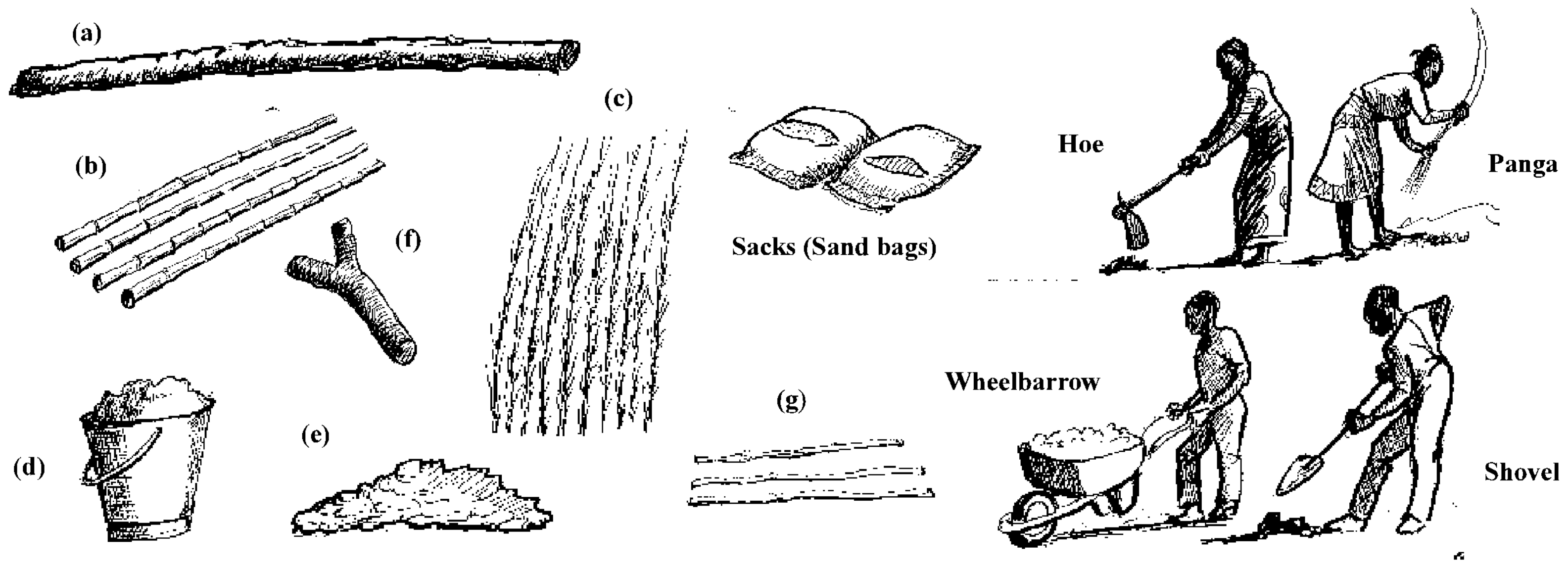
Examples of Single-line Weir (Mbala District (left), Mporokoso District (right), Northern Provicne)

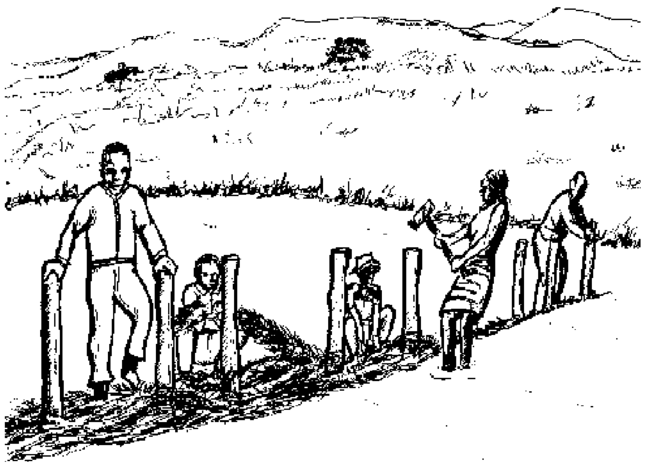
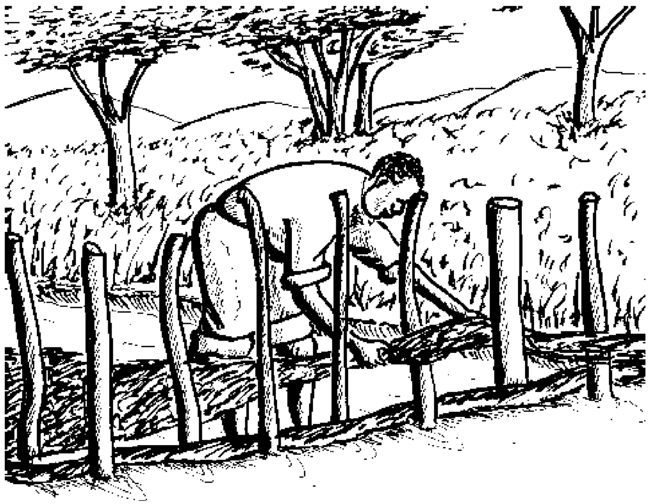
Common type of single-line weir

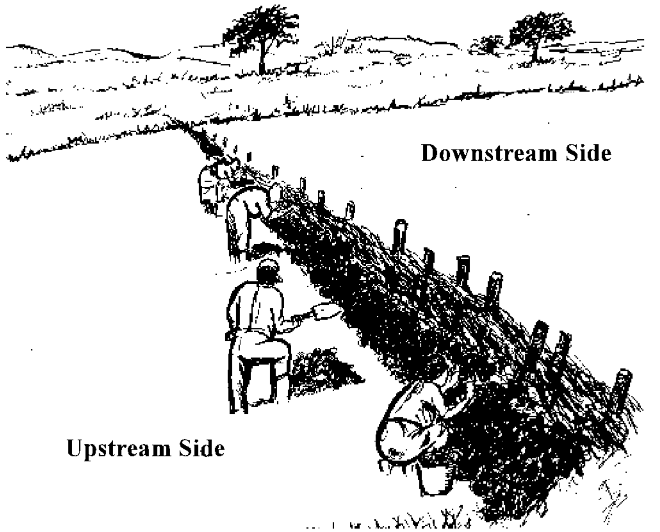
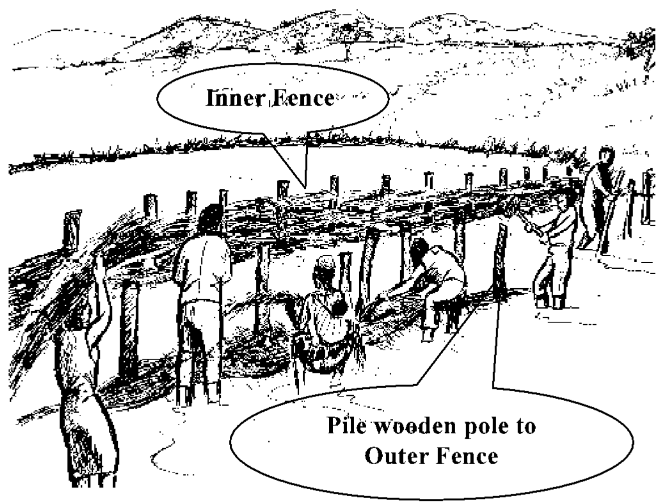
An Improved single-line: There are 2 lines of poles in which there are grasses sand-witched.

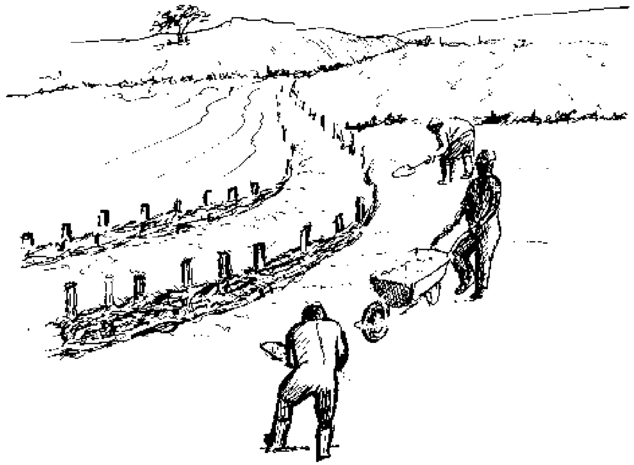
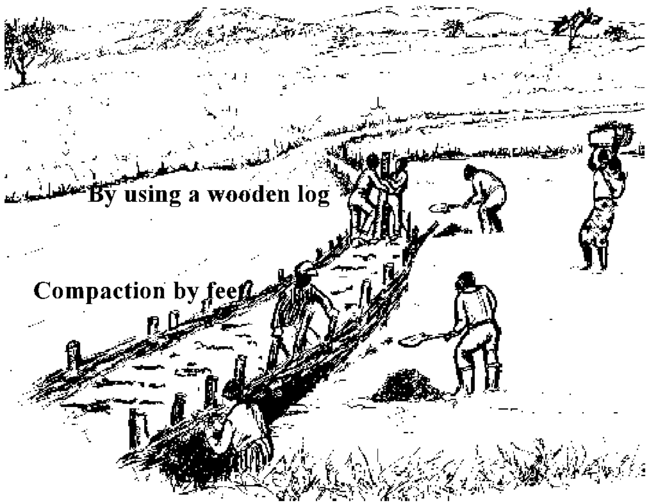
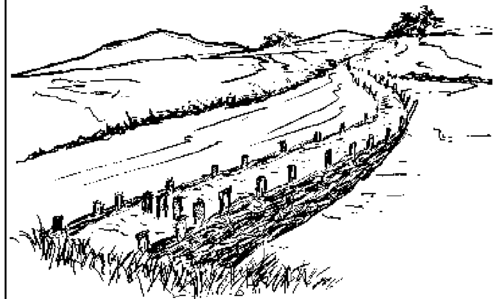
There are 2 lines of poles in which there are grasses sand-witched.

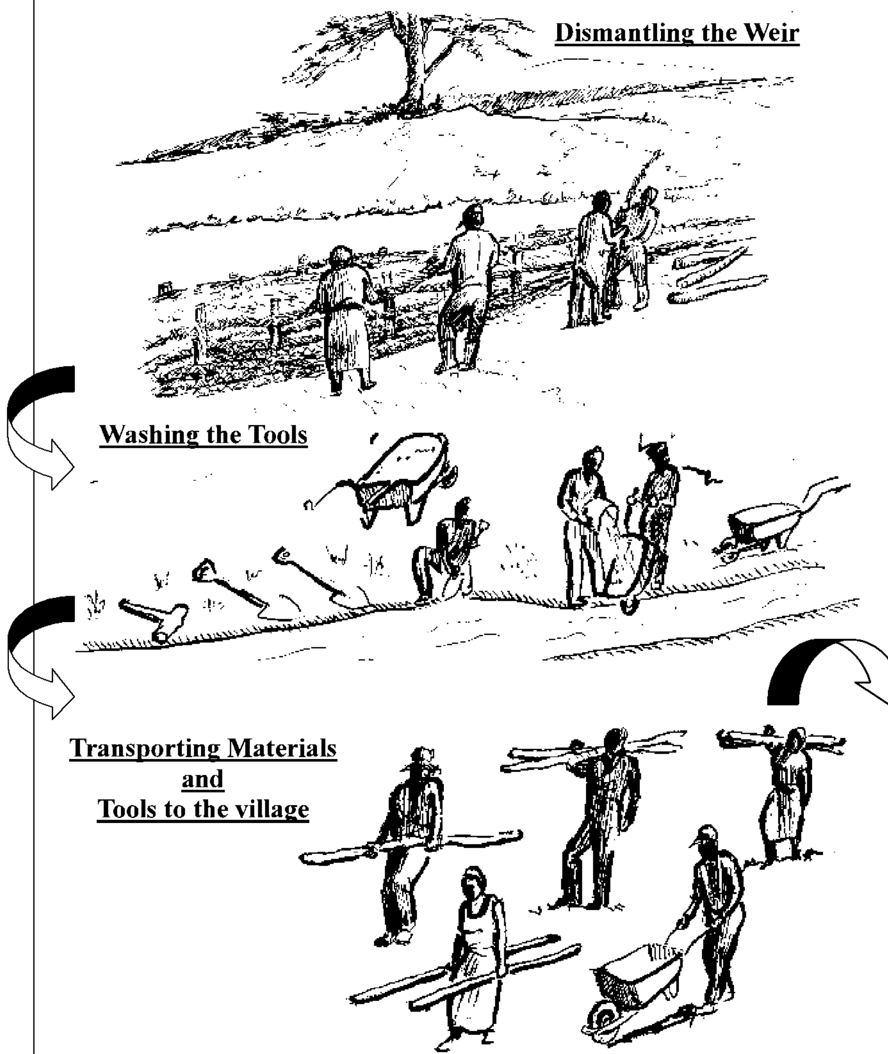
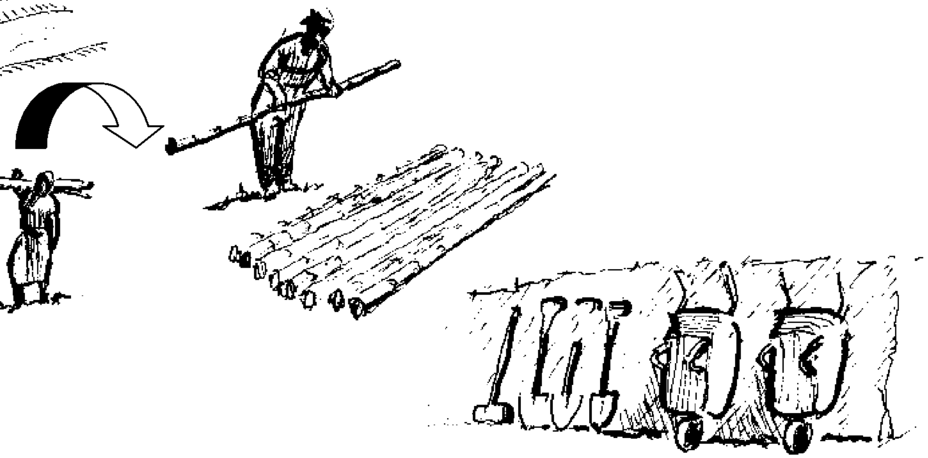
3. Construction of A Temporary Weir: Double-line Wall Type (best suited at wider streams whose foundations are not rock)

Step	Materials to be collected
0	**Collect all the following materials**; (a) Log/Bamboo/Twigs: to make the fence both inner and outer (Quantity: 30-35nos. per 10 meter length of the dam, Refer to Step-1 & 5) (b) Grasses (Elephant grass): to weave into the fences (Quantity: depend on the size of the dam, Refer to Step-2 & 6) (c) Clay soil: to patch in front of inner fence (upstream side) and stuff into the opening of the fences (Quantity: depend on the size of the dam, Refer to Step-4 & 7) (d) Ordinary soil: purpose is same as clay soil **Implements;** Hoe, Shovel, Panga knife, Wheelbarrow, Hammer (Quantity of these implements depends on the number of participants for construction of the dam)
	

Step	Process	Description	Remarks
1		**<u>Pile Wooden Poles to the Inner Fence (Upstream Side);</u>** To make the inner fence, the wooden poles such as log, bamboo and twigs are piled every 30-50cm interval on the line crossing the stream. When the poles are properly positioned, they are driven into the streambed by a hammer.	In fact, this process of putting inner fence is just same as that of single-line weir construction. As single-line weir may hardly be able to stop water due to the leakage through the weir body, this double-line weir was devised. Therefore, one may say this weir is best suited at a site whose width is relatively wider, so that it is impossible to construct inclined type weir, whose foundation is formed with soil (not rock), so that we can drive poles into the foundation, and where we need to minimize water leakage probably due to a fact that there is little water flowing in the stream.
2		**<u>Weave Grasses into the Inner Fence;</u>** To tap the stream flow, grasses (elephant grass etc.) are woven horizontally into the inner poles following Step-1. Then, the grasses woven are compacted by feet. The moment any grass is weaved between the poles, press it tightly with feet. Continue doing this until a required height of this weir is obtained. The weaving of grass should be done to both fences, so that a space is left in between the parallel fences.	The grasses are bundled and woven horizontally between the wooden poles. A good chunk of grass twisted is taken and finally it is woven between poles. When the bundle has reached the end, the next bundle should not start at the very ending of the last bundle but it should start at midway in order to minimize creating gaps. The bundled grasses which are woven between the poles are treaded layer by layer so as to compact it in order to achieve a water tight situation.

Step	Process	Description	Remarks
3		**Put Clay/Ordinary Soil on the Inner Fence;** Furthermore, clay/ordinary soils are put on the upstream side of inner fence to prevent water from passing through the weir body as leakage. To protect water leakage through the gap of grass fence and boiling due to sand bed material of the stream, the clay soils are put on the upstream side of inner fence and the bottom of stream up to a certain level.	The above Steps-1, 2 and 3 are exactly same as those of single-line weir construction. There may be a difference from the single-line weir; that is the interval of the poles. Since this is to be a double-line weir, a wider interval than that of single-line weir may be accepted, say 50 to even as wide as 70cm interval.
4		**Pile Wooden Poles to the Outer Fence (Downstream Side);** The outer fence is constructed following the Step-3. As first step of making the outer fence, the wooden poles are piled on the line of outer fence such as that of Step-1, preferably 50cm to 1m downstream from the inner fence. Then, being same as Step-2, grasses (elephant grass etc.) are woven horizontally into the outer poles. The grasses should, of course, be compacted by feet/ or using a log in order to achieve a water tight situation.	The poles are hammered into the ground with double lines (namely at outside of inner fence). The whole essence of hammering is to make the structure strong, and to make the poles go beyond sand deposits. The interval between the poles can be 50cm – 70cm, a little wider than that of single-line weir.

Step	Process	Description	Remarks
5		**<u>Stuff Clay/Ordinary Soils;</u>** Put the soil which exist around the site into the opening between the inner fence and outer fence. To prevent water leakage from the grass fences, clay/ordinary soils are put into the space between the inner fence and outer fence. The clay soil and ordinary soil can be collected around the diversion site.	It should be noted that the wider the space between inner and outer fences, the more soils should be prepared and put into. The wider the space, the less leakage we can expect but the harder the job of putting soils in between becomes.
6		**<u>Compact the Soils;</u>** The clay and soil ordinary soil thrown into the space between the inner and outer fences should be compacted heavily by feet or with a wooden log. After all the process above is followed, the weir is now completed and water starts backing up on the upstream of the weir, then the water starts getting into the diversion canal to flow.	Completion ! 

Step	Process	Description
7		**Note; Dismantling the Weir and Set Aside the Main Materials** These types of weirs are constructed as temporary facilities for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. 

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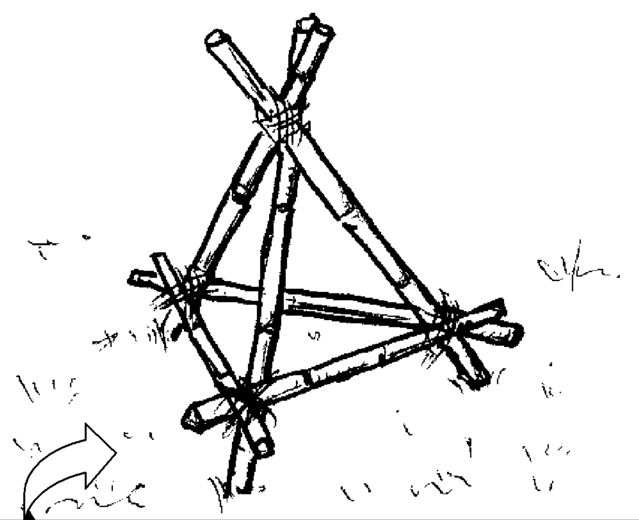
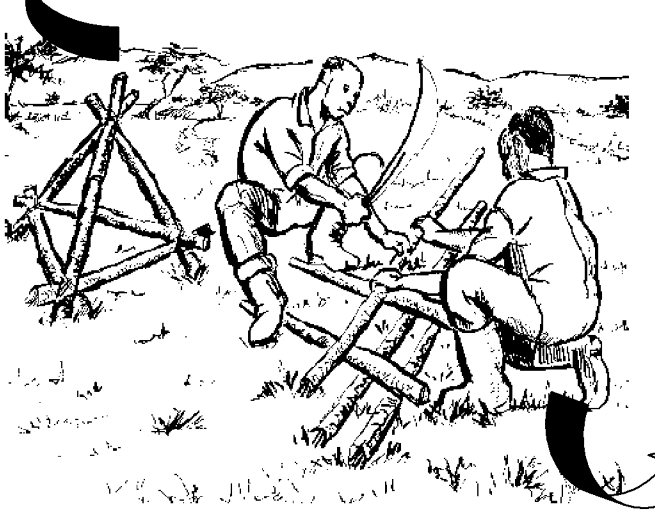
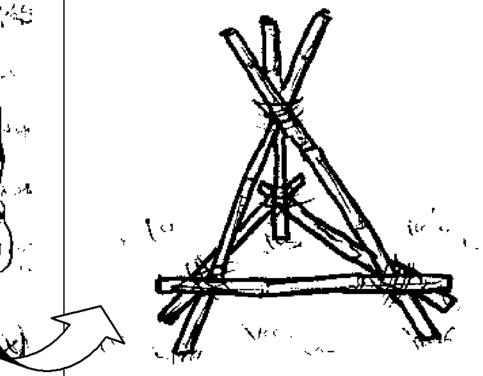
Examples of Double-line Weir (Mansa District (Left), Luapula Provicne, Mungwi District (Right), Northern Province)

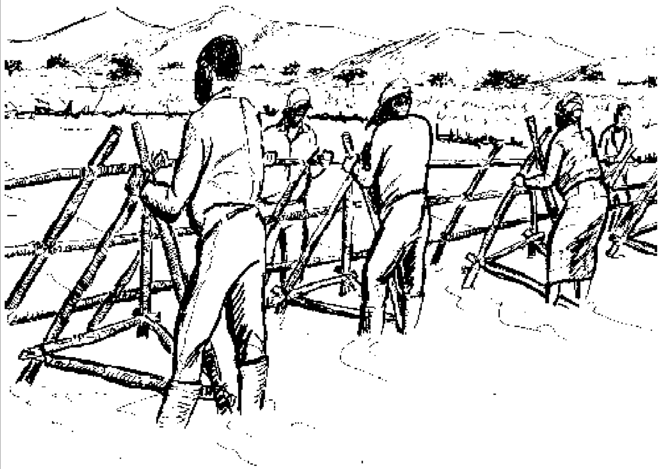
A double-lien weir which works village road as well.

The frame of the inner and outer fences are [illegible] put up.

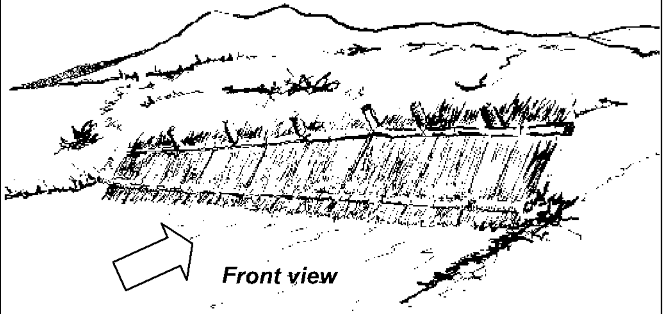
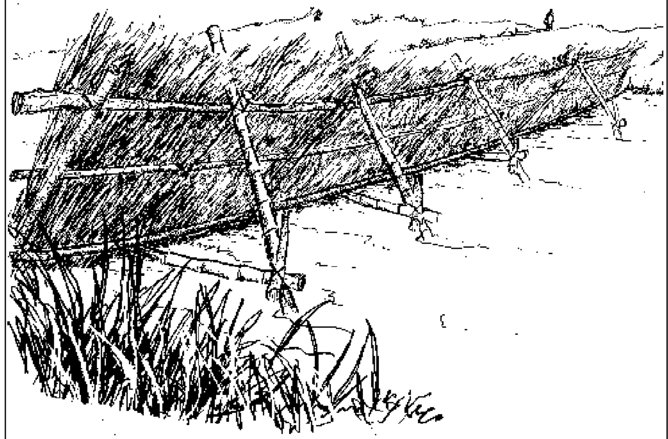
Villager are [illegible] soils in the space of the inner and outer fences.

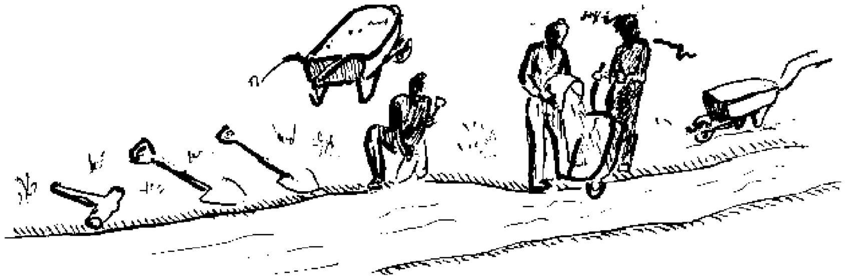
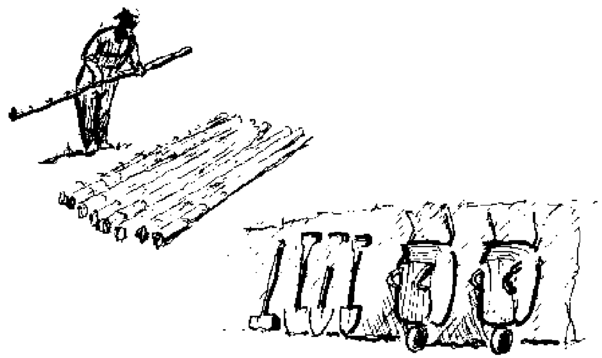
4. Construction of A Temporary Weir: Trigonal Supported Wall Type (can be installed on a rock foundation where wooden logs can't be driven)

Step	Process	Description	Remarks
1		<u>**Assemble the Trigonal Prop (Standing Structure);**</u> To support the brush dam made of grasses/clay soil, the trigonal prop standing structures are assembled as shown in the left illustration.	The trigonal prop can be made of log/bamboo. The size of this structure is adjusted depending on the site condition with reference to the design tapping water level. As an example, each member is cut with a length of 1.3m for 0.5m of tapping water depth design. The diameter can be of the log's/bamboo's one for the trigonal prop; around 7cm - 15cm each. The front of this structure, namely the upstream side, has an inclination to act as support for the fence made of logs, bamboos and grasses with clay soil, and lastly, to stand against the water pressure.
		<u>Refer to the Illustrations</u> Cutting of trigonal prop members and assembling of this structure. 	An angle of inclination of the front face is around 70 - 80 degrees. To tie the members to each other, local materials such as runners/grass/sisal can be used. The horizontal 3 members of the prop, forming the horizontal triangular, should be placed outside of the inclined members, so that it can stand more against water pressure.

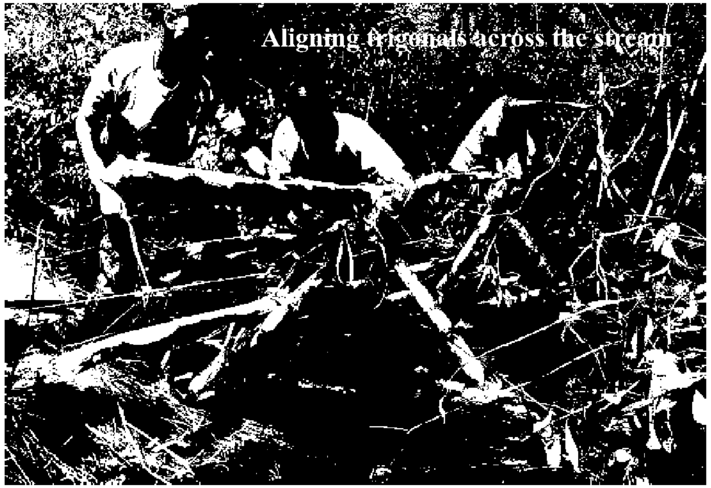
Step	Process	Description	Remarks
2		**<u>Set up the Trigonal Props across the Stream;</u>** The trigonal props are set at the diversion point across the stream. Then, horizontal members are fixed to the trigonal props to keep them in place and in line to each other. At least, 3 horizontal members i.e. upper, middle and lower members should be fixed on the trigonal props. As a result, all of the trigonal props are connected by the horizontal members and will withstand the water pressure as one structure.	The trigonal props are placed at a proper interval in order to prevent this structure from falling down by water pressure. In case of a site in Mungwi district, the width of the stream at the diversion point was about 15m, and 10 trigonal props were set up giving an interval of 1.5m apart. The diameter of fixed horizontal members can be around 3cm - 10cm each. The materials can be wooden poles and bomboos.
3		**<u>Place the Grasses on the Trigonals;</u>** To tap the stream flow, the grasses are placed vertically in front of the trigonal props touching the bed level of the stream.	To reduce the water leakage, it is better to put the grasses very closely. In particular, at the bottom portion of stream, a lot of grasses should be used and should be placed tightly. The horizontal member to be fastened on the top of the grass is the bottom one. Then the second and finally third on top. This helps to keep the grass very tight to the trigonal prop and indeed reinforces the trigonal prop.

Step	Process	Description	Remarks
4		**Tie the Standing Grasses to the Trigonal Structure;** To prevent swelling out of the standing grasses, these grasses should be pressed against the trigonal prop by using horizontal members again tied with runners. Three horizontally parallel members, at the bottom, at the middle and at the top, are finally fastened with the props or otherwise with the horizontal members already set behind the grasses. The grasses are thus sandwiched by those horizontal members set in front and behind.	To press down the grasses on the trigonal prop, another layer of horizontal members are put in front of grasses which are made to run parallel with the first horizontal members already placed at beginning but at a specified interval between each other and these are tightly tied to the first layers of horizontal members. In so doing, grass is tightly sandwiched between horizontal members. The number of layers of horizontal members is dependent on the height of the trigonal weir. In general, 3 lines of horizontal members are placed.
5		**Put the Clay Soil on the Grass Fence;** Clay soil is placed on the grass fence starting from the foundation or streambed level. To prevent water leakage, the clay soil is patched on the grass fence. The clay soil is put not only on the grasses as a part of brush dam but also on the gap between the bottom edge of the grass fence and the natural ground/exposed rock foundation.	Putting of clay soil should be started at the bottom, and much attention should be put at this stage. This is because this area is very critical in reducing water leakage and thus where the water pressure is the highest. A lot of clay soil should be placed at the bottom in order to make it water tight as much as possible to prevent leakage.

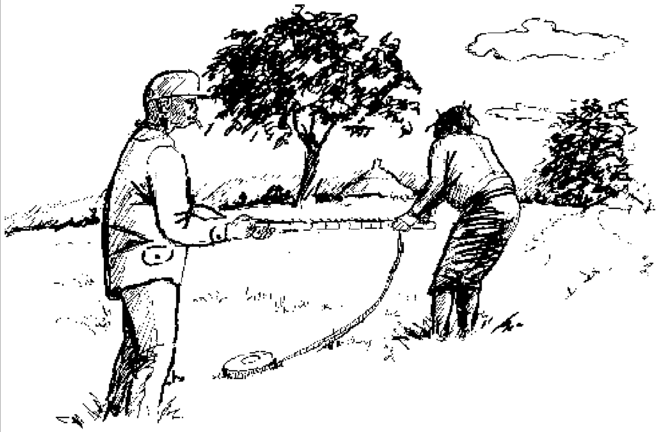
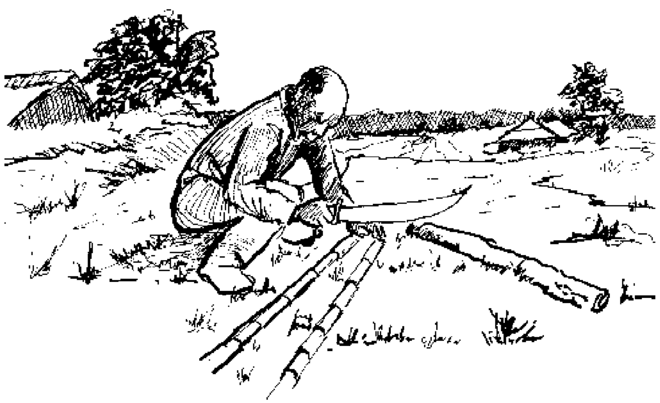
Step	Process	Description	Remarks
6	 *Diversion Weir in a Wide Stream: Rock Foundation*	**<u>Completion of Construction;</u>** <u>The front / Upstream of the Weir</u> Water finally backs up at the upstream of the weir and the duration of backing up depends on the stream width. The weir is finally completed. 	With this trigonal supported weir, water depth stored could reach over 1.0 m or even more than 1.5 m. However, the higher the water level is, the riskier it is and therefore it may fall down. Therefore, it is not recommended to store water over 1.0m.
		<u>The back / Downstream of the Weir</u> 	Check the inclination of the weir. The bamboos supporting the trigonal prop, which is at an inclined angle, is clearly seen / shown in the pictures with its horizontal support. The water level in the downstream is lower than the upper stream of the weir. The trigonal props also help resisting the water pressure which is greater at the bottom, hence the unique design the trigonal prop.

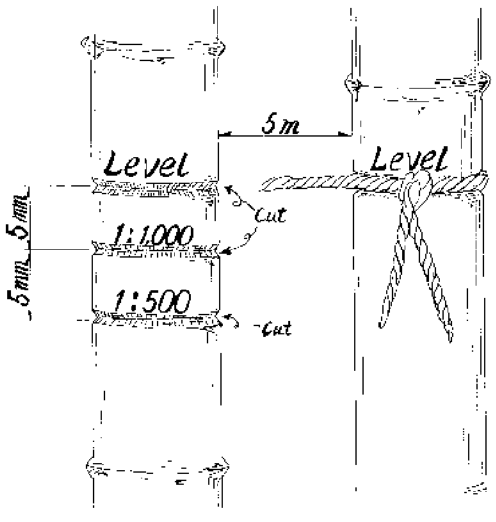
Step	Process	Description
7	**Dismantling the Weir** **Washing the Tools**  **Transporting Materials & Tools to the village** 	**Note; Maintaining the Weir** During operation of the irrigated farming, the diversion weir should be maintained carefully. For instance, if a hole is found on the weir, it should be immediately sealed with clay/ordinary soil. This process will restore the weir its original good shape. **Note; Dismantling the Weir and Set Aside the Main Materials** These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. **Setting Aside the Materials & Tools** 

Examples of Trigonal Supprted Wall Type (Mungwi and Mpila Districts, Northern Province)



5. Canal Alignment with Sprit Line-level (Section 1; Assemble Line-level)

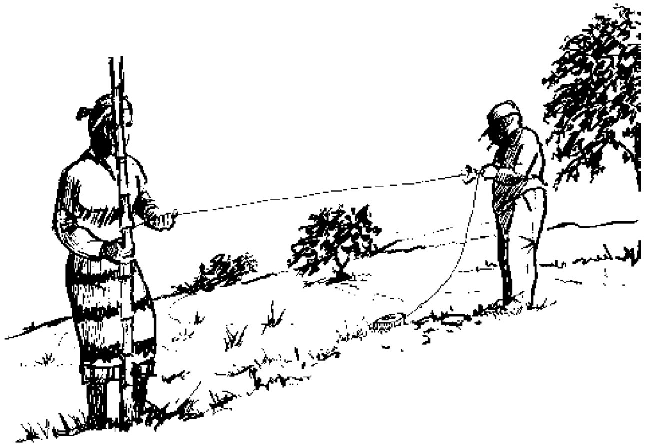
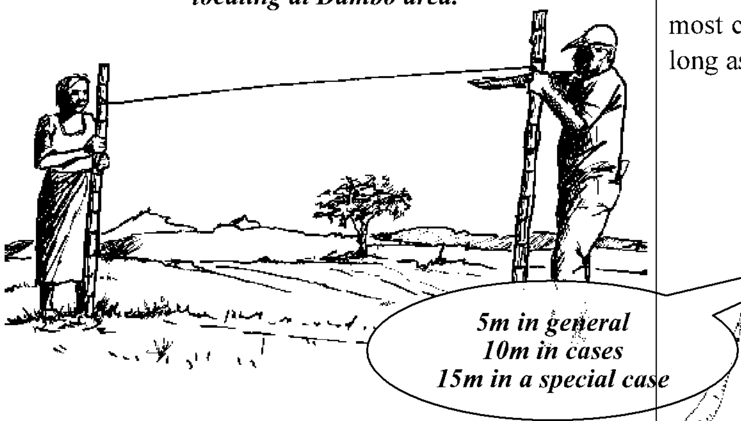
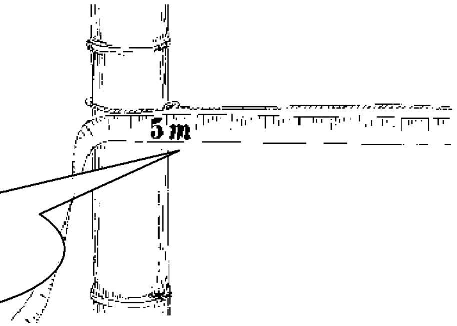
Step	Process	Description	Remarks
1		**Adjust the Poles;** Two (2) poles should be prepared and are cut in the same length. 	Local materials such as bamboo/wooden poles are applicable. The lengths of poles should be adjusted to the height of pole holders. Usually, the poles are about 1.7m to 1.8m in height. The poles should have a sizable diameter so that they are easy to hold. Bigger poles with bigger diameters would be difficult to handle.
2		**Make Groove on the poles (to know gradient on field);** To tie and fix a string, make circular groove around the poles at the same height of both poles—around 1.0-1.3 m from the bottom.	The position of the groove should be set in accordance to the height of the reader of the spirit level. Usually, the height of the groove is from 1.0m to 1.3m from the bottom of the poles. When measuring the level point on field, the grooves should be marked with same height of both poles. However, when measuring a particular slope, grooves should be set at different heights. The table on the next page shows an example of positioning the groove on each pole according to a required slope (same as canal longitudinal gradient).

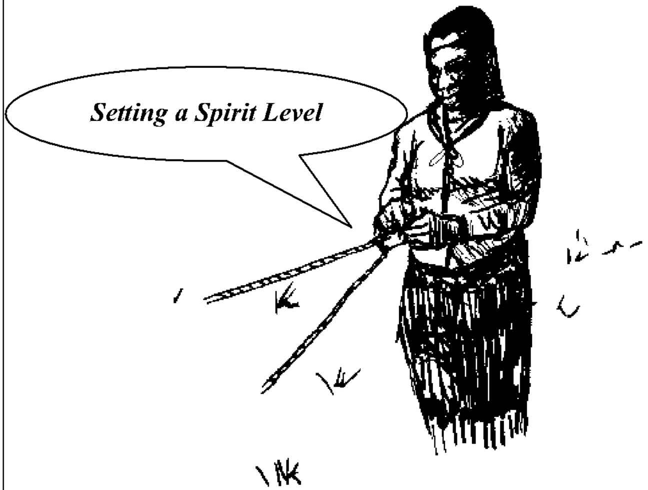
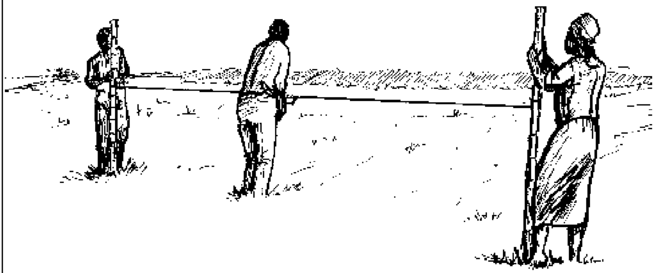
Step	Process	Description	Remarks
3	 B A	**<u>Put Grooves at Different Heights on One of the Poles:</u>** Take one of the poles and make grooves on the pole as shown in the left illustration. The position of the groove is 5mm lower than the first one (top one), and another 5 mm from the first one. The pole at the right side has a groove fixed at, for example, 1.3m from the bottom of the pole as an example (see the groove on the Pole A). On the other hand, the pole standing at the left hand side has 3 grooves (see the grooves on the Pole B). These grooves indicate the level line, 5mm lower than the level line and 10mm lower than the level line.	In conventional way of using a sprit line level, the 2 grooves should be put on the same height in order to know the same elevation points at the 2 poles. However, to align a canal with a designed gradient, we need to make a difference of the elevation in between the grooves of the 2 poles. As an example, 5 mm difference over a distance of 5m gives 1/1,000 (5mm/ 5,000mm) gradient, and 10 mm difference over the same 5m distance gives 1/500 (10mm/5,000mm) gradient. If the 2 poles are placed over a distance of 10m, 10mm difference gives 1/1,000 (10mm/ 10,000mm) gradient and 20mm difference gives 1/500 (20mm/ 10,000 mm) gradient.

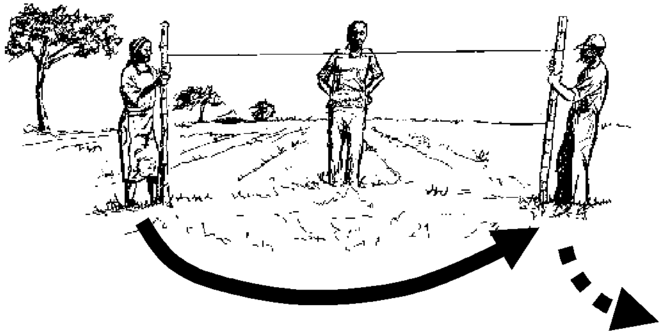
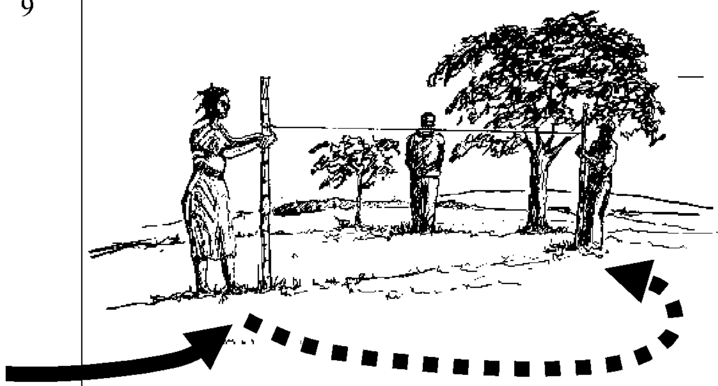
Design gradient of canal	Elevation difference of 2 grooves	Distance between the 2 poles	The position of grooves from the bottom	
			Stick-(A)	Stick-(B)
1/1,000	5.0 mm	5 m	1.3 m	1.295 m
1/500	10.0 mm	5 m	1.3 m	1.290 m
1/1,000	10.0 mm	10 m	1.3 m	1.290 m
1/500	20.0 mm	10 m	1.3 m	1.280 m

The table shown on the left gives an example for the position of the grooves (tying position of the string for the 2 poles) to set the designed slope of canal on the site.

On a gentle topography like *Dambo* areas, 1/1,000 is recommended while on a sloped topography, 1/500 slope is recommended.

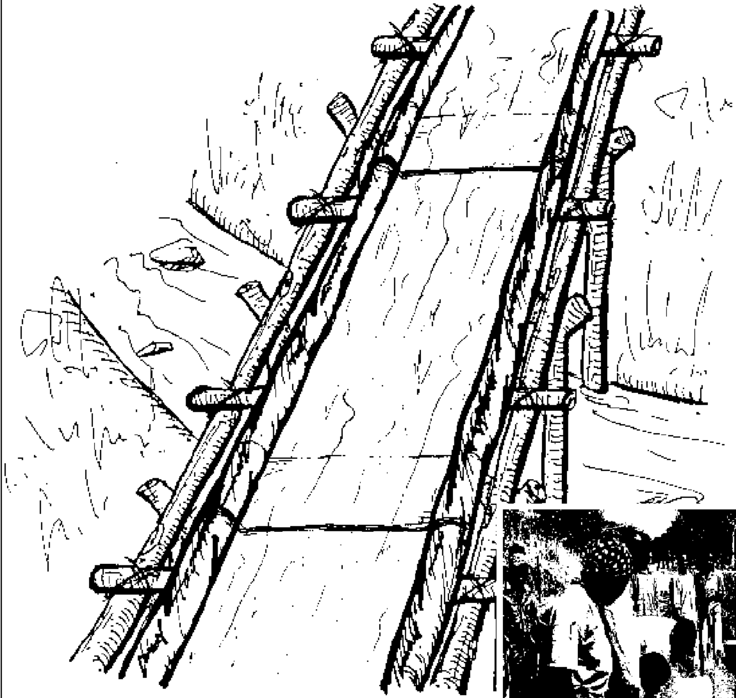
Step	Process	Description	Remarks
4		**Fix the String;** Tie the string on a grove marked on the above steps. 	
5	***The distance should be 5m in general, but may be extended to 10m in the site locating at Dambo area.*** 	**Testing the line-level;** The length of the string, same as the distance of the 2 poles, should be 5m in most cases but in some cases it can be as long as 10m. 	The length of string depends on the site condition. Usually, 5m length of string is ideal as it is easy to handle. However, if the topography is too gentle and difficult to find an appropriate point within the 5m distance, extend the string up to 10m. Elevation difference of 10-20 mm could be found within the 10m distance. In case you cannot still find out appropriate point within the 10m distance, you might extend the distance of the 2 poles up to 15m as a special case. In this case, 15mm elevation gap can give 1/1,000 gradient (15/15,000) and 30mm elevation gap can give 1/500 gradient (30/15,000).

Step	Process	Description	Remarks
6		**<u>Set a Spirit Level (completion of assembling the line-level):</u>** After the required span between the poles is set, set the spirit level on the string. 	The position where the spirit level is fixed should be the center of the string, e.g. 2.5m point with 5m of string, 5.0m point with 10m of string.
7		**<u>Starting the Canal Alignment with Sprit Line Level:</u>** Line-level can be used to know a sloping point for the design longitudinal slope of the canal. To survey that, at least three persons are needed: two for pole holders and one to read the level.	A slope of 1/500 on a sloped (inclined) land is recommended while 1/1,000 slope may be applied on a flat land e.g. *dambo* areas. One may think 1/1,000 slope is too gentle for water to flow. However, this slope is quite enough to let the water flow in the canal by gravity. As most topography in Zambia is very gentle, steep canal slope with more than 1/500 is not recommend. On the other hand, gentler gradient than 1/1,000 is not recommended either since spirit line level may not accompany such accuracy.

Step	Process	Description	Remarks
8		**<u>Surveying Sloping Point on the Field;</u>** The pole holders should stand at an interval of 5 meters or 10 meters according to the length of the string put over the poles. At this time, the pole holder whose string is tied at a lower position than that of the other pole should stand at a higher position e.g. at the starting point of the canal (He/she stands on the left side in the illustration). The other pole holder (the person on the right) will move to the point where the bubble in the spirit level comes to the center. The level reader checks whether the bubble in the spirit level is at the center or not.	The tied point on the right pole is, as an example, higher by 5 mm than the tied point on the left pole in the illustration. With this situation, when the bubble in the sprit level comes to the center, it automatically means that the ground at the right pole is 5 mm lower than that of left pole. If the distance of the 2 poles is 5m, it gives 1/1,000 gradient (5mm/ 5,000 mm) to the ground over the 2 points).
9	 This placing may be called off-set leveling since the evaluation gap between the grooves is off-set by the elevation difference of the ground where 2 poles are placed.	**<u>Do progressing Placing of the Poles:</u>** After a sloping point is set, the pole holder who stands at higher point (left person in the illustration) should move the point to where the other one was (right person in the illustration). The points where the pole holders stand act as bench marks where the pegs are now driven. After this, repeat the same procedure until the required distance of canal is achieved. Upon completion of the line-leveling over the designed distance of the canal, re-align some pegs to get a smoother canal alignment (avoid zigzag alignment).	This method is completely different from conventional pole placing. Conventional placing requires us to place the 2 poles alternately in order to identify a counter level, while this canal alignment necessitates us to place the 2 poles progressively. By placing the 2 poles progressively, designed elevation difference, corresponding to the canal longitudinal slope, over the 2 points is secured since the tying points of the string on the 2 poles are different in elevation.

6. Canal Design and Construction

Canal Ancillaries

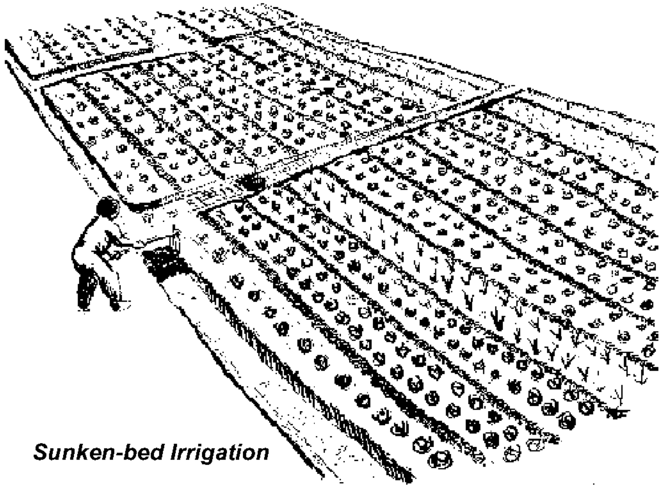
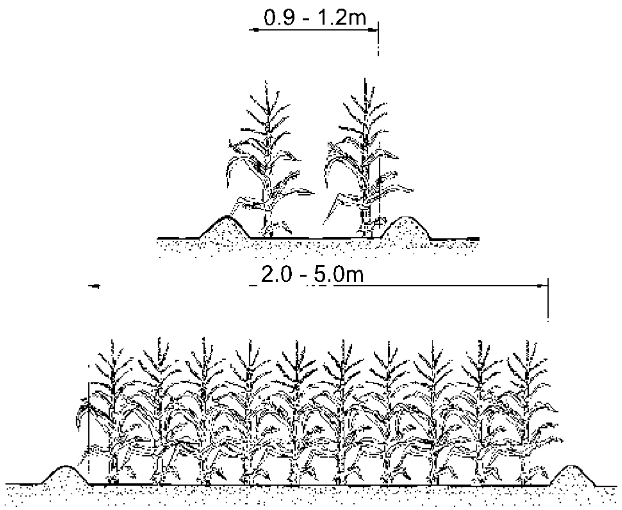


A Canal Bridge crossing a gully:
On the frame assembled with wooden poles and supported by twigs from the ground, long tall grasses are placed on and a bunch of grasses about 20 cm in diameter is placed on the both edges, and thereon plastic sheet is placed.

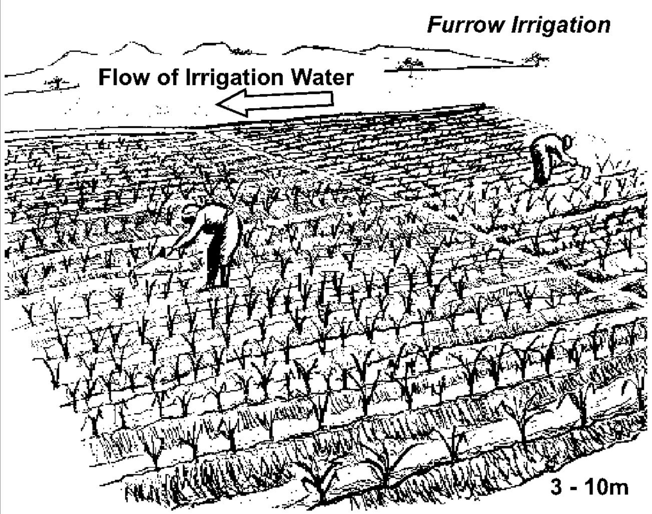
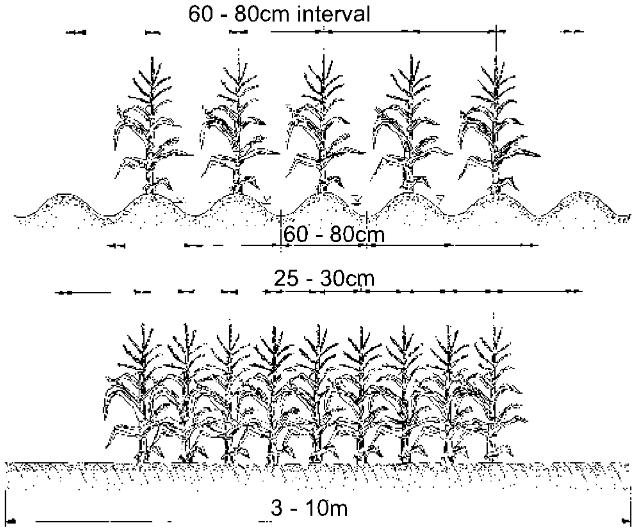
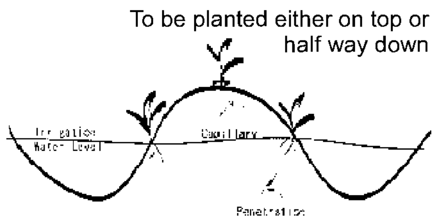
On-farm ditch covered with stone pitching:
Where farm land is located on a sloped area, stone pitching can be applied on the ditch in order to prevent the soil from being eroded.

If stone is not available in and around the site, even banana sheath can be used as a temporal material for ditch lining in order to prevent soils from being eroded.

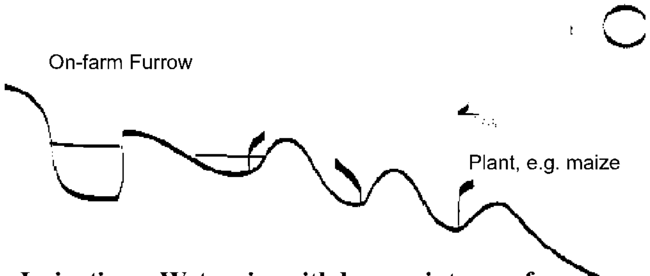
7. On-farm Irrigation Method (Section 1; Sunken-bed Irrigation)

Step	Process	Description	Remarks
1		**<u>Making the Sunken Bed;</u>** This sunken-bed on-farm irrigation system is applied to a very flat area, and not to steep topography. To do this on-farm irrigation method, make a sunken bed, which is a leveled area in the field, surrounded by earth bands. The leveled area is flooded during the on-farm irrigation. Sunken-bed irrigation is suitable for many crops.	In sunken beds, the crops grow on the flat surface, which are surrounded by small earth embankment and are kept wet for a long time when the bed is irrigated. The advantages are; 1) the amount of water can be given with a minimum amount of labor if beds are well leveled, 2) water losses can be kept low by minimum run-off, and 3) beds last for a long time once they are constructed.
2		<u>Refer to the Illustrations</u> Sunken-bed irrigation needs a good water supply to fill the basin quickly. This in turn requires accurate land leveling with a good earth embankment surrounding the bed. Also it is required that the intake at the bed should be clogged when the water reaches around 3/4 of the length of the bed, after which water is to reach up to the end by gravity in the bed.	The width and length of the sunken bed is normally 0.9 - 1.2m and 2.0 - 5.0m respectively but depends on the type of crops and soil. If the soil is sandy, it is recommended to shorten the length, say to 3 m or even to 2 m length.

On-farm Irrigation Method (Section 2; Furrow Irrigation)

Step	Process	Description	Remarks
1		<u>**Making the ridges and furrows;**</u> This furrow on-farm irrigation system is applied to a relatively steep topography, and not to very flat area. To practice this on-farm irrigation, make ridges and furrows, just same as the one for rain-fed agriculture. Note that the interval of ridges, same as that of furrows, should not be too wide, say not over 100 cm in any case. Intervals of over 100 cm can be seen in rain-fed agriculture, however with these wide intervals, irrigation water can hardly wet the crops planted on the ridges.	Under furrow irrigation, water is taken to the plant through long and narrow on-farm channels (on-farm furrows) formed in the soil at regular intervals, between the crop rows (ridges). The length of the furrow is normally 3 - 10 m but depends on the type of soil and the land slope. If the topography is very uniform, the length of furrows/ridges can be extended up to 10m or otherwise better to limit within 5m in most cases.
2		<u>Refer to the Illustrations</u> Water is gradually absorbed into the bottom and sides of the long on-farm channel (on-farm furrow) wetting the soil. Crops are usually grown on top of or half way down the ridges between furrows. 	It is important to use the right shape of furrow, furrow spacing and length. Good water management is of course very much important for the method to work well. The interval of ridge is usually 60 – 80 cm, equivalent to the one applied under rain-fed agriculture or somewhat narrower than that. Ridge height, equally to furrow depth, should be around 20 – 25 cm in order for capillary to lift the water toward ridge. Cops are planted at intervals of 25 –30 cm on top of or half way down the ridges, which is also equivalent to the practice of rain-fed agriculture.

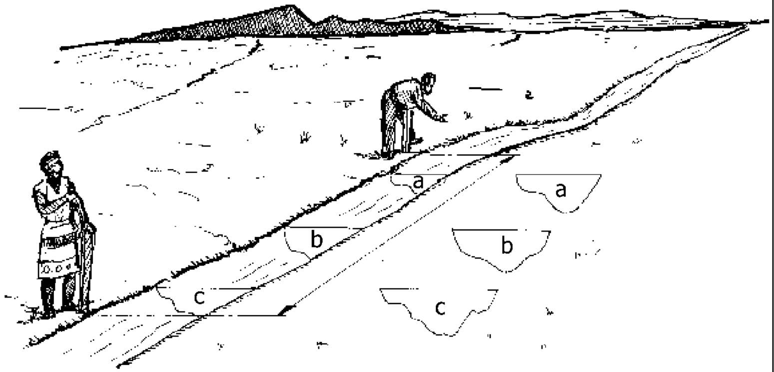
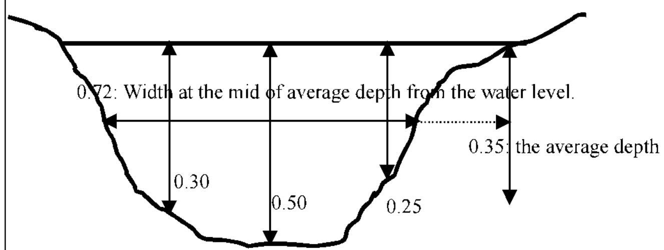
Examples of On-farm Irrigation Method (Furrow rrigation and Sunken-bed Irrigation)



Furrow Irrigation: Water is withdrawn into on-farm furrow, and then wets the soils by capillary.

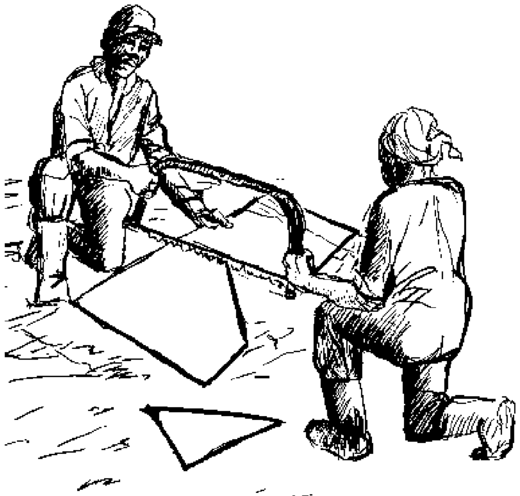
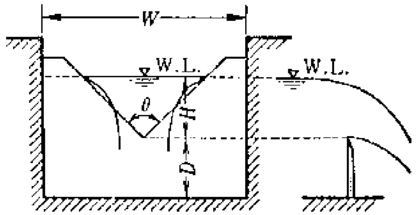
Sunken-bed irrigation: Sunken-bed is a leveled area surrounded by earthen band. Water is led to this bed and wets whole the bed area for the plants.

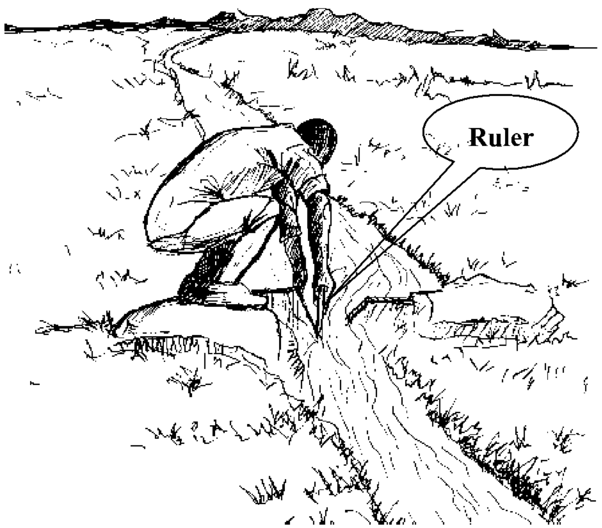
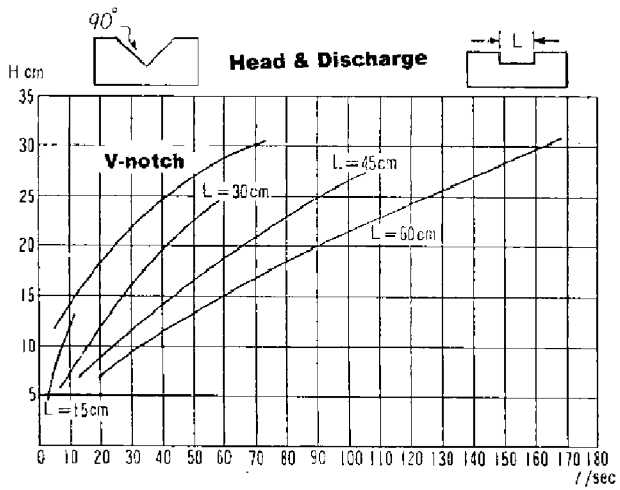
8. Discharge measurement (Section 1; Float Method)

<table>
<tr><th>Step</th><th>Process</th><th>Description</th><th>Remarks</th></tr>
<tr><td>1</td><td>
</td><td><u>Measurement of the Water Area;</u>
The float method is available to know a rough estimate of the stream flow. The amount of flow (Q) can be estimated by measuring the size of the stream (A=water area) and the speed (V=velocity) of the water (Q=A*V).</td><td>The water area of the stream (width multiplied by depth) has to be measured. It is better to select a clean and straight section on the stream, at least 5 – 10m long. Measure the depth at one cross-section for at least 3 points (e.g. at 1/4, 1/2, and 3/4 of total width as in the bottom illustration) and calculate the average depth. Then, multiply the average depth into average width of the section, which is the width at the mid point of the average depth from the water level. After the water area for each cross-section is calculated, the representative water area (A) is estimated by averaging all the cross-sectional areas.</td></tr>
<tr><td>2</td><td>How to estimate a cross sectional area:


<table>
<tr><th colspan="2">Depth (m)</th><th>Width, m</th><th>Area, m³</th></tr>
<tr><td>Depth 1 (1/4)</td><td>0.30</td><td rowspan="4">0.72</td><td rowspan="4">0.252 m³
(0.35x0.72)</td></tr>
<tr><td>Depth 2 (1/2)</td><td>0.50</td></tr>
<tr><td>Depth 3 (3.4)</td><td>0.25</td></tr>
<tr><td>Average</td><td>0.35</td></tr>
</table></td><td><u>Measurement of the velocity;</u>
A float (e.g. a piece of dry wood) is thrown into the water to measure the velocity. Measure the time (in second) taken by the float to move between the upstream cross-section point (section-a) to the downstream one (section-c). Repeat this measurement at least three times, and calculate the average velocity. Velocity is calculated as follows:
Velocity=Length (m) of the 2 points (e.g. section-a to section-c in the illustration) / time (in second)</td><td>The measured velocity at the surface is larger than the velocity along the bottom and sides. Therefore, the measured velocity at the surface needs to be corrected as follows:
-When the water depth<30cm,
Velocity=average velocity times 0.70
-When the water depth>30cm,
Velocity=average velocity times 0.85
Finally, multiply the average water area by the corrected average velocity. This is the amount of flow (Q=A*V) in cum per second. When multiplied by 1,000, it is now the flow in litter per second.</td></tr>
</table>

Discharge Measurement (Section 2; V-notch Method)

Step	Process	Description	Remarks
1		**<u>Making a V-notch;</u>** Generally, the v-notch is made of wooden board at an angle of 90 degrees. 	If the amount of stream flow is small such as up to 100 lit/sec, v-notch is available to measure the discharge. The application of v-notch is as following (refer to the figure show in the left): • 0.5m<=W<=1.2m • 0.1m<=D<=0.75m • 0.07m<=H<=0.26m • H<=W/3
2		**<u>Set the V-notch in the Stream;</u>** The v-notch is set up at suitable site near the place where it is planned to construct the diversion weir.	The v-notch must stand perpendicularly to the stream flow. To stabilize the v-notch, sand bags can be used.

Step	Process	Description	Remarks
3		**Measure the Depth of Nappe;** After setting of the v-notch, the stream flow starts overflowing through the v-notch. The v-notch will be left as it is. When the nappe has become stable, the depth of the nappe has to be measured. The depth here means the distance between the deepest point of the V-notch and the water level right above the deepest point.	To measure the depth of the nappe, a ruler should be prepared. The ruler should be placed perpendicular to the flow exactly, or error in the measurement will take place.
4		**Read the Graph or use Tables;** The amount of stream flow can be known by the graph shown on the left column, or refer to the tables on the following table.	After measurement of the depth of nappe, the depth is checked against the graph to know the volume of flow. The graph shows the relationship between the depth of nappe and discharge. Or otherwise refer to the table on the following page. An exercise in case of V-notch; The depth of nappe: 25cm The amount of flow: 40 lit/sec

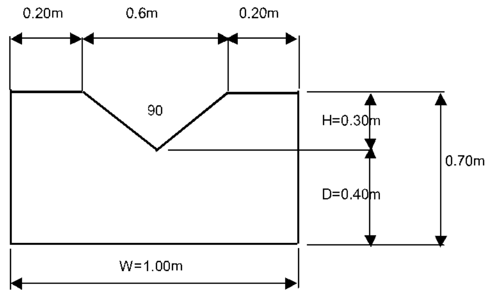
AP-I-A-35

Step	Table of Discharge against Ovewflow Depth

4

In case of V-notch:

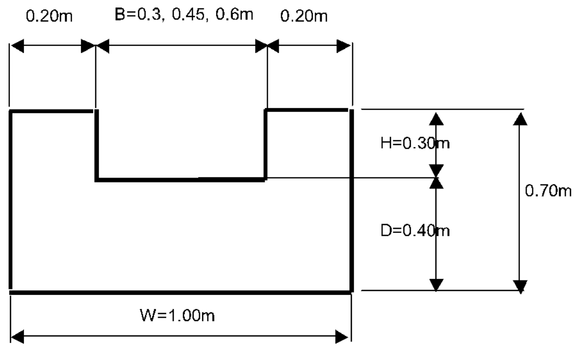
Over flow depth on V-notch	Discharge	
h (m)	Q (m^3/min)	Q (lit/sec)
0.07	0.11	1.83
[redacted]		
0.12	0.42	6.92
[redacted]		
0.16	0.85	14.14
[redacted]		
0.20	1.48	24.67
[redacted]		
0.24	2.34	38.95
[redacted]		



4

In case of rectangular notch:

Over flow depth on R-notch h (m)	Discharge		
	B=30cm	B=45cm	B=60cm
	Q (lit/sec)	Q (lit/sec)	Q (lit/sec)
0.10	16.59	25.17	34.00
[redacted]			
0.14	27.72	41.36	56.02
[redacted]			
0.18	40.96	60.09	81.56
[redacted]			
0.22	56.23	81.11	110.29
[redacted]			
0.26	73.51	104.27	142.03
[redacted]			



T-COBSI

(Technical Cooperation for Community Based Small Holder Irrigation)

Engineering Manual for Irrigation & Drainage

May 2014

Ministry of Agriculture and Livestock (MAL)

Japan International Cooperation Agency (JICA)

PREFACE

This guideline applies for construction of irrigation facilities for small scale irrigation schemes. It applies for simple and small scale structures which are made of stone masonry, brick masonry, stones, earth etc. However, it does not include construction of sophisticated structures e.g. reinforced concrete as well as use of heavy equipment. Most of the works under this guideline are to be done by the farmers manually. However, the guideline also contains other related detailed hydraulic analysis, structure analysis and stability analysis for structures.

TECHNICAL GUIDELINE

CONTENTS

CHAPTER 1 GENERAL

1.1 Definition and Ranges Covered by this Guideline

These criteria provide the fundamental concepts and points of attention with reference to the basic factors necessary for establishing projects concerning upland irrigation. Upland irrigation is the basic measure for supplying the water necessary for the improvement and maintenance of the growing environment of upland crops cultivated mainly on ordinary uplands orchards and pastures. The criteria deal with the general water utilization system for irrigation ranging from water sources to farmlands.

These criteria provide the fundamental concepts necessary for the establishment of upland irrigation project. They are not intended to restrict the judgment of responsible persons or to make plans uniform, but to facilitate planning work by indication ideas and planning processes that will help overcome complicated selection.

Persons responsible for planning are required to make their utmost effort to establish a plan suitable for local conditions through utilizing their own experience and creativity in accordance with the courses shown in these criteria.

1.2 Objective of Upland Irrigation

The objective of upland irrigation is to improve the land productivity and the labor productivity of project areas through supplying the water necessary for upland crops and improving the employment of water usage by multipurpose application of irrigation facilities.

Upland irrigation supplies the moisture necessary for upland crops, thus increasing the yield and improving the qualities. In addition, the multipurpose application of irrigation facilities contributes to the rationalization of lot management, prevention of meteorological disasters, labor saving in management works, and so on. Upland irrigation thus enables the introduction of profitable crops and new varieties of crops, the rationalization of the farming system, the upgrading of crop intensity, and planned production and marketing, and establishes the basis of farm development. Accordingly, it is necessary to examine carefully the irrigation plan from a wide range of views.

1.3 Basis of Plan Establishment

Prior to the establishment of the plan, the accessibility and the economy of water sources, the farming program of project areas, related projects, etc. shall be fully examined based on the principle that the entire water utilization system needs to be well balanced including future operation and maintenance.

With regard to the production system, group unity and rearrangement of production, organizations are required to cope with the expected rise in marketing after the initiation of water utilization. Also, in order to stabilize production, the establishment of a production system to conduct organizational quality control and continuous marketing is required. The point is how the benefit of upland irrigation is utilized in the production system.

As the cropping pattern and the decision of the seasonal crop structure greatly affected water requirements for irrigation, they shal1 be estimated based on the forecasted future farming system.

If the farming program on the basis of water utilization, seasonal cropping pattern considering beneficial area are roughly decided, the total water requirements throughout the year and the maximum water requirements for' crop cultivation could be approximately estimated in the project area. On the other hand, based on examination of the kinds of water sources and the volume of available water, it is possible to decide roughly how much water should be obtained from the water source. Accordingly, in the stage of examining the whole water supply and demand, it is necessary to study the required volume of irrigation water and the benefit of the water utilization and compare with the project cost, water cost, etc. in order to balance the plan as a whole economically.

In addition, when planning basic facilities such as the water source, water conveyance, water distribution, regulating reservoir, and pump, it is necessary to prepare the basic plan to establish a generally consistent and balanced organization as a whole including the control method and future organization.

CHPATER 2 UPLAND IRRIGATION

2.1 Investigation

2.1.1 Investigation Procedures

- Procedures of investigations necessary for the establishment of the plan shall be provided in accordance with the scale of the project to be executed and the regional characteristics.
- It is necessary to promote the investigation and the establishment of the plans side by side in liaison with each other, and to conduct them rationally and efficiently.

[Explanation]

- ✓ Investigation procedures shall be decided in accordance with the scale of the project to be executed and the regional characteristics. Therefore, it is not appropriate to provide one specific procedure. A standard procedure is shown in **Fig. 2**.1
- ✓ As a general rule, in order to make a rational and efficient investigation, regional characteristics should first be understood comprehensively, then a detailed investigation of necessary items should be conducted. The former is a reconnaissance investigation and the latter is a detailed investigation.
- ✓ The reconnaissance investigation is a rough study of the exiting condition by which the need for the project is judged, basic plan prepared and basic and detailed investigation plans are prepared.
- ✓ The detailed investigation is conducted to obtain the basic dimensions necessary for the establishment of the plan. In accordance with the basic plan and utilizing the results of the reconnaissance investigation, a plan of the detailed investigation is prepared and conducted.
- ✓ As a rule the ultimate validity of a plan is judged on the basis of the result of the detailed investigation. However, the feasibility of the whole project may depend upon the assessment on the need and validity of the project made in the reconnaissance investigation. Accordingly, the reconnaissance investigation has to be performed very carefully.

2.1.1.1 Reconnaissance investigation

(1) Items to be clarified by the reconnaissance investigation

1) Outline of weather, land-form, geology, and soil
2) Conditions of farmland consolidation
3) Condition of water usage (irrigation and drainage, and main irrigate drainage facilities)
4) Social, economic, and farming conditions of project areas and regions
5) Outline of development plans and related projects of the prefectures, towns, and villages
6) Intention of farmers in the project area

(2) Procedure and contents of reconnaissance investigation

Investigation procedure and contents to be noted are described below.

1) Collection of the following published works or literature and under-standing of the project area.

a) Topographical maps (scale of 1/25,000 - 1/50,000) .
b) Handbooks of cities, towns and villages on census (prepared by each city, town or village office)
c) Geological maps
d) Soil maps
e) Irrigation blocks in each water source

2) Interview

Interviews with relevant farmers, officers of city, town, village offices, and the land improvement districts on the present conditions of farming, roads, farm lots conditions such as arable land, irrigation and drainage, water usage as well as, farming improvement, accessibility to applicable water sources and future plans in the regions .

3) Survey

The scope of the survey shall be decided in accordance with the investigated results of 1) and 2) mentioned above. Using drawings and simple measuring instruments such as a hand level, distance measuring instruments, the following points shall be surveyed: the conditions of the farm lots, roads, irrigation and drainage facilities, landform and geology, streams of rivers exploitable as water sources and water-intake points. The survey results shall be specified into drawings and arranged. It is desirable to conduct a survey with the assistance of persons who know the details of the project area.

4) Judgment based on the result of the reconnaissance investigation

On the basis of the findings obtained by the reconnaissance investigation, the need and validity of the project in the relevant area shall be examined. In accordance with the development plans in the relevant land improvement projects of the prefectures, cities, towns and villages, the basis plan of the project shall be prepared so as to be in harmony with the development goals of the region. Contents of the basic concept - rough selection of beneficial areas, principal crops, irrigation method, water source and intake sites, simultaneous execution of land consolidation, etc.

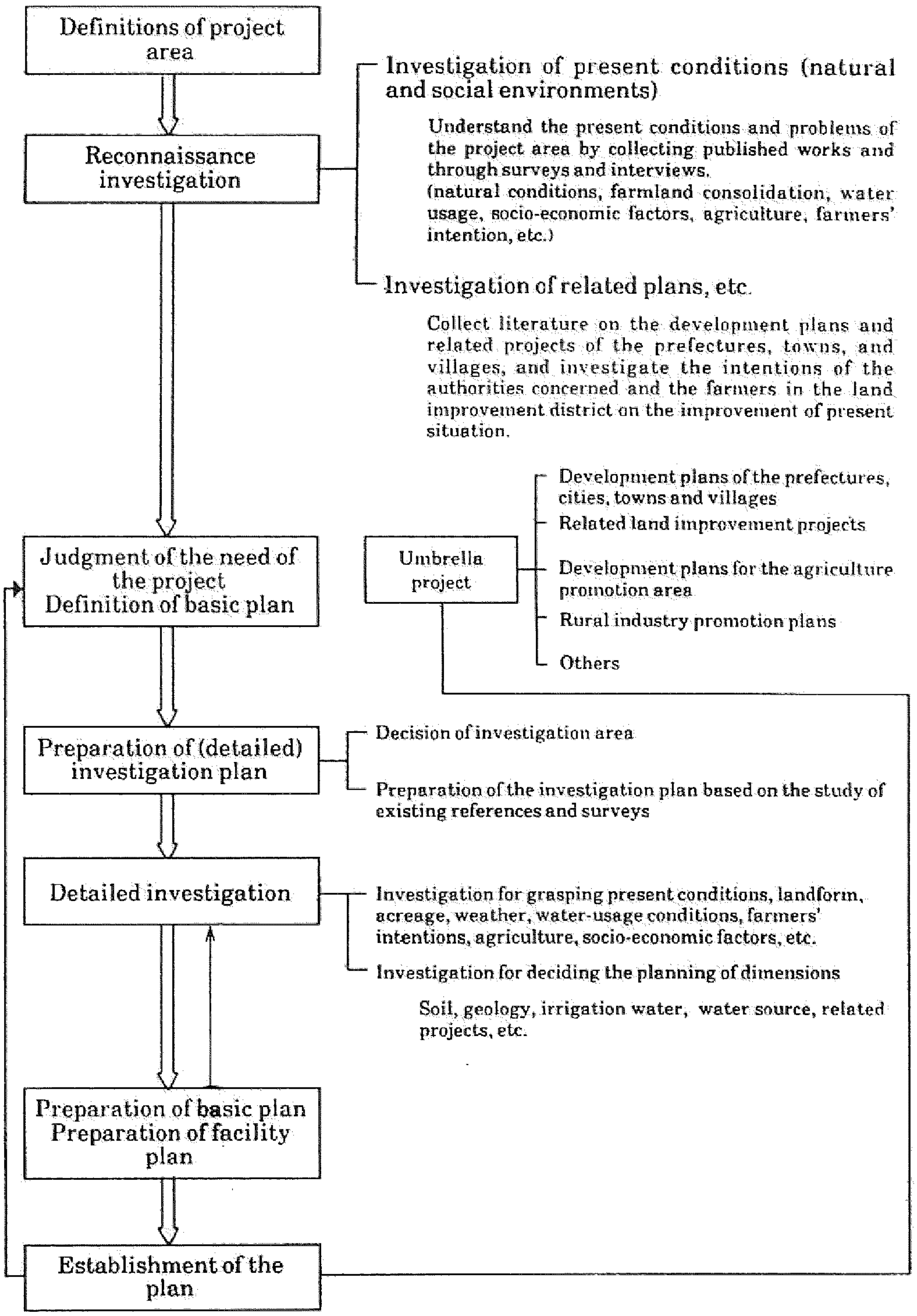


Fig.2.1 Investigation Procedure

2.1.1.2. Detailed investigation

On the basis of the results of the reconnaissance investigation, an investigation plan including the scope of the area, necessary items to be investigated, duration of the investigation and the selection of the sites for the installation of observation facilities shall be prepared, and put into execution. Items and contents of the detailed investigation are described in 2.1.2 below. It is advisable to conduct the investigation focusing on the necessary items, while fully utilizing the published works. In addition, the detailed investigation and the establishment of the plan should be conducted hand in hand, so that one can cope with any new conditions arising in the course of the planning.

2.1.2 Detailed Investigation Items

2.1.2.1 Landform and Acreage Investigation

- Since the landform is an important element which affects the irrigation plan, a topographical map shall be drawn with necessary precision in accordance with contents of the plan.
- Acreage shall be measured correctly to calculate the beneficiary area.

[Explanation]

(1) Preparation of a topographical map

If any topographical maps with sufficient precision for the plan are already available from the basic national land survey, the cadastral survey, and the relevant land improvement projects, they can be used. If they have not been prepared yet, it is desirable to prepare them at the initial stage of the investigation. Necessary precision and the scope of the drawing are as follows.

1) Scale of drawing - The necessary scale for irrigation plans such as the scope of the project area, acreage, irrigation method, irrigation systems is in the range of 1/2,500 - 1/5,000 with the contour interval of approximately 1.0 - 2.5m.

2) Scope of drawing - Generally, the topographical map shall be prepared to cover the following area: the beneficial area which is roughly defined in the reconnaissance investigation, its peripheral areas, and areas necessary for planning for irrigation system.

2.1.2.2 Meteorological Investigation

- Weather in the project area shall be investigated by analyzing data collected over a long period at a representative meteorological station of the area.

[Explanation]

✓ As the weather is one of the basic factors of an irrigation plan, the data collected over long period (10 years or more in principle, and 20 years or more with regard to data on temperature, consecutive no-rainy days and pan evaporation, which are closely related with the irrigation plan) at the representative meteorological stations in the area shall be investigated. When the necessary data are not available in the project area, those derived from similar meteorological conditions can be used.

✓ Investigation items are classified in accordance with the type of plan as shown in **Table 2.1**. They shall be selected depending on the type of plan and need.

Table 2. 1 Investigation items for each plan

Item		Classification of Plan		
		Farming plan	Irrigation water plan	Other facilities plan
Temperature	Mean temperature	○		
	Minimum temperature	○	○	
Precipitation	Daily precipitation	○	○	
	Monthly precipitation	○	○	
	Annual precipitation	○	○	
	Maximum hourly precipitation			○
Rainy days		○	○	
Sunshine duration		○	○	
Continuous droughty days		○	○	
Snowfall period		○	○	
No-frost days		○	○	
Most frequent wind direction		○		○
Maximum wind velocity		○		○
Pan evaporation		○	○	

2.1.2.3. Soil Investigation

■ As the basic reference to the irrigation plan, the soil characteristics, the intake rate, etc. the project area shall be investigated.

[Explanation]

(1) Soil investigation

1) Investigation items - The thickness of the plow layers and effective soil layers, the soil texture, soil color, the place of gley horizon, the hard pan and its hardness and the distribution of crop roots shall be clarified.

(2) Investigation of intake rate

The intake rate is the rate for irrigation water or rainwater infiltrated into soil under the specific conditions, and generally measured in terms of mm/hr. As an index of water permeability in unsaturated soil, it is an important factor to be considered in deciding the irrigation method and the appropriate irrigation intensity for upland irrigation. The intake rate is measured either by the cylinder intake rate or by the furrow intake rate, depending on the purpose of the measurement. For furrow irrigation, the intake rate is measured by the furrow intake rate.

1) Cylinder method

Iron cylinder, placing iron plate, placing hammer, hook gage, stopwatch, water transportation tools, etc. Length of iron cylinder (height) shall be 30-50 cm, and three cylinders with diameter of 28 cm, 29 cm, and 30 cm make up one set.

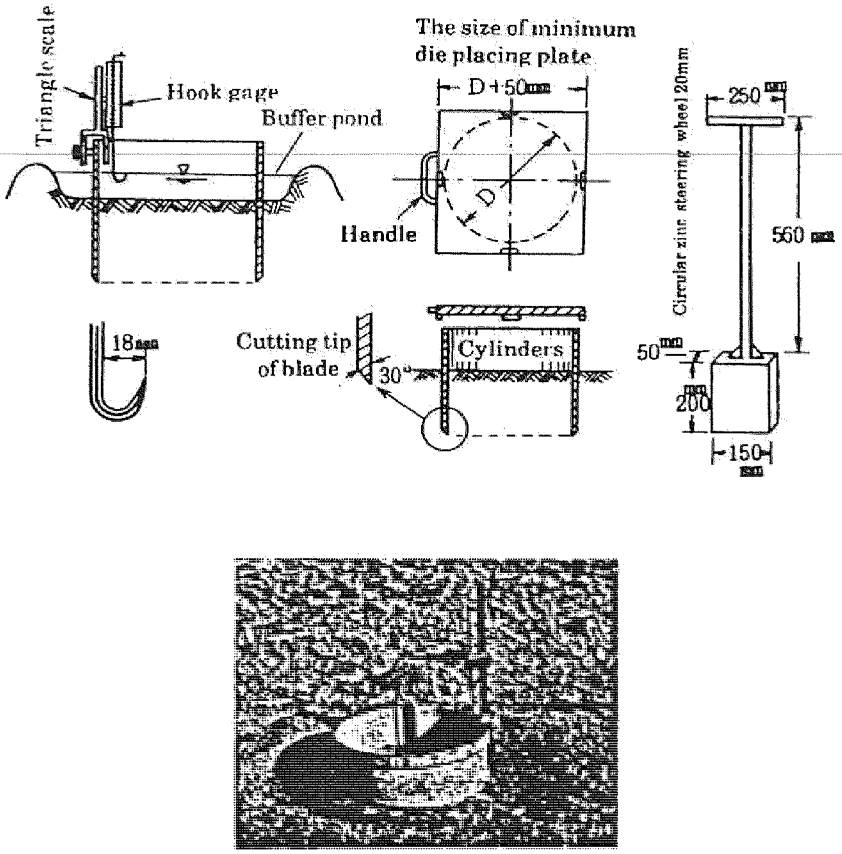


Figure 2. 2 Cylinder Method

(2) Furrow ponding method

Feed water tank, water-blocking iron plate, hook gage, stopwatch, water transportation tools shovel and

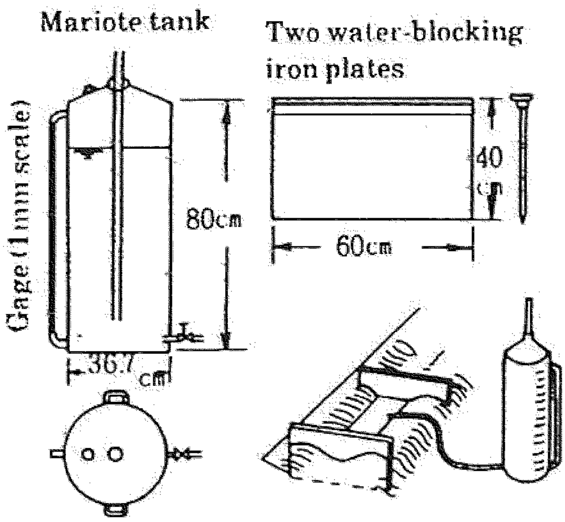


Figure 2.3 Furrow Ponding Method

3) Flow Method

Discharge gage, hook gage, stopwatch, shovel, tape measure, level, box scale, tape, stake, and water transportation tools

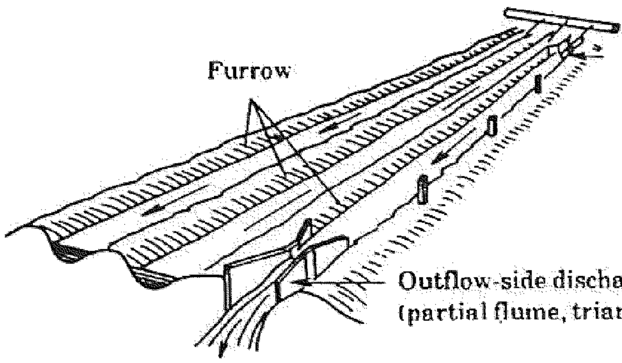


Figure. 2.4 Flow Method

2.1.2.4 Geological Investigation

■ Investigate the geology of the project area and its periphery as one of the basic data for the facilities plan.

[Explanation]

✓ Geological conditions greatly affect the suitability of the installation site and the possibility of constructing various facilities. Accordingly, it is necessary to collect existing data on the geology of the area as well as its peripheral areas, and, when necessary to conduct a site survey to understand the geological conditions.

✓ Principal items to be investigated for the site survey are as follows.

① Dam: Geological survey, geophysical prospecting, trenches, boring, adits, etc.

② Head works, pump station, and regulating reservoir: Boring, etc.

③ Tunnel: Geophysical prospecting, boring, etc.

④ Canal: Surface investigation, etc.

2.1.2.5 Investigation on Water Utilization Conditions

■ As one of the basic references for the plan, investigate the installation and the utilization conditions of the water-supply facilities and damage by drought, etc.

[Explanation]

(1) Contents of investigation on water-utilization conditions

- ✓ Investigate the irrigation area, the amount of water intake system, the scale, the capacity and the extent of water-supply facilities in the project area and its periphery. In addition, depict the location of the intake facilities, the irrigation canal and the irrigation area in the drawing for arrangement.
- ✓ Investigate the present situation of irrigation facilities for pest control, village water supply, and drinking water facilities, etc. in the area.

(2) Investigation on damages from drought

- ✓ Investigate the history of the drought in the project area over approximately the past ten years through interviews with farmers and relevant organizations and a search of existing literature in order to clarify: the weather conditions during drought (consecutive no-rain days, precipitation, etc.), the types of crops damaged, the damaged areas, the extent and the amount of the damage, the countermeasures taken by farmers, etc.

2.1.2.6 Investigation of Water Source

- ■ In order to formulate a water-source plan, investigate the amount of water, the water temperature, quantity and rights such as water rights for rivers, lakes, underground water, etc. in the project area and its peripheral areas.

[Explanation]

- ✓ Upland irrigation projects require a new water source, which greatly affects the water-supply plan, the project costs, and the operation and maintenance after the completion of the project. Accordingly, as the basic data for the formulation of the water-source plan, collect the existing data, conduct interviews with officials in the cities, towns, villages, the land improvement district, etc., while conducting survey and actual measurements on various water sources in the project area and its periphery, if necessary.

(1) Collection of existing data

In order to examine the validity of the water source in the project area and its periphery, conduct interviews and collect data on the currently used amount of water, the intake sites and methods, the amount of water at the water source, the discharge observation results, etc.

In addition, as the basic data for calculation of the discharge at the water source in the planning, collect the discharge observation data of rivers measured in the adjacent areas of the project.

(2) Examination of water volume

On the basis of the data collected in (1) above as well as the results of investigation on rights (see (4) below), and the views and information of officials and people concerned in the cities, towns, villages and land improvement districts, and the managers at the relevant water source, conduct the survey and select the expected water intake point from the water source applicable to the plan. Then, examine the amount of water, etc., and calculate the amount of applicable water.

(3) Investigation of water temperature and quality

①Water temperature

When upland irrigation is conducted for the prevention of drought, the use of underground water as a water source is rare, when it has a lower temperature than the ambient temperature in summer as this will cause cold-water damage to crops. Accordingly, the investigation of the water temperature is required only when the temperature in melted water from up above is expected to be low, for instance, mountains as a water source.

②Water quality

Investigate the water quality only when such problems at the water source are suspected. Investigation items include pH, COD, SS, DO, T-N, the electric conductivity (salinity), arsenic, and heavy metals such as zinc and copper.

(4) Investigation on rights

Investigate rights regarding water sources in the project area and its periphery. Principal investigation items are: 1) Agricultural and other water rights, 2) Fishing rights, and 3) Regulation on the environment such as nature protection. Accurately investigate their contents.

2.1.2.7 Investigation on Socio-economic Conditions

- ■ Investigate the socio-economic conditions that affect agriculture in the project area in order to clarify the future direction of agriculture in the area and utilize the results for the establishment of the most suitable plan.

[Explanation]

- ✓ Collect statistical data such as population censuses, statistics of agriculture and forestry, cities, towns, and villages to clarify the socio-economic environment surrounding the agriculture and its status, and investigate constraints on agricultural development. In addition, identify goals and strategies of agricultural development and the need for agricultural development including upland irrigation development by analyzing the regional development plan, the agricultural development plan, etc.
- ✓ Principal investigation items and their outline are described below.

(1) Investigation on geographical and economic conditions

Investigate the geographical and economic conditions surrounding the project area, such as, the present situation of land utilization, the traffic system, and the river utilization conditions to assess the suitability of the project area for upland irrigation development.

(2) Investigation of socio-economic conditions

Investigate the total population, number of households, the labor force and income structure in industries, the major economic activities in the area, the situation of conversion of farmland into non-farming use, etc. to identify the roles of agriculture in the socio-economy situation of the area.

(3) Investigation regarding regional plans

To examine the future development of agriculture in the project area, investigate the development plans, town planning, various agricultural development plans, etc. of prefectures, cities, towns, and villages in the area. The results of the investigation will be used to determine the boundaries of the beneficial area.

(4) Investigation of agricultural structure

Examine the constraints on the development of agricultural production in the area with respect to farm management, income, the marketing, water supply and farmers' consciousness of them. Examine the direction of agricultural development, the need for land improvement projects, etc. In this context, the following items should be investigated and analyzed.

① The investigation of farm production and income reveals those factors of land, labor, capital, crops produced and farming households which constitute agricultural production structure (scale, organization, capital composition, and differentiation of farmers). Also, investigate the farmers' economy and the profitability (production costs) of each crop. When the land and water-supply conditions constitute the constraints on the increasing farm productivity, examine their present conditions and the factors causing such problems.

② The investigation of marketing reveals the marketing and distribution of agricultural products focusing on the quantity and the prices of each crop for each season according to marketing and distribution channels, and offers a prospect for the demand and supply by crops as well as identification of the problems and measures.

③ The investigation of the water supply, reveals the current land and water utilization conditions and the past development process of land improvement, projects, the bodies managing the land improvement facilities, the property of water use facilities, customs of water use, and water charges to identify the constraints on agricultural development in relation to the water supply.

2.1.2.8 Investigation on Farming and Cultivation Conditions

- Identify the farming and cultivation problems and their causes to seek the improvement methods and the need for the project. In addition, investigate the present conditions of the farming and the cultivation management to enable the examination of the development courses and the establishment of the plan.

[Explanation]

✓ The main investigation items and their contents are as follows.

(1) Land utilization condition

Investigate the present patterns and recent changes in land utilization in each city, town, village, and division. In addition, examine the direction of the farming improvement and necessary counter projects taking account of various regulations on land utilization.

(2) Major crops and cultivation management systems

As basic data for future farming plans, the necessary project and the appraisal of economic effects, investigate the cropping intensity, recent changes in cropping, the cropping season and technology used for the currently cultivated major crops to identify problems of farming and cultivation techniques.

Investigation contents and method;

①Investigation of crops cultivated

a) Using statistics in the agriculture and forestry, and information from agricultural extension service, investigate the crops cultivated (summer and winter crops) and the cropping intensity in cities, towns, and villages.

b) Investigation in a) should be supplemented by field investigation at site in order to improve the precision of the investigation.

②Investigation of cropping season

Investigate the cropping calendar (sowing, transplanting, and harvesting seasons respectively) of each major crop by survey at the agricultural experimental stations, the agricultural extension service offices, at sites, etc.

③Investigation of cultivation technology

Investigate the present cultivation technology of major crops by survey at the agricultural experimental stations, the agricultural extension service offices, the land improvement districts, and at sites. Based on the investigation results from ① to ③ identify farming and cultivation technological problems, and examine their countermeasures.

(3) Yield and amount of damages

Investigate the yield of present major crops and crop losses according to factors, and the yield of such crops to be introduced by the plan. In addition, examine the causes of damage affecting the present yield, the possibility of improvement, and the necessary countermeasures, and utilize them as the basic data for formulation of the farming plan and the calculation of the project economy.

①Collect data on yields per 10acres and the amount of damages using agricultural statistics and information from Farmers' Mutual Aid Union. – as a rule, collect information on yield per 10 acres over the recent five years, and the amount of damages over the recent ten years (according to the cause) in cities, towns, and villages.

②Investigation of local yields - When the local yields, depending on the factors specific to the area, are expected to be greatly different from those given in statistical data collected in ① above, decide the yield per 10 acres based on the yield test, the site survey, etc. In this case clarify the reason for deciding the yield of 10 acres and the basis for the decision.

④ Investigation of local damage conditions - Based on the damage investigation records of cities, towns, and villages and agricultural cooperatives, conduct interviews at site to identify the areas affected by damages, the hectarage damaged, the extent of damages, the causes of the damages, etc., and draw a map of the damage ocurrence conditions.

④Problems affecting the yield by cause and necessary countermeasures - In accordance with investigation results in ①, ②, and ③ above as well as the present field and cultivating conditions, identify the causes of damage affecting the yield, the possibility of improvement - and the necessary countermeasures.

(4) Conditions of livestock breeding .

Investigate the number of livestock, number of farmers keeping livestock, breeding scale, systems, production conditions, etc. to identify present problems and examine how to improve the situation.

(5) Agricultural management conditions

Roughly classify the farming types according to management scale and the crops produced, then investigate the actual situation of agricultural management and the farmers' income from each farming type. In addition, clarify the problems of agricultural management, the direction of improvement and the measures to reduce the production costs and to increase agricultural income. This can be used as basic data for the establishment of future management plans and the examination of the burden of the project costs, etc.

2.1.2.9 Investigation of Farmers' Intentions

- ■ Investigate the farmers' intention on the future farming and the field irrigation plans

[Explanation]

- ✓ Investigation shall be conducted through local farmers, the land improvement districts, the agricultural cooperatives, the agricultural extension service offices, and city, town, and village offices.

(1) Investigation method

Interviews are most desirable. However, if it is difficult to interview a large number of sample farmers, investigate by sending out questionnaires. When selecting respondents by sampling, it is important to design the sampling method so that the samples will represent the opinions of the entire district including various areas, farm sizes, farmers' ages, etc.

(2) Investigation items

①Actual farming conditions

②Farming improvement measures

③Intentions on improvement of agricultural infrastructure

④Judgment items of the burden of the project cost

⑤Intentions on operation and management of facilities

⑥Other necessary items

2.1.2.10 Investigation of Related Projects

- ■ Investigate the contents of land improvement and other projects related with the irrigation including those existing, ongoing and under planning in the district or its peripheral areas. Also investigate areas designated for such projects.

[Explanation]

- ✓ The major related projects to be investigated and contents of the investigation are as follows.

(1) Land improvement projects

In order to establish the design and the construction plan, examine whether there are any other agricultural infrastructure development projects, including those under planning, in such fields as the improvement of main irrigation and drainage facilities for agriculture, farm road improvement, soil dressing and under-drainage managed or financed by national or prefectural governments or groups.

If there are any, investigate the features of their plan and design, the route selection, the structure, the construction year, the conditions at the time of construction, and conditions of the yearly repayment for such projects. In addition, investigate how land improvement districts, cities, towns, and villages, agricultural cooperatives and persons related with agriculture evaluate these projects by means of the analysis of the data in the plans and design specifications of these projects as well as by interviews.

(2) Other projects

①River improvement project

When there are improvement plans for rivers in the district or in the peripheral areas, investigate the route, the river width, the section, the gradient, the flood level, the ordinary water level, the riverbed level, the construction time, the unit drainage discharge, the submergence conditions in the district, how to acquire the land, etc. after the completion of the improvement work.

②Road improvement and new construction projects

When there are improvement and new construction projects of roads in the district or its peripheral areas, investigate the route, the width of the site, the structure, the construction time, how to acquire the land, etc.

③Water utilization project

When. there are dam projects for power generation and flood control etc. and industrial water projects in the district or in its peripheral areas, investigate the contents of the plan for water utilization.

(3) Designation of regional development and protection

①Development plan for agricultural promotion areas - The plan shall be integrated into the agricultural land utilization plan and the agricultural infrastructure development plan which are specified in the development plan for the agricultural promotion areas. Accordingly, it is necessary to understand thoroughly the contents of the development plan for agricultural promotion areas.

Regarding the water supply, investigate the current water requirements, the amount of water shortage, the water utilization conditions and the custom of water use in the relevant district, and the burden of maintenance costs of water supply facilities.

With reference to drainage, examine the displacement from the relevant district, the burden of management costs of drainage facilities in the district, the drainage customs, etc.

Regarding roads, investigate the location, the width, the structure, the improvement plans, etc. of roads adjacent to the district.

③Introduction of agricultural machines, facility installation projects, and other projects related with agricultural policies.

When there is an introduction plan of agricultural machines such as tractors and various harvesters, an installation plan for processing and storage facilities and collection and marketing facilities of vegetables and fruits, remote rural area development projects, a modernization plan for vegetable production and shipment, and a fruit production development plan, etc., investigate the contents of the construction and the projects.

⑤ National parks and others - Investigate the existence of the land utilization restriction areas such as national, quasi-national, prefectural and other parks, the natural environment conservation areas, and mining areas. If there are any, it is necessary to identify completely such designated areas, the contents of the restrictions, etc.

2.2 Planning and Design

2.2.1 Basic Concept and Plan

2.2.1.1 Procedure of Planning

- ■ To establish a plan, referring to a basic plan and facility planning, determine first the major factors and then the details based on the basic concept in principle. Ask for feedback, if necessary, to make the most suitable plan.

[Explanation]

- ✓ To plan, based on a basic concept, the main factors should be studied first followed by details. However, procedures depend on particular cases with a different project size or local circumstances to be implemented.
- ✓ The planner should select the most effective procedure, according to the plan's components. The standard procedure for planning is shown in **Fig. 2.5.** This procedure is largely divided into four steps: basic idea plan, basic plan, facility design plan, and plan evaluation. To start, a sufficient study should be performed in the steps of basic concept, basic plan, feasibility design plan. Finally, the plan will be evaluated and its feasibility will be judged, then the plan will be settled.
- ✓ If evaluation proves the plan to be inadequate, the procedure returns (feedback) to the first step of basic concept plan.

2.2.1.2 Basic Concept Planning[1)]

1) Basic concept

- ■ In formulating the plan, it is, necessary that the extent of the beneficial area, farming plan, irrigation plan, water-resources plan should be formulated considering various regional developments in prefecture, city, town, or village.

1) Refer to FAO Irrigation and Drainage Paper NO.24, Crop Water Management, p.67, Table33 (p.88 in translation).

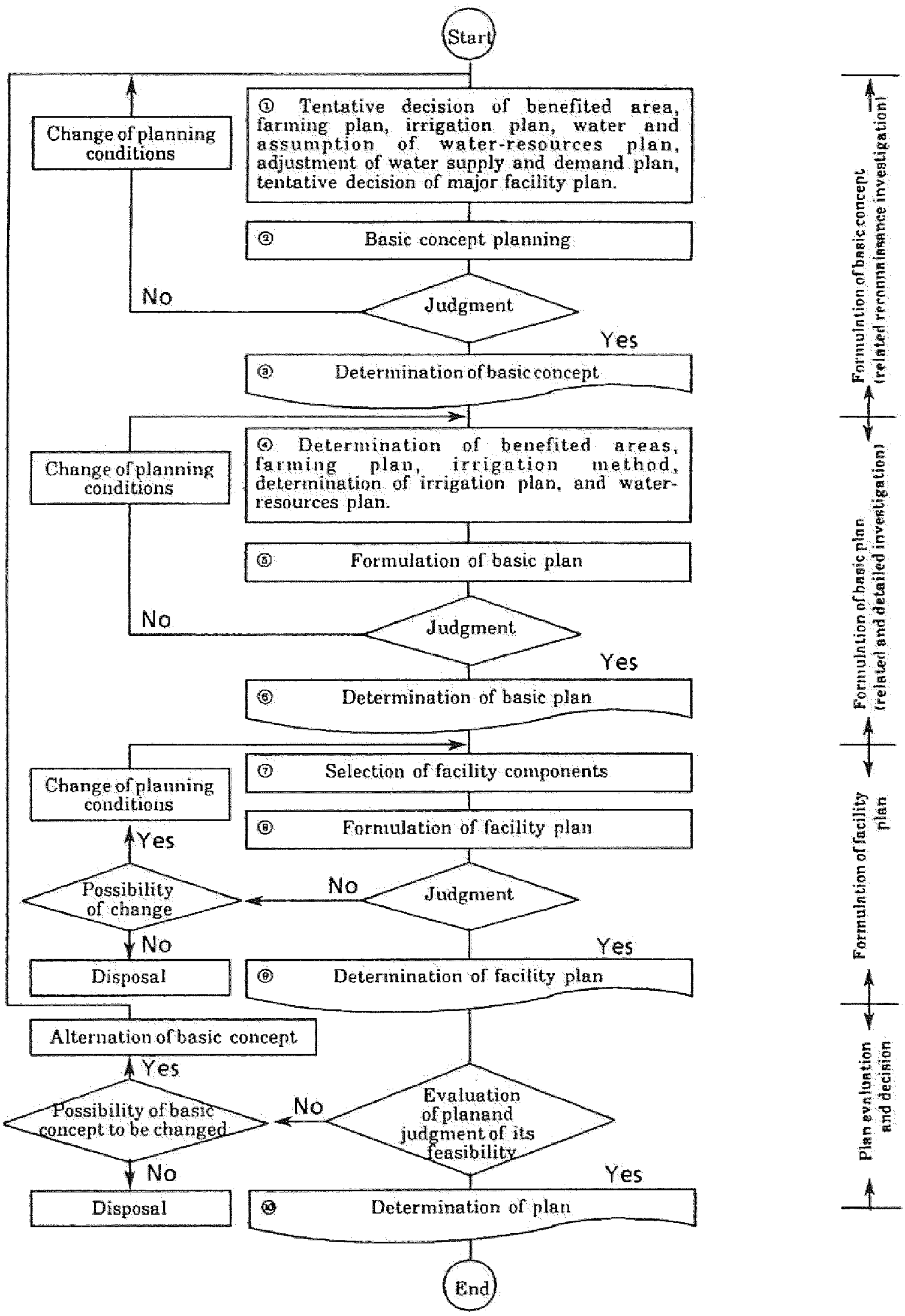


Fig2.5 Procedure of planning

[Explanation]

✓ In formulating the plan, basic items such as extents of the benefited area, a farming plan, a irrigation plan, and a water source plan should be taken into consideration to formulate a plan reasonably and effectively. It is also important to examine various development plans prepared by the prefecture, city, town or village before formulation of the basic plan.

✓ For upland irrigation, it becomes increasingly difficult to secure a new water source, and large-scale irrigation may require more than one water source. In this situation, a careful examination of the basic items mentioned above is indispensable.

2) Delineation of benefited areas

■ Delineate the benefited areas considering natural conditions, farming conditions, socio-economic conditions, smooth operation and maintenance of proposed facilities and other conditions.

[Explanation]

✓ The benefited area shall be preliminarily identified through the examination of administrative districts, the range of farmers' cooperatives, the coverage of collection and marketing facilities, investigation results of farming group expansion, various development plans, future direction of farming, and requirements of local communities, as well as natural conditions, farming conditions, socio-economic conditions, smooth operation and maintenance of proposed facilities, and other conditions.

3) Delineation of farming plan [2)]

■ Delineate a farming plan considering natural and socio-economic conditions of local communities, various regional development plans, and farmers' intentions.

D

[Explanation]

✓ A farming plan shall be a purpose or a guide for a land-use plan or individual management of farmers after the completion of the project. The plan, therefore, should guarantee an increase in the farmers' income and the improvement of their farm management, and also it should be a plan which can be implemented.

✓ In the delineation of the plan, based on the various development prepared by local governments, the prevailing farming pattern, crops introduced, cropping pattern, and farming techniques should be studied.

4) Delineation of irrigation plan[3)]

■ Delineate the required irrigation water requirements based on the proposed farming plan, climate, types of soil and water-utilization condition.

[Explanation]

✓ The necessary irrigation period, at first, is studied from a meteorological point of view by analyzing the annual rainfall and its distribution and the frequency of drought days, based on weather data obtained.

- ✓ Next, the seasonal farming program will be formulated by the proposed cropping pattern on the basis of the farming plan, and it will be classified into two groups of farming programs, one requiring irrigation and the other not, depending on the crops and the soil conditions. In this ease, the data such as drought days, soils, and the water-supply situation are referred for the crops requiring irrigation, the irrigation period, average water consumption per day of each month, the number of irrigation days and the effect of irrigation for each crop should be assessed from existing data and other local examples.
- ✓ Then the area of each crop to be irrigated and the water requirements are estimated. Under these situations, it is desirable to be able to estimate the irrigation requirements in the design year or a similar drought year.

5) Delineation of water-source plan

- ■ Estimate the available amounts of water depending on the type of water sources and location from relevant data.

[Explanation]

- ✓ Excluding the case of a small benefited area with a single affluent water source, the available water source amount shall be calculated depending on the type and the location of water sources. In this ease, it is desirable to estimate the irrigation requirements in the design year or a similar drought year. To calculate the available amount of water, existing water utilization and water in the rights downstream shall be taken into consideration.
- ✓ Moreover, the type and location of water-source facilities which are important in water-sources such as dams and headworks shall be carefully discussed with regard to the possibility of constructing the headworks from the examination of land-form and geographical conditions etc., since they will influence the basic conception of the irrigation project.

6) Study of water supply and demand program

- ■ A study of the water supply and demand shall be conducted at the stage of the basic concept plan, based on the estimated irrigation requirements and available water sources.

[Explanation]

- ✓ The relation of supply and demand which affects the formulation of a plan should be carefully examined in the stage of the basic concept plan.
- ✓ It is considered that adjustment methods when available water sources fall short include ① re-examination of the water-source plan, ② alternation of farming and irrigation plans, and ③ re-examination of the benefited areas.
- ✓ The development of upland irrigation generally has a water shortage and requires large amounts of money for water-source development; therefore, it is necessary to analyze the project economy inclusive of the project cost and benefits to be created by the project.

7) Plan of major project facility

■ Plan the location, scale, structure, and cost of facilities, water-conveyance facilities, water-distribution facilities and others.

[Explanation]

✓ Since the major facility plan is the basis of the estimation of the project cost and the analysis of the project economy, and also affects the establishment of the plan, such major facilities should be both technologically feasible and economically viable.

2.2.1.3 Preparation

1) Basic plan

■ Based on the detailed investigation, farming plans, irrigation and water-source plans will integratedly, studied and a basic plan shall be formulated in the direction of the basic concept plan.

[Explanation]

✓ The basic plan includes the determination of benefited areas, farming plans and water-source plans.

✓ The basic plan influences the facility plans and overall evaluation and benefit of the project. Therefore, the detailed investigation should be undertaken sufficiently to make the plan harmonious.

2) Determination of the benefited areas

■ Determine the benefited area properly based on the detailed investigation, It is the fundamental of the plan formulation.

[Explanation]

✓ The benefited areas, which are already delineated in the basic concept plan, are determined based on detailed investigations on the topography, geographical features, acreage, agricultural economical aspect, farmers' intentions, and related projects, with the method and scale of irrigation, and the smoothness of the irrigation facility management taken into consideration.

✓ Since the benefited area has a close relationship with the farming, irrigation and water-source plans, the balance with these factors shall be fully taken into account.

3) Determination of farming program

■ A farming plan inclusive of the cultivation period, farming method and fertilization management which will be the basic factors for making the irrigation plan will be formulated, and an improvement plan for farm management shall be prepared considering the supply and demand situation of the crop.

[Explanation]

- ✓ In the farming plan, the land-use plan applicable to the area will be determined, and the organization plan of the farmers necessary for the specific management plan and management activity of each farmer categorized into same groups in terms of the farm management scale and objectives will be prepared. The management basis such as labor force and farmland on which the plan is prepared is subject to changes, and the supply and demand and the prices of crops also fluctuate. Therefore, the farming program has to be flexible enough to cope with changes in environmental and management conditions of the regions.
- ✓ The selection of the crops to be introduced shall fully reflect the intentions of the farmers as well as regional development and program, agriculture promotion area development plans and the expected supply and demand of the crops shall be studied for reference. The crops to be introduced will satisfy the following conditions.
  - Crops which are in line with the agricultural promotion plan of the region and match the supply and demand situation.
  - Crops which are suited to natural conditions and offer economic benefits.
  - Crops whose cropping pattern is compatible with arable land and working conditionf of farmers, as well as being efficient and reasonable.
  - Crops whose cultivating method is feasible judging from the local agricultural technical level.
- ✓ A management improvement plan is prepared to set a goal or a process to improve the management with this opportunity of an irrigation project for each major farming pattern, based on the labor force, area, capital of the individual farmer. The plan will be made up in cooperation with related administrative body and beneficiaries.

To judge the economic benefit of the land improvement project and the improvement level to be realized by redemption, the plan shall contain the following items.

- Direction of farming
- Goals and processes to attain the goals about farming size, capital, technological system, and agricultural organization, for each typical farming pattern
- Cropping, working, financial, and farm household economy for each farming pattern

4) Determination of irrigation method*

■ Because the irrigation method is closely related to the wate supply at the on-farm level, and affects the cost for facilities and maintenance, the most suitable irrigation method for the area by examining its location, farming conditions, and the water-supply situation shall be decided.

** Refer to FAO Irrigation and Drainage Paper No.1, Irrigation Practice and Water Management, p.44-45, Table 14 Guide for selecting the method of Irrigation*

[Explanation]

1) Classification of irrigation methods

Irrigation methods are mainly classified into following four groups:

(1) Sprinkler irrigation:

(2) Fixed pipe irrigation: Perforation piped irrigation and Drip irrigation

(3) Surface irrigation: Furrow irrigation, Border irrigation, Contour ditch irrigation and Basin irrigation

(4) Sub-soil water irrigation:

The contour ditch and basin irrigations included in surface irrigation have rarely been performed as a land improvement project, and are not so feasible in Japan. The technology of subsoil-water irrigation has not yet established completely. As a result, these irrigation methods will not be covered in these criteria.

(1) Sprinkler irrigation method

This method sprays compressed water like rainfall on the soil using a sprinkler. Several types of sprinklers are available differing in the diameter of the spraying circle, the sprinkling type, and pressure. Generally, a surface or an underground fixed pipe is laid on the farming field, on which sprinkler heads are placed at certain intervals so that the sprinkling circles are overlapped, and even sprinkling can be expected. The method lessens the penetration and loss of supplied water into deep ground or penetration loss due to an uneven soil surface which often occurs in the surface irrigation method, but the sprinkling is easily deflected by wind. Compared with surface irrigation, it is suitable for frequent irrigation on a small scale, and requires less management.

(2) Fixed pipe irrigation methods

①Perforated pipe irrigation method

This method uses perforated pipes or hoses made of aluminum, vinyl chloride, or polyethylene, placed on the field surface. The irrigation area formed a rectangle. The method employs relatively low pressure with a large irrigation intensity. Compared with the sprinkler irrigation, the spraying distance is short, and the pipes are arranged densely.

②Drip irrigation method

This method is also known as trickle irrigation. The method irrigates from drip nozzles (emitters) or drip holes made at a certain intervals on polyethylene pipes laid on the soil surface along a line of plants. Water is slowly and frequently dripped around the roots, and is decompressed by several pressure-reducing methods. The drip nozzles have a spiral fluid path in them and the partition tube has a porous orifice in it, both of which are decompressed when compressed water in the primary side passes through. In this irrigation method, only the drip points and nearby surface areas are wet, which makes this method suitable for the smallest but frequent type of irrigation.

Features: ①An elevated soil moisture around the drip points increases the yield. ②Limited water supply only to crop roots saves water. ③High moisture around main root zone means low salinity and less damage even with salt-containing water. ④Low fluid rate in the pipe facilitates an even water supply. ⑤It is controlled with less labor force.

Generally the system operates on 1kg/cm^2 of terminal pressure, using a decompressor and a filter to prevent clogging.

(3) Surface irrigation methods

①Furrow irrigation method

The method irrigates plant roots by water permeated from the side of the furrow. Supply channels are arranged at certain intervals between the moderately sloped furrow, and cause a fixed amount of water to flow. Water is retained for the minimum necessary time to secure water depth downstream to supply sufficient water to the roots, while upstream where water is retained for an excessive time, water penetration loss to the deeper layer cannot be avoided. The irrigation efficiency is influenced by geographical features, intake rate, furrow length, and discharge amount. To make a uniform slope of a furrow, construction machinery is required. -

②Border irrigation method

The field is divided into bands by low boundary ridges, and sloped to cause water to flow as a thin laminar flow. The deep layer penetration loss and irrigation efficiency are similar to those of the furrow irrigation method. Compared with the furrow irrigation method, it requires less labor force; whereas it requires greater amount of water and as the limitation factor is the slope, land leveling over a wider area is indispensable. It is often used for irrigating pasture land.

③Contour ditch irrigation method

A ditch to introduce water is prepared with a slope of 1/1,000 along the contour line, and water is supplied from the turnout provided at the ditch. The method is applicable even on relatively irregular land, but the irrigation efficiency is low.

⑤ Basin irrigation method

According to this method, farm land will be flattened and enclosed by ridges. The irrigation water will be conveyed through irrigation canals or pipelines to irrigate the farmland intermittently.

(4) Subsoil-water irrigation method

This method involves supplying water to the subsoil and irrigating roots by capillary action and is divided into two types. The open channel method arranges water canals at certain intervals, causes water to flow, and raises the groundwater level to supply water to the roots from the bottom. The pipe method employs an underground pipe for the water supply. To use these methods, the texture of the top-soil should be such that it promotes gradual capillary action in the upper and side directions, the water permeability should be excellent, and the impermeable layer should exist in a relatively shallow zone to prevent penetration and loss of the water into deeper layers.

2) Determination of the irrigation method

The irrigation method should be the most suitable for the area, and therefore shall be determined by examining following various conditions fully such as a farming program.

- Location

Geographical conditions such as the land slope and contour line, and meteorological conditions such as soil permeability and climate conditions such as wind velocity.

- Farming conditions

Cultivated crops: Restricted factors for determining the irrigation method according to the types of crops

Cultivation method: Plant density, furrowing method, crop rotation system

Level of grouping: Grouping of crops, possibility of cooperative management, level of mechanization

Farming Size: Size of farm management area, farming program, etc.

- Water-supply circumstances

Restriction of available water resources, water requirements and irrigation efficiency, etc.

- Economy, etc.

3) Determination of irrigation plan

■ The irrigation plan is a fundamental in determining water resources and the dimension of irrigation facilities. Based on the careful studies of these factors, the basic figures requirement, multipurpose usage, and the amount of water shall be determined.

[Explanation]: For details of the irrigation plan, refer to 2.3.2 "Irrigation Plan".

(1) Determination of basic figures for estimating the water requirements

The soil moisture characteristics and moisture permeability of upland fields are investigated to determine the total readily available moisture (TRAM), daily consumptive use of water, irrigation interval days, and net amount of water to be replaced at each irrigation.

(2) Determination of water requirement

Irrigation water shall be determined based on the proposed irrigation areas and available water resources, taking into account the fundamental figures of irrigation water requirements, daily rainfall, parameters of multipurpose usage, etc.

(3) Study on Water Resources Dependency

An available water resource will be allocated to meet the estimated water requirements, and the required amount of each water-source will be studied.

4) Determination of Water-source Plan

■ Based on the irrigation plan and the detailed investigation, the type, location of facility and size of water resources shall be decided.

[Explanation]

✓ Water requirements (water-source dependency) calculated in the irrigation plan shall correspond to the allowable amount of water source in type and location. Then the discharge water balance of the source will be studied from the rainfall and river discharge to decide the design year and the size of the water-source facilities.

✓ For details of the water-source plan, refer to 2.3.2.4 Water-Source Program.

2.3 Irrigation Plan

2.3.1 Basis of Water Requirement Decision

■ Water requirements will be decided properly taking the climate of the benefited area, characteristics of soil and crops, and future direction of farming and cropping pattern into consideration.

[Explanation]

✓ To formulate the irrigation plan, the characteristics of rainfall and soil shall be examined carefully, and it is important that the water-holding capacity of the soil should be properly used to increase the ratio of effective rainfall in the water supply, and that the major dimension of the irrigation plan shall be decided.

✓ To improve the quality as well as the yield of crops, it is important to understand the characteristics of water relation for growing plants, so that the starting time of irrigation and the soil moisture need to be studied for each crop.

2.3.2 Decision of Parameters for Irrigation Plan

1) Water requirement

(1) Procedure for calculation of water requirements*

■ The water requirement for supplemental irrigation is decided based on the meteorological characteristics, soil moisture and the characteristics of the benefited area and water consumption of upland crops to be irrigated.

**Refer to "FAO Irrigation and Drainage Paper NO.24, Crop Water Management, pg. 2, Calculation Procedures "*

[Explanation]

✓ The procedure of estimating the water requirements for supplemental irrigation is shown in **Fig. 2.6.** The calculation of the water requirements shall be proceeded by the determination of the estimated daily consumption of water, irrigation intervals, and net amount of water to be replaced, and these items are important figures in the irrigation plan. These figures will be decided based on the climate, soil moisture and the characteristics in the benefited areas and characteristics consumptive use of water by crops to be irrigated.

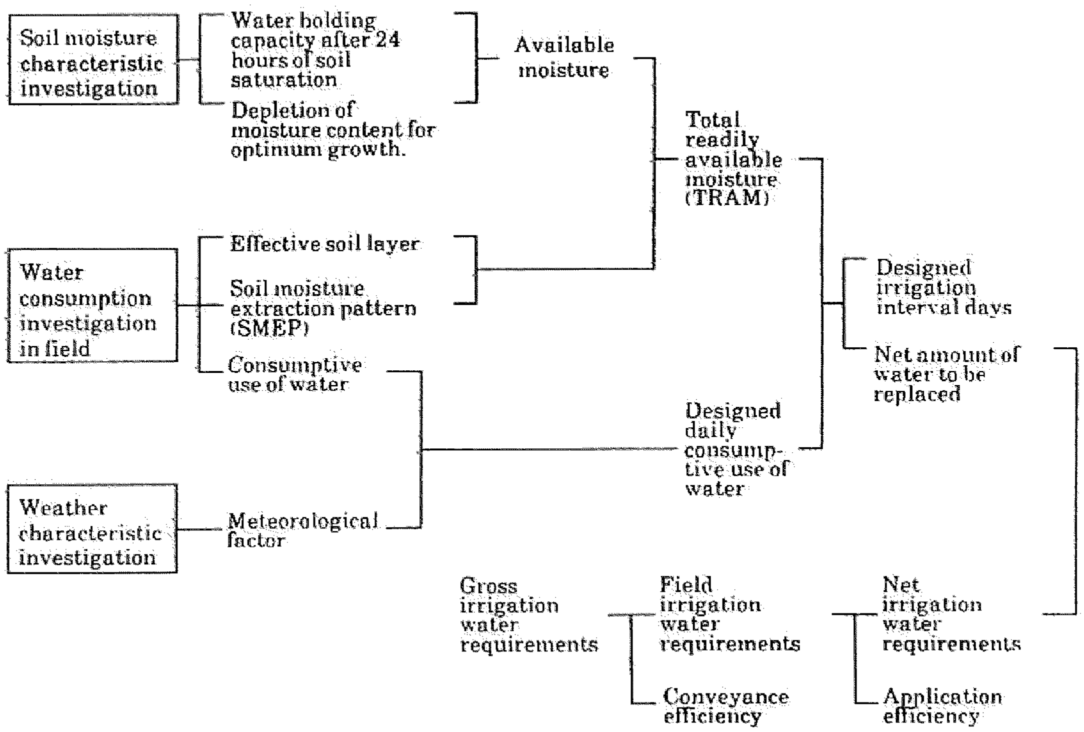


Fig2.6 Procedure of water requirement calculation

- ✓ Field irrigation water requirements and gross irrigation water are calculated based on the net amount of water to be replaced and irrigation efficiency.
- ✓ The designed daily consumptive use of water is decided from the consumptive use obtained through field investigations on crop consumptive use, and the weather characteristics.
- ✓ For details refer to the next items.

2.3.2.2 1) (2) ③Decision of moisture constants (water-holding capacity after 24 hours, depletion of moisture content for optimum growth, available moisture, effective soil layers, and SMEP)

2.3.2.2 1) (2) ④Decision of water consumption and designed daily consumption of water

2.3.2.2 1) (3) Decision of designed irrigation interval days and net amount of water to be replaced (total readily available moisture (TRAM), designed irrigation interval, and net amount of water to be replaced)

2.3.2.3. Calculation of designed water requirements (irrigation water, application irrigation efficiency, and rate of conveyance loss)

(2) Soil moisture investigation

1) Selection of investigation sites

- Points to investigate the soil moisture are selected for each major soil type based on a soil investigation. It is necessary to select crops which are planted correctly in the field under proper management.

[Explanation]

- ✓ The physical characteristics of the soil are mainly influenced by the parent material. In sloped ground, the pattern of deposition is also an important factor in the irrigation plan. Therefore, the soil investigation results must be fully examined to decide the investigation points.
- ✓ Furthermore, from the viewpoint of crops to be introduced in the plan, the fields under good management shall be selected. If investigation sites are located near to a large windbreak or a wide road, those sites shall be at least 15 meters away from such a place.

2) Measurement and display of soil moisture

- Measurement and display of soil moisture shall be decided considering the objectives of measurement and their characteristics, although there are many methods for measurement and display of soil moisture.

[Explanation]

1) Popular measurement methods are as fo1lows.

(1) Soil sampling method

The soil in the field is sampled directly, and is taken to the laboratory with care taken to protect it from any change of moisture contents, and dried at 100 to 110C° until it reaches a certain weight. The weight loss is the soil moisture. To sample the soil, it is convenient to use a soil sampler (100 cc capacity).

The sample should not be too small to prevent a large dispersion of measured values. As the size of gravel increases, the sampling amount should be increased. This method of measuring the absolute amount of the soil moisture directly is a basic measurement method to obtain correct the water consumption by the soil moisture depletion method. It is also used to verify the soil moisture by the tensiometer method and the electric resistance method.

(2) Tensiometer method

This method measures capillary tension in the soil using a pressure gage and porous medium. Generally the porous medium is a porous cup, and the pressure gage is a mercury manometer. The soil moisture is obtained from a moisture tension rating curve prepared beforehand.

The tensiometer, because of its mechanism is designed to measure up to one atmospheric pressure (pF3.0). However, as it approaches one, air enters into the measurement device causing its function to deteriorate; the operational range is up to 0.85 atmospheric pressure. It is suitable to measure relatively wet soil (pF0 - 2.8).

(3) Electric resistance method

The moisture absorber with built-in electrode is laid underground to measure the electric resistance by an ohmmeter. The prepared curve of the soil moisture and electric resistance (calibration curve) shows the soil moisture. For the absorber, a gypsum block, nylon unit, or glass filter block should be used. The glass filter block in particular allows a wide measurement range (pF 1.4 - 4.6). The gypsum block is less likely to be affected by soil salts, but is weak in water and operated on AC power.

(4) Other methods

There are many other methods such as the dielectric soil moisture meter method, the neutron moisture meter method, and the heat ray soil moisture meter method. The most suitable one for each ease should be selected in cooperation with research institutes.

5) Decision of moisture constants

- The soil sampled from investigation sites is measured in terms of the water-holding capacity after 24 hours of soil saturation, and the depletion of moisture content for optimum growth to decide effective moisture.
- The change of the soil moisture at the investigation site is measured to decide the effective soil layer, the important soil layer for growth and SMEP.

[Explanation]

(1) Soil moisture characteristic investigation

The important soil moisture characteristics in the field irrigation plan are water-holding capacity after 24 hours and depletion of moisture content for optimum growth. Both of them are measured directly from the soil sampled at the investigation sites.

(2) Investigation of moisture consumption in upland field

Changes of soil moisture at site are surveyed to decide effective soil layer, important soil layer for growth and SMEP.

① Effective soil layer and important soil layer for growth

Effective soil layer in the upland irrigation plan indicates the depth of soil in which moisture is consumed by surface evaporation or moisture absorption and capillary replenishment of crop roots after the water-holding capacity of 24 hours is attained. Here the viewpoint is different from that of soil fertility, and not necessarily about the presence of root zone. The depth where soil water changes fluctuate, if a dry period is long, the water level is deep. The general provision is decided on the basis of a period of hypothetical general continuous droughty days.

Important soil layer for growth is included in effective soil layer, and dominates moisture consumption. In other words, moisture condition in this layer directly influences the growth of crops, yield and quality. Therefore, it is the layer with the smallest total readily available moisture to be calculated from available moisture and SMEP. It can also be estimated by observing the layer section and judging the root distribution.

When soil moisture of the field can be measured, and a layer is found to decrease moisture far more than other layers' after continuous droughty days, it is an important soil layer for growth. In this layer, the soil moisture is decreased to the depletion of moisture content against optimum growth and has already stopped moisture reduction, (in most eases, down to 20cm from the surface), which indicates moisture consumption will proceed in the lower layers.

② SMEP

Moisture decrease in effective soil layer is not uniform, and generally shrinks in the lower layers. The SMEP is the ratio of moisture decrease in each layer of the whole effective soil layers and is an important element to decide the required amount of irrigation water.

SMEP naturally varies with crops, soils and growing stages, and has to be measured. It may be different with moisture conditions even with the same crops and soils.

Particularly in Japanese farmland, rootlets are dense near the surface, and effective soil layer is thin, therefore, soil moisture is consumed in a complicated manner with the direct absorption by roots and the capillary movement phenomenon in the layer.

Most important factor affecting SMEP will be the growing condition of crop roots and the water-holding characteristics. Shockley supposed SMEP is nearly uniform, and water consumption in four divided root zones is 40, 30, 20, and 10% respectively in the descending order from the surface layer. The designed SMEP should be more than the depletion of moisture content for optimum growth.

6) Decision of consumptive use and designed daily consumptive use of water

- Consumptive use of water is the amount of moisture in the effective soil layer consumable under the conditions where normal growing of crops and a high quality and gross yield are expected.
- In principle, it is decided by actual measurement and the soil moisture depletion method.
- Designed daily consumptive use of water is decided properly by consumptive use and additional meteorological factors etc.

[Explanation]

✓ To obtain the consumptive use in the effective soil layer, the soil moisture depletion method is considered as one of the most suitable methods. It is desirable to continue actual measurement all through the irrigation period. However, since it takes great labor and time, it is acceptable to measure at selected times with maximum consumptive use, and estimate the figures in the rest of the period using reliable measured data in the nearby area and the evapotranspiration ratio method, etc.

✓ The consumptive use is affected by meteorological conditions in the measurement period, and should be measured together with meteorological factors relating to rainfall and evaporation (pan evaporation, quantity of solar radiation, sunshine duration, temperature, humidity, wind speed, etc.).

✓ The daily consumptive use of water (consumption of water per day) is affected by daily meteorological factors and should be adjusted based on the following methods.

①It is problematic to decide the daily consumptive use of water only from observed values in a short period. The average of the daily consumptive use of water in a period which can be regarded identical in cultivation management level should be used.

If the designed daily consumptive use of water is thus regarded as the average in a certain period which includes cloudy and drizzly day (ineffective rainfall value in design), the value will be much more realistic.

②Even if the measured value of consumptive use is obtained from the soil moisture depletion method, the value obtained in the above item ① cannot always be used at the designed value. Meteorological factors in the measurement period and those in the designed year are to be compared to enable the addition of any correction.

For the study of ① and ②, the pan evaporation is useful. Pan evaporation represents many meteorological factors relating to evapotranspiration. Correction is easy with the actual measurement value. If the measurement value of pan evaporation in cumulative years cannot be obtained, the correlation between quantity of solar radiation, sunshine duration, temperature, humidity, and wind s peed should be analyzed statistically.

Daily consumptive use of water thus obtained in the end is called the designed daily consumptive use of water, and the maximum value in the period is the maximum designed daily consumptive use of water.

(3) Decision of designed irrigation interval days and net amount of water to be replaced

- The total moisture consumed in the effective soil layer when the average moisture in the important soil layer for growth falls from the water holding capacity after 24 hours down to the depletion of moisture content against optimum growth is called total readily available moisture (TRAM).
- The designed irrigation interval is calculated by dividing total readily available moisture by designed daily consumptive use of water.
- Net amount of water to be replaced is calculated by multiplying the designed irrigation interval days by design daily consumptive use of water.

[Explanation]

(1) Total readily available moisture (TRAM)

In calculation, total readily available moisture is obtained by dividing the available moisture in the important soil layer by the value of E MEP in that layer. This is the maximum irrigation water amount at one time in theory. Total readily available moisture= (fe - ML) ・ D × 1 /Cp (mm) (3.2.4)

Here, fe : Water holding capacity after 24 hours (volume ratio %)
ML: Depletion of moisture content against optimum growth (volume ratio %)
D: Thickness of important soil layer (mm)
Cp: SMEP in the important soil layer (%)

If important soil layer is not clear, calculate total readily available moisture for each layer and set the smallest value as designed total readily available moisture. And also, total readily available moisture can be measured by the soil moisture depletion method and others.

(2) Designed irrigation interval days

Designed irrigation interval is calculated by dividing total readily available moisture by maximum designed daily consumptive use of water with decimal points discarded. If the designed daily consumptive use of water is not for the peak irrigation interval days will not be changed only with the adjustment of irrigation water supply hours.

(3) Net amount of water to be replaced

Net amount of water to be replaced is obtained by multiplying defined irrigation interval days by designed daily consumptive use of water for each season. When maximum designed daily consumption is used instead, the result will be maximum net amount of water to be replaced.

2.3.3 Decision of designed water requirements

(1) Crop Water Requirement

In the process for estimating the irrigation water requirements, the reference crop evapo- transpiration (ETo) for upland crops could be estimated using the "CROPWAT for Windows Computer Software" [1], being popular in the agricultural development plan in Africa, which is based on the FAO Penman-Monteich Equation. On the other hand, the ETo for paddy rice could be estimated using the modified Penmam Methods. The Penman-Monteith equation is given by the following equation:

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma \dfrac{900}{T + 273} U2(es - ea)}{\Delta + \gamma(1 + 0.34u2)}$$

Where;

ETo	=	Reference evapo-transpitation (mm/day)
Rn	=	Net radiation at the crop surface (MJ/m^2per day)
G	=	Soil heat flux density (MJ/m^2per day)
T	=	Mean daily air temperature at 2 m height (℃)
U2	=	Wind speed at 2 m height (m/sec)
Es	=	Saturation vapour pressure (kpa)
Ea	=	Actual vapour pressure (kpa)
Es – ea	=	Saturation vapour pressure deficit (pka)
△	=	Slope of saturation vapor pressure curve at temperature T (kpa/℃)
γ	=	Psychometric constant (kpa/℃)

Crop water requirements (ETc/CWR) were estimated by multiplying ETo mentioned in the above by a crop coefficient (Kc), that is:

ETc = ETo x Kc

Where;

ETc/CWR	=	Crop water requirements (mm/day)
ETo	=	Reference crop evapo-transpiration (mm/day)
Kc	=	Crop coefficient

(2) Cropping Patterns

Cropping patterns are planned to calculate crop water requirements and irrigation water requirements, considering topography, water availability, soil conditions, current farming practices, marketing conditions, etc. around each areas

Sample Cropping Pattern

Cropping Pattern	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Type-1: Maize (S) + Maize (W1) + Maize(W2)	Maize (S)				Maize (W1)				Maize (W2)			
Type-2: Rice (S) + Maize (W2)			Rice (S)						Maize (W2)			

(3) Estimation of Irrigation Water Requirements

In estimating irrigation water requirements applying the "CROPWAT" equation mentioned above, following procedures and assumptions are taken into considerations;

Crop coefficient : Crop coefficients for maize and upland crop are referred to the authorized values in the computer program, while those for paddy rice are quoted from FAO Technical paper NO. 24

Effective rainfall : Upland Crops

Effective rainfall for the upland crop is counted in calculating irrigation water requirement. Following UDDA Soil Conservation Service method (USSCS) will be applied to estimate an effective rainfall;

Effective rainfall/month = monthly rainfall (R) x (125 – 0.2 x R) / 125 for R < 250 mm

Effective rainfall/month = 125 + 0.1 x R for R > 250 mm

Paddy Rice

Effective rainfall for paddy rice was estimated based on the following criteria;

10-day rainfall (R10) < 10 mm : 0 %

R10 < (N +LP) x 10 day : 100 %

R10> (N +LP) x 10 day : (N+ LP) x 10 day x100/R10

Where : N : Nursery water

LP : Land preparation water

FWS

2008/05/07 CropWat 4 Windows Ver 4.3

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Crop Water Requirements Report

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- Crop # 1 : MAIZE (Grain)
- Block # : [All blocks]
- Planting date : 21/11
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 50%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
21/11	53.96	100.00	0.30	16.19	31.54	26.68	0.00	0.00
1/12	51.18	100.00	0.30	15.35	42.47	33.55	0.00	0.00
11/12	47.89	100.00	0.33	15.95	53.05	39.05	0.00	0.00
21/12	44.23	100.00	0.54	23.65	62.54	43.10	0.00	0.00
31/12	38.51	100.00	0.76	29.27	65.95	43.61	0.00	0.00
10/1	38.14	100.00	0.99	37.62	70.60	45.61	0.00	0.00
20/1	38.02	100.00	1.18	44.77	74.28	47.65	0.00	0.00
30/1	37.74	100.00	1.20	45.28	75.71	49.02	0.00	0.00
9/2	37.31	100.00	1.20	44.78	74.24	49.22	0.00	0.00
19/2	36.79	100.00	1.20	44.15	69.58	47.77	0.00	0.00
1/3	36.22	100.00	1.16	42.20	61.79	44.32	0.00	0.00
11/3	35.64	100.00	0.96	34.05	51.33	38.70	0.00	0.00
21/3	35.12	100.00	0.72	25.35	39.06	31.06	0.00	0.00
31/3	17.39	100.00	0.55	9.51	14.69	12.17	0.00	0.00
Total	548.15			428.12	786.82	551.50	0.00	[0.00]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

****

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Calculated Crop Water Requirements (CWR)

(4) Irrigation Efficiency

- For deciding designed water requirements, water conveyance losses from water source to the field, and various water losses due to spraying in the field is added properly to the designed parameters for irrigation water requirements.

[Explanation]

(1) Water losses

Water losses are obtained from irrigation efficiency which includes application and conveyance efficiencies in the field. It is decided on the reference the values shown in **Table 2.2**

Irrigation efficiency (IE) :

Irrigation efficiency is calculated by following formula:

Ep = Ea x Eb x Ec

Irrigation efficiency Ep

Conveyance efficiency Ec: ratio of quantity of water at inlet of a block of field / intake water at source

Field canal efficiency Eb: ratio of quantity of water at field inlet / a block of field

Application efficiency Ea: ratio of quantity of water directory available to the crop / field inlet

Distribution efficiency Ed = Ec x Eb

Field efficiency Ef = Eb x Ea

Table 2.2 shows values determined by international institutes.

According to the table below, following coefficients are adopted in this study.

Ed = 0.3, Ea = 0.7

Ep = 0.7 x 0.3 = 0.21

Table2.2 Irrigation efficiency Ec, Eb, Ed, and Ea

Conveyance Efficiency (Ec)			ICID/ILRI
Continuous supply with no substantial change in flow			0.9
Rotational supply in projects of 3,000 – 7,000 ha and rotation areas of 70 – 300 ha, with efficient management			0.8
Rotational supply in large schemes (>10,000ha) and small schemes (<1,000 ha) with respective problematic communication and less effective management: Based on predetermined schedule			0.7
Based on advance request			0.65
Field Canal Efficiency (Eb)			
Blocks larger than 20 ha: unlined			0.8
lined or piped			0.9
Blocks up to 20 ha: unlined			0.7
lined or piped			0.8
Distribution efficiency (Ed = Eb x Ec)			
Average for rotational supply with management and			
Communication adequate			0.65
sufficient			0.55
insufficient			0.40
poor			0.30
Field Application Efficiency (Ea)	USDA	USSCS	
Surface methods			
Light soils	0.55		
Medium soils	0.70		
Heavy soils	0.60		
Graded border		0.60-0.75	0.53
Basin and level border		0.60-0.80	0.58
Contour ditch		0.50-0.55	
furrow		0.55-0.70	0.57
corrugation		0.50-0.70	
Subsurface		Up to 0.80	
Sprinkler, hot dry climate		0.60	
Moderate climate		0.70	
Humid and cool		0.80	0.67
Rice			0.32

ICID: International Committee of Irrigation and Drainage

ILRI: International Institute for Land Reclamation and Improvement

USDA: United States Department of Agriculture

USSCS: United States Soil Conservation Service

(5) Irrigation Water Requirements

Irrigation water requirements are classified into net irrigation water requirements and gross irrigation water requirements including water losses. They are the base for designing the capacity of irrigation facilities and are calculated by following expressions.

Net irrigation water requirements (NWR):

Net irrigation water requirements (NWR) will be calculated by deducting the effective rainfall estimated on the 10-day basis by following equation;

NWR = ETc - Re

Where;

NWR	:	Net irrigation requirements (mm/day)
ETc	:	Crop evapo-transpiration (mm/day)
Re	:	Effective rainfall (mm)

Gross irrigation water requirements (GWR):

Gross irrigation water requirements (GWR) will be calculated by taking into consideration overall irrigation efficiencies (IE). The GWR will be estimated by the following equation.

GWR= NIR/IE

Where;

GWR	:	Gross irrigation water requirements (mm/day)
NWR	:	Net irrigation water requirements (mm/day)
IE	:	Overall irrigation efficiency

(6) Irrigation Water Requirements for System Capacity

Irrigation water requirements (IWR) to plan the system capacity will be determined by taking into consideration the time of irrigation hours per day and working day per week. The following equation will be used for the determination of the IWR:

IWR = GWR x A x 10,000 /(Hr x 3,600) x 7/v

Where,

IWR	:	Irrigation water requirements for system capacity (lit./sec)
GWR	:	Gross irrigation water requirements (mm/day)
A	:	Irrigation area (ha)
Hr	:	Water supply hours per day (hrs)
V	:	Working days per week (days)

2.3.4 Water-Source Plan

1) Designed year for planning

The designed year for planning is basically a drought year which after comes around once in a decade. It should be judged based on the meteorological and rainfall records of a long period.

■

[Explanation]

To prepare an irrigation plan, the designed year for planning should be set, and the possibility of water utilization in the year is studied to prepare a plan which applicable to the water source (including expansion of water source). The designed year for planning is usually a drought year which comes around every ten years.

(1) Water from river run - off

The designed year for planning years is a drought year, coming about once in ten years (probability of 1/10 year).

(2) Other water sources

The designed year is decided from statistical processing of the consecutive drought days and effective rainfall amount during irrigation period with probability of 1/10. The decision of designed year should be based on meteorological and rainfall data of more than 20 years as a rule.

2) Effective rainfall'

- Effective rainfall is a part of rainfall in the field which is useful for the growth of crops. It is obtained from rainfall, rainfall intensity, rainfall distribution, geographical features, permeability of soil and kind of crops.

Refer to FAO irrigation and Drainage Paper NO.25 Effective Rainfall in irrigated Agriculture

[Explanation]

Rainfall less than 5mm in the field is not counted as effective rainfall. The effective rate of rainfall is about 80% when geographical features, permeability of soil, kind of crops, rainfall intensity and distribution are taken into consideration. Subtracting the available moisture of the soil just before rainfall from total readily available moisture (TRAM) is maximum effective rainfall. Maximum value is total readily available moisture. If it rains immediately after irrigation, effective rainfall is almost zero.

The upland irrigation is done intermittently according to a rotation block. Therefore, effective rainfall and irrigation requirements are calculated on the daily basis.

Effective rainfall is calculated as follows:

① Multiply rainfall (R) by 0.80.

$0.80 \times R$ (if $R < 5$ mm, $R = 0$)

② Maximum effective rainfall (Ro) is calculated by subtracting moisture (available moisture) of the field just before rainfall from total readily available moisture (TRAM).

Ro = (TRAM - available moisture just before rainfall)

③ Decision of effective rainfall '

a) If Ro $\geqq$ 0.80・R, Effective rainfall = 0.80・R

b) If Ro $\leqq$ 0.80・R, Effective rainfall = Ro

3) Water source plan

- Water source plan is to examine technical possibility of various water sources as rivers, groundwater, reservoirs, and others and to decide the most economical water source according to the irrigation method and the water requirements.

(Explanation)

Amount of available water will be obtained from data of a long period, and its statistical processing is used to secure the water source and the plan itself. As far as technology allows, many water sources should be compared and examined. To optimize water from rivers with low drought discharge, it is necessary to install a farm pond between water source and the irrigation area, and examine water source facilities about the extension of pump operation, and the reduction of the pump capacity. A pump is supposed to operate 24 hours.

To decide a water source plan, a cropping pattern and crop intensity are also examined to use water source efficiently.

In addition, in some structures of irrigation facilities and water management system, operation loss in the irrigation system is expected. Such losses should be recognized and available water source must he sufficient to cover them.

4) Whole System Plan

- Irrigation systems from the field to the water source for the upland irrigation includes on-farm irrigation, the water distribution, and the water conveyance systems.
- These three systems relates closely each other, and their harmonious connection with emphasis on economy, function and safety is desired in planning of irrigation systems.

① On-farm irrigation system

On-farm irrigation system is a general item for valves (including diversion valves) controlling a plurality of sprinkling blocks and other secondary facilities. In 2.3.4 "On-farm Irrigation System Plan", the sprinkler irrigation is mainly stated, and basic explanation will be given also about fixed pipe irrigation and surface irrigation.

② Water distribution system

Water distribution systems is a general term for a series of facilities from a farm pond to the on-farm irrigation systems.

③ Water conveyance system

Water conveyance system is a general term for a series of facilities from the water source to the water distribution system.

(2) General items

Factors in upland irrigation systems relate each other. Change of one factor will influence the whole system of the plan.

To cope with hourly fluctuation of water demand in the on-farm, the area, except for those which can obtain necessary water readily from the water source, should prepare a farm pond or a regulating reservoir facilities.

The function of each factor to be furnished is, therefore, different according to the circumstances of the area, conditions of the plan, and design conditions. Besides, each factor consists of several sub-factors. So that these factors should keep relation and harmony with the whole systems.

2.3.5 On - farm Irrigation System Plan*

2.3. 5.1. Surface Irrigation

1) Furrow irrigation

■ For furrow irrigation planning, furrow discharge, furrow length, width, and irrigation time are decided according to the intake rate, so that the root zone of the cultivated crops is included in the wet area after irrigation.

[Explanation]

1) Irrigation plan

(1) Decision of proper field discharge

In order to reduce the water depth difference in the furrow longitudinal direction, the irrigation time difference between the upper and lower streams on the field should be reduced. Proper field discharge is the volume which does not cause soil erosion. After water reaches the lower end of the field with maximum discharge, the volume of discharge should be cut in accordance with the reduction of intake rate in order to prevent overflow loss in the lower field. However, with the gradual decrease of the intake rate, which takes a long time, it is practically impossible to cut the discharge continuously. The discharge is usually cut once or twice.

The velocity in the furrow is determined by the inclination and discharge per furrow. In designing, examination of the erosion of the upper stream is made by actually supplying water to the sloped furrow and deciding the maximum discharge.

(4) Decision of furrow length and width

① Decision of furrow length

In furrow irrigation, furrow length is restricted by irrigation application efficiency, and soil maintenance. Maximum furrow length should be the length which allows water to reach without soil erosion or great deep zone loss. The larger the furrow discharge, or the smaller the intake rate, the longer the furrow becomes.

To improve labor efficiency of water distribution at one time, a longer furrow is preferable. However, there is a certain limitation in relation with the irrigation application efficiency.

Table 2.3 shows an example of maximum furrow length of different soils. The maximum furrow length of sandy soil, which has small water-holding capacity and large intake rate, is 10m or less. In terms of irrigation labor, furrow irrigation is not appropriate for sandy soil.

Table 2.3 Example of maximum furrow length of different soils

Soil	Root zone depth	One-time irrigation volume	Maximum furrow length
Sandy soil	40cm	16mm	4m
Volcanic ash soil	40cm	44mm	29m
Sandy loam	40cm	34mm	36m
Loam	40cm	38mm	99m
Clay	40cm	44mm	121m

Note: Furrow inclination is 10%.

② Decision of furrow width

In furrow irrigation, the distribution of irrigation water to the furrow crossing direction should be examined. In other words, irrigation water should enter into the furrow sides, and the furrow should be wide enough to include the root the zone in the wet area. Water distribution to the furrow of uniform soil is as shown in **Fig. 2.7.** Much of the infiltration is in the horizontal direction in clayey loam, and is in a downward direction in sandy soil. Therefore, furrow irrigation is not suitable for sandy soil, because the width cannot be wide for furrow irrigation, while the one-time irrigation volume to the section is limited due to deep zone loss prevention. In any case, in designing the one-time irrigation volume that controls deep zone loss is determined by making a part of the furrow (about 50 cm) partition to irrigate a provided volume of water to examine the mode of horizontal infiltration. When the furrow is so wide that the crop root zone is not included in the wet area, furrows should be brought close to the furrow.

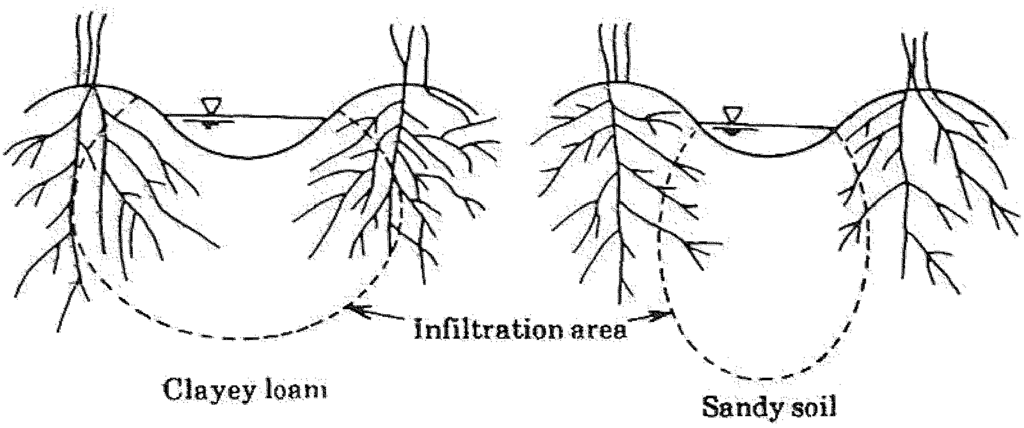


Fig.2.7 Horizontal infiltration in furrow

(5) Irrigation efficiency

One of the concepts of irrigation efficiency in the field is an application efficiency which shows how much irrigation water is held in the root zone and used for crop growth. In the case of furrow irrigation, it is designed so that the application efficiency is at least 70%.

If irrigation water introduced to furrows reaches the end in t minutes, when water at end point starts entering into the soil, infiltration has been continued for t minutes at the starting point. It shows in **Fig. 2.8**, that if it takes T minutes to obtain infiltration water depth of end D (mm), the infiltration time at the starting point is (T + t) minutes . Then infiltration water volume D' is expressed as follows:

$D' = K/\{60 \times (n+1)\} \times (T+t)^{n+1}$ (mm)

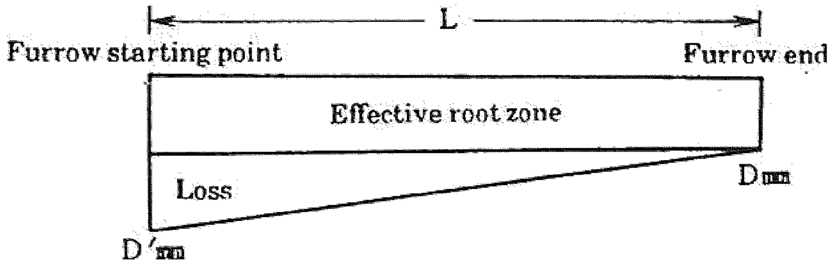


Fig.2.8 Water loss of furrow irrigation

In a rotating dry field which is flat and free from overflow loss by partitioning the field at the lower end, application efficiency Ea is calculated by the following expression.

Ea= D/{1/2 x (D'+ D)} x 100 = (200 x D) / [{K/60 x (n+ 1) } x (T+a x Lβ)$^{n+1}$ + D] (%)

The rate of water infiltration from the effective root zone into the lower stream is called deep zone loss (W_L). W_L = (1 - Ea) / 100

From the viewpoint of the actual operation of furrow irrigation, the method which allows irrigation water to reach the furrow end within T/m hours is usually employed. (t = T/m) Then m is decided by soil intake constant K, and n.

If D = [K/{60 x (n+1)}] x T^{n+1}, and K/60 (n+1) = D, then D = C x T^{n+1}

In Fig. 3.4.(10), filtration water depth after *t* minutes is D_1 at point A, or zero at point B; after 2*t* minutes, the depth is D_2 at point A, or D_1 at point B. Therefore, the distribution of infiltration water after *mt* minutes is D_m at point A, or D_{m-1} at point B ; after D_{m-1} (m+1) minutes, it is D_{m+1} at point A, or Dm at point B.

$$D_{m+1} = C\cdot\{(m + 1) \cdot t\}^{n+1} = C\cdot t^{n+1}\cdot (m+1)^{n+1}$$

$$D_m = C\cdot(m\cdot t)^{n+1} = C\cdot t^{n+1}\cdot m^{n+1}$$

Then application efficiency (Ea) is expressed as follows :

$$Ea= [D_m/\{1/2\cdot(D_m +1+ D_m)\}] \times 100 = (2\cdot m^{n+1}) / \{(m+1)^{n+1} + m^{n+1}\} \times 100$$

This expression is shown in Fig. 2.3. 4. (11).

As *m* becomes larger, discharge expands, which increases possibilities of erosion. The *m* should not be too large, 3 to 4 seems appropriate from previous experiences.

Even on sloped ordinary upland, decreasing the discharge in accordance with the decreasing intake rate could theoretically prevent overflow in the lower stream. But such an operation is difficult in reality. Clarify the overflow loss of different soil conditions from experiments, and set the water volume, with deep zone loss taken into account, for application efficiency.

2) Planning of on-farm furrow

(1) Water supply system

The size of a cross section of the furrow is decided by field discharge necessary to perform efficient irrigation. The field discharge is obtained by the discharge necessary for irrigation flow requirements within the range of a certain application efficiency, and the most labor-saving number of furrows. According to past examination, appropriate field discharge for water management is a minimum of 5-10 lit/sec, which is multiplied by the number of inlets simultaneously in a rotation block to obtain the on-farm furrow system capacity. The interval of water-supply valves is slightly different according to the soil conditions, but at least one is usually required for one field lot. When a field lot is 30 x 100 m wide with canals running along the shorter side, the intervals of turnouts are 30 m. Even in irregular-shaped orchards, the intervals should be shorter than 100 m.

(2) Furrow irrigation facilities

1) Water-distribution facilities

The water-distribution facilities for the field should be easy to operate, with little unusable land. If efficient surface irrigation is expected from maintenance and soil conditions, the possibility of utilizing open channels should be examined.

2) Border irrigation

- For border irrigation planning, a proper field discharge according to intake rate, border width and length, and irrigation duration should be determined so that the root zone of cultivated crops is in a wet area after irrigation.

[Explanation]

- ✓ Border irrigation is an irrigation method infiltrating a thin layer of water which runs the whole soil surface into lower furrows or border strips of the field peripheries. The field is divided by elongated furrows. The method requires less labor than the furrow irrigation, but large discharge. **(Fig.2.9)**
- ✓ The border irrigation is applied to 4% or less inclined land for cereals and upland rice, and to 6% or less inclined land for pasture. The peripheral furrows should be high enough to prevent irrigation water from overflowing, but should not be too high to operate agricultural machines. If the field discharge is 30 - 50 lit/sec, the furrow should be 15 cm high and 40 - 60 cm wide.

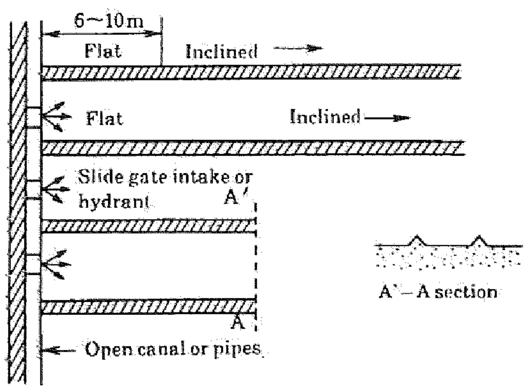


Fig.2.9 Example of border irrigation

(1) Irrigation plan

① Decision of field discharge

In designing border irrigation, the discharge volume to a block should be deliberately examined to send water uniformly to the end of the field. The field discharge is calculated by the next expression based on intake rate and water discharge tests.

$Q = (100 \times A \times I) / [(1 - 10 \times S \times h) / (\mu \times c) \}^{1/n}$

Q: Field discharge volume (lit/min)

A: Block area (a)

I: One-time irrigation water depth (mm)

μ: Uniformity index flow-toe traveling, which is 0.5 – 0.6 in sandy soil, 0.6 – 0.7 in loam, or 0.7 – 0.8 in clay

h: Irrigation depth at inlet (cm), usually 5 - 10cm

s: Coefficient experimentally obtained according to the submergency type, which is 0.6 in 1/1000 inclination and 70 – 90 lit/min. discharge (per 1m width), or 0.7 – 0.8 in zero inclination and 60 - 120 lit/ min. discharge (per 1 m width).

Integrated infiltration and water progress characteristics are expressed as follows, which is the same as the furrow irrigation.

$D = c \cdot T^n$

$t = \alpha \cdot L^\beta$

D : Integrated infiltration

'I' : Time required for infiltration (min)

L : Water progressing distance (m}

t : Time required for water head to progress (min)

c, n,α, and β: Empirical constants

The value of μ is expressed as general water progress as:

$p = 1 - \{n / (\beta+1)\}$

① Block width and length

The width of the block is determined by the size of discharge, land slope, the degree of land reclamation, and the kinds of machinery to be used. The relation between the width and land slope is shown on **Table 2.4.** The length of the block is mainly determined by the land slope and discharge. Irrigation should be determined for each field individually in order to irrigate at uniformly as possible from the upper end to the better end of the strip. Generally, more than 80% of a root zone should be irrigated at any point of a block.

Table 2.4 Peripheral width limitation of different Land slope

Land slope (%)	Peripheral width (m)

0 – 0.1	36
0.1 – 0.5	18
0.5 – 1.0	15
1.0 – 2.0	12
2.0 – 4.0	9
4.0 – 6.0	6

CHAPTER 3 DESIGN OF WEIR

Diversion weir is a structure, which diverts water from a river into a canal for irrigation use. A fixed type weir is such a structure as to secure the required water level at intake, to avoid a considerable obstacle to floods and to have a section which is safe enough against external forces. In this project, fixed type weir is applied and its components are limited to main weir, apron, riverbed protection, riverbank protection etc. On the other hand; gate facility, control facility, sluice and fish ladder have not been included in the guideline.

3.1 Construction Criteria

1) Material

Most of materials for construction work are procured locally whilst use of input from outside is minimized. Local materials include sand, stone, bricks, while cement, gabion, tools are regarded as outside materials. Local materials and outside materials are to be provided by the beneficiaries and donors respectively.

2) Labor

The construction work is done by the farmers under supervision of CEOs and TSB officers. Labor force is provided by the farmers group.

3.2 Investigation

Field investigations are carried out at and around the site as regards river conditions, effects on flood control and water use upstream and downstream, and foundation conditions. Prior to the investigations selecting necessary items for investigation, the appropriate investigation plan should be put in practice.

1) Investigation of river conditions

Investigation of river condition should be executed on (i) water level and discharge, (ii) sedimentation, (iii) stream centerline, (iv) riverbed slope, (v) riverbed materials.

(i) Water level and discharge

Highest water level and representative water level in each month are required to be obtained. Highest water level is obtained by observing past flood mark and by interviewing the villagers. Representative discharge in each month is estimated from water level, flow velocity and cross-section.

(ii) Sedimentation

River sediment is measured in order to arrange for sand removal plan. Sediment at a river structure of vicinity area can be referred.

(iii) Stream centerline

The location of the weir should be selected at a site where the stream centerline is stable and located near the riverbank where the intake is required.

(iv) Riverbed slope

Riverbed slope is an essential hydrological parameter and necessary to estimate discharge. Riverbed slope is obtained by surveying the elevation at 20m interval from 100m upstream to 100m downstream of the weir.

(v) Riverbed materials

Riverbed materials should be observed to estimate roughness coefficient. Value of roughness coefficient is shown in the **Table 3-1**.

Table 3-1 Roughness Coefficient of Natural Flow Canals

Materials and conditions of canals	Roughness Coefficient		
	Minimum	Standard	Maximum
Small canals on flat land			
1). Not weedy, straight. Neither cracks nor crevices are seen when water reaches the high water level	0.025	0.030	0.033
2) Weedy and stony. Neither cracks nor crevices are seen when water reaches the high water level	0.030	0.035	0.040
3) Not weedy but meandering. Some crevices and shallows are seen.	0.033	0.040	0.045
4) Some weeds and stones, meandering. Some abysses and shallows are seen.	0.035	0.045	0.050
5) Meandering. Some crevices and shallows are seen. The changes in gradients and cross-sections are few at low water level.	0.040	0.048	0.055
6) The same as 5) but stony.	0.045	0.050	0.060
7) Weeds and deep crevices are seen along moderate flow areas.	0.050	0.070	0.080
8) Area where weeds grow densely, deep crevices are seen, or many trees are present	0.075	0.100	0.115
Canals in mountain areas. No plants in canals. River banks are usually steep. Trees and shrubs along river banks are submerged when water reaches the high water level.			
1) Cobblestones and gravel on river bed	0.030	0.040	0.050
2) Large cobblestones on river bed	0.040	0.050	0.070
Large canals			
1) Constant cross sections without large cobblestones or shrubs	0.025		0.060
2) Rough and irregular cross sections	0.035		0.100

Source: Engineering Manual for Irrigation and Drainage Canal Works, The Japanese Institute of Irrigation and Drainage 1987.

2) Investigation on the influence of flood control and water use

The condition of drainage discharges into rivers upstream and downstream during the ordinary flow should be investigated in order to find the influence of rise of water level by weir upon drainability upstream and downstream. Flood water level and flood pond area should be investigated to decide the height of weir. Present condition of river utilization such as irrigation, hydropower, water rights, fishery and others should also be investigated.

3) Investigation on the foundations

Investigation on the foundations are executed for items such as the structure and properties of the ground, bearing capacity of the ground, conditions of riverbed deposits, ground water level and flow condition of ground water.

Investigation on the foundations should be carried out in order to design suitable foundation structures for the ground condition. Test pitting makes possible appraisal of strata and geology by the naked eye and to estimate bearing capacity. Standard allowable bearing capacity is shown in **Table 3-2**.

Table 3-2 Allowable Bearing Capacity of Foundation

Foundation		Allowable Bearing Capacity (kN/m^2)	Remarks		
			N-value	* qu (kN/m^2)	Friction Coefficient
Rock		1,000	~100		0.7
Solid Sand		500	~50		0.6
Semi consolidated silt, clay		300	~30		0.7
Conglomerate layer	Thick Not thick	600 300			0.6
Sand ground	Thick Medium thick Loose Very loose	300 { 200 { 100 50 0	30 – 50 { 20 – 30 { 10 – 20 5 – 10 ~5		0.6 0.5
Clayey ground	Very solid Solid Medium solid Soft Very soft	200 100 50 20 0	15 – 30 8 – 15 4 – 8 2 – 4 0 – 2	~250 100 – 250 50 – 100 25 – 50 ~25	0.5 0.45
Loam	Solid Rather solid Soft	150 100 50	~5 3 – 5 ~3	~150 100 – 150 ~100	

* Unconfined compression strength

Source: Technical Standard for River Works and Erosion and Sediment Control Works, Ministry of Land, Infrastructure and Transport, 1997

4) Investigation for construction works

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

(i) Meteorology, stream condition, ground water, riverbed conditions

Meteorology and stream condition should be thoroughly investigated because of their utmost importance for deciding the construction schedule based on the investigation on 10 year data of rainfall and river run off, channels, elevation of cofferdam, etc. Especially, temperature is important for work plan of concrete (mortar) works.

(ii) Construction equipment, tools, materials, transportation and labor.

Construction materials include cement, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should also be checked. Transportation of materials should be arranged if necessary. Minimum use of construction equipment is encouraged for small scale irrigation schemes. Number of skilled labor and unskilled labor should also be checked.

5) Topographical survey

Topographical survey for weirs should be done on the following items;

(i) Plane survey

Plane survey is necessary not only for construction of the weir and intake but also for the planning and design of cofferdam. Curvature conditions of the river should be surveyed. It is desirable to draw contour lines on the map.

(ii) Longitudinal and cross section

Profile and cross section of the river are used for designing weir and hydraulic calculations.

(iii) Collection of topographic and other related maps

Prior to field investigations and surveys, topographic maps and other related maps around the scheme should be collected in order to prepare the investigation schedule, and to make a preliminary design.

6) Investigation for rehabilitation of existing facilities.

In case of rehabilitation of existing weir, following items should be investigated in addition to above items.

i) Present condition of existing weir

ii) Topographical survey for rehabilitation items

Table 3-3 List of Items to be Investigated (River Diversion Weir)

Items	Description	Method	Outputs
1. River Conditions			
(i) Water level and discharge	- Highest water level	- Observation of past flood mark and interview to the villagers	HWL=
	- Representative water level and flow velocity in each month	- Observation at the river	WL=
(ii) Sedimentation	- Sediment at a structure of vicinity area	- Observation of sediment configuration.	Stones, sand or silt
(iii) Stream centerline	- Stream centerline is stable.	- Visual observation at the river	Yes or no
	- Stream centerline is located near the bank where intake is required	- Visual observation at the river	Yes or no
(iv) Riverbed slope	- Riverbed slope	- Surveying. 20m interval, from 100m upstream to 100m downstream.	Riverbed slope=
(v) Riverbed materials	- Materials and conditions of the river	- Visual observation at the river	Estimated roughness coefficient=
2. Influence of flood control and water use			
(i) Drainage discharge into the river	- Influence to the drain	- Surveying location and elevation of drain	Location=, Elevation= No influence
(ii) Flood pond area	- Flood pond area does not influence farmland, trees etc.	- Observation at the site	No influence
	- Flood water level does not exceed river bank.	- Observation at the site	No influence
(iii) River utilization	- Present utilization of the river	- Irrigation for downstream Fish pond, Others	Requirement= lit/s Requirement= lit/s
	- Water rights	-Interview to relevant party	Quantity = lit/s. Water fee= MK
3. Foundation			
(i) River bed	- Depth of bedrock, allowable bearing capacity	- Visual observation, Test pitting, visual observation Penetration test	Outcrop, Depth of bedrock= Blow number at the

(ii) Abutment	- Depth of bedrock, soil property - Ground water	- Visual observation, test pitting - Visual observation	depth= Outcrop, Depth of bedrock=, Soil property Ground water level=
4. Construction works (i) Meteorology	- Collection of all existing meteorological data	- Data collection and site observation	Annual rainfall, Stream condition, temperature, water level, Height of cofferdam
(ii) Construction equipment, materials, transportation	- Availability of materials - Number of available tools - Available transportation - Number of available labor	- Stone, Sand, Cement - Wheelbarrow, Bucket, Shovel, Pickaxe, etc. - Truck, tractor, oxcart - Skilled labor, Unskilled labor	= km from the site, = to be procured in___ = units, = pcs DAO, DA, ADD, Farmers, = number
5. Topographical survey (i) Plane survey	- Configuration of the river, centerline of the weir, location of intake, cofferdam, stockyard etc. should be indicated.	- Site surveying with measuring tape and compass. Plane table.	Plan: scale 1/100
(ii) Longitudinal and cross section	- Longitudinal section of the river. - Cross section of the river along the weir centerline. - Longitudinal section of the main canal from inflow point to intake structure. - Cross section of the main canal at the intake structure.	- Site surveying with measuring tape and level. - Site surveying with measuring tape and level. - ditto - ditto	Longitudinal section: scale 1/50 Cross section: scale 1/50 Longitudinal section: scale 1/50 Cross section: scale 1/50
(iii) Collection of topographic and other related maps.	- Available maps around the scheme	- Data collection	Various maps
6. Investigation for rehabilitation (i) Present condition of existing weir	- Dimensions of the weir - Material of the structure - Condition of material - Crack at the weir - Water leakage - Damage of the structure - Stability	- Site investigation, observation, measuring tape. - ditto - ditto - ditto - ditto - ditto - ditto	Length= m, Base width= m, Top width= m, Upstream slope= , Downstream slope= , Material is= Condition of material is good/bad Location, length and width of the crack= Location of water leakage. Quantity of water leakage= lit/min. Location, situation Stable/not stable

(ii) Topographical survey for rehabilitation items	- Sediment - Longitudinal section of the structures to be rehabilitated. - Cross section of the structures to be rehabilitated.	- ditto - ditto - Site surveying with measuring tape and compass.	Configuration and depth Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50

3.3 Construction Planning / Design

1) General Layout

River diversion work is comprised of main weir, intake, spillway, apron, riverbed protection and slope protection.

The location of the weir should be decided considering stability of structure, operation and maintenance, canal slope, canal length and elevation of beneficiary area. Intake floor must be higher than the highest elevation of beneficiary area. The shorter length of canal is economical.

The elevation of both side banks should be high enough to avoid flooding upstream. If the elevation of the bank is not high enough, may result into a flood upstream by rising water level by the weir. The height of the weir should be decided considering flood water level of upstream. General layout of gravity diversion weir type irrigation scheme is shown in **Figure 3-1**.

Raising the crest of existing weir should be decided very carefully considering flood elevation and influence to riverbed, abutment and river bank.

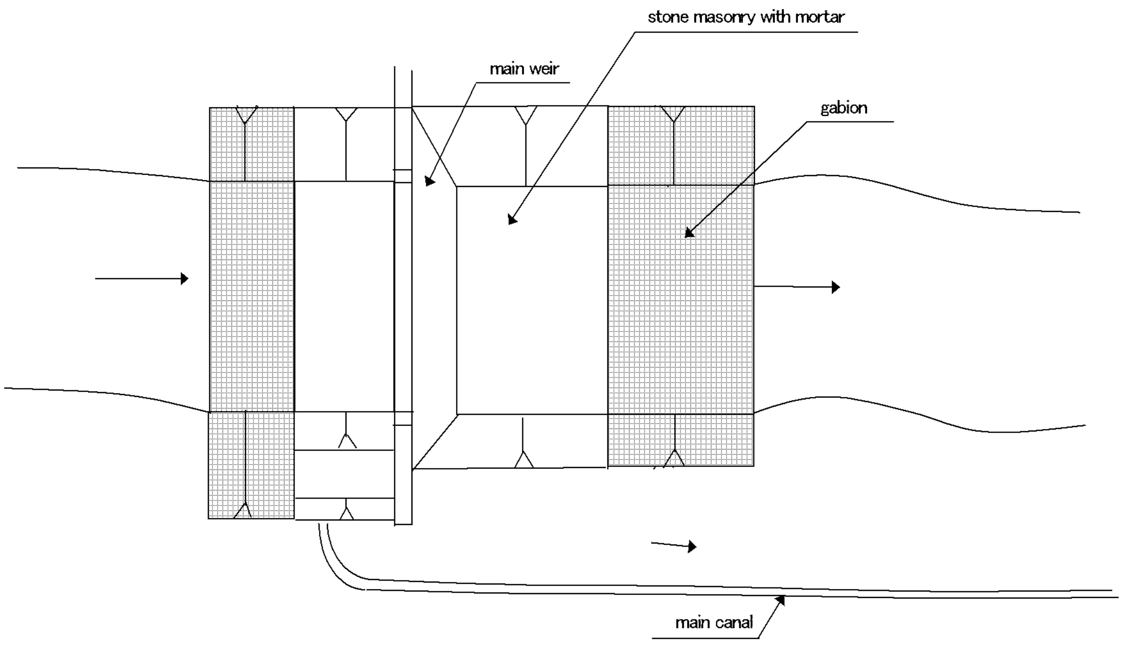


Figure 3-1 General Lay-out for Gravity Diversion Weir Type Irrigation

2) Design intake discharge and design intake water level

Design intake discharge should be the maximum intake discharge of the main canal at intake point. Design intake water level should be the water level of maximum intake discharge of the main canal at intake point.

3) Design flood discharge and design flood water level

a. Design flood discharge

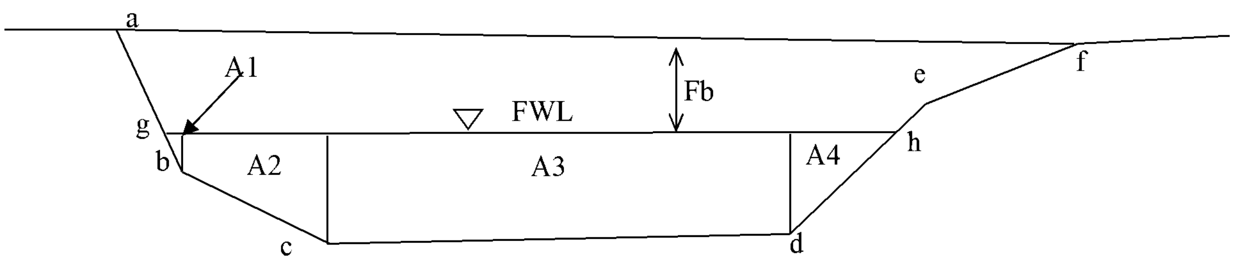


Figure 3-2 Sample Cross Section of a River

Design flood discharge should be the larger value of maximum experienced flood discharge or regional maximum flood discharge. Maximum experienced flood discharge is roughly estimated by Manning Formula. Required data and information are cross section of the river (refer to **Figure 3-2**), gradient, past maximum flood mark (elevation) and roughness coefficient.

$Q = A \times V$ (m^3/sec)
Where;
Q = Discharge (m^3/sec)
A = Flow area (m^2)
V = Flow velocity (m/sec)
$V = 1/n \times R^{2/3} \times I^{1/2}$
n = Roughness coefficient refer to **Table 3-1**
I = Gradient of the riverbed
R = Hydraulic mean depth (m)

Example
Coordinates; a(ax, ay), b(bx, by), c(cx, cy), d(dx, dy), e(ex, ey), f(fx, fy)
FWL; h (from past maximum flood mark)
$gx = ax + (bx - ax) \times (ay - h) / (ay - by)$, $gy = h$
$hx = dx + (ex - dx) \times (h - dy) / (ey - dy)$, $hy = h$
$A = A1 + A2 + A3 + A4$
$A1 = (bx - gx) \times (gy - by) / 2$
$A2 = ((h - by) + (h - cy)) \times (cx - bx) / 2$
$A3 = ((h - cy) + (h - dy)) \times (dx - cx) / 2$
$A4 = (hx - dx) \times (h - dy) / 2$
$R = A / P$ P: Wetted Perimeter
$P = \underline{gb} + \underline{bc} + \underline{cd} + \underline{dh}$
$= \sqrt{((bx - gx)^2 + (h - by)^2)} + \sqrt{((cx - bx)^2 + (by - cy)^2)} + \sqrt{((dx - cx)^2 + (dy - cy)^2)}$
$+ \sqrt{((hx - dx)^2 + (h - dy)^2)}$

Table 3-4 shows referential hydraulic analysis result of uniform flow for simple shape river.

Regional maximum flood discharge is computed from specific discharge of maximum flood discharge of another dam in neighboring districts.

$Q = A \times q$
Q = Discharge (m^3/sec)
A = Catchment area (km^2)

q = Specific discharge ($m^3/sec/km^2$)

b. Design flood water level

Design flood water level should be lower than embankment. In this guideline, difference between design flood water level and top of riverbank (Fb in **Figure 3-2**) should be more than 0.6m. If Fb is less than 0.6m, a weir should not be constructed at the location. The weir should be designed so as to have Fb more than 0.6m.

Upstream depth of the river after construction of a weir is computed with various hydraulic analyses. However, in this guideline, simplified calculations, Manning Formula should be adopted. Calculation method is the same as that of design flood discharge explained in "a. Design flood discharge". Cross section for calculation should be at the weir. Riverbed should assume as weir crest considering accumulation of sediment. Water flow area for calculation should be area (j, k, l, e, m) in **Figure 3.3**.

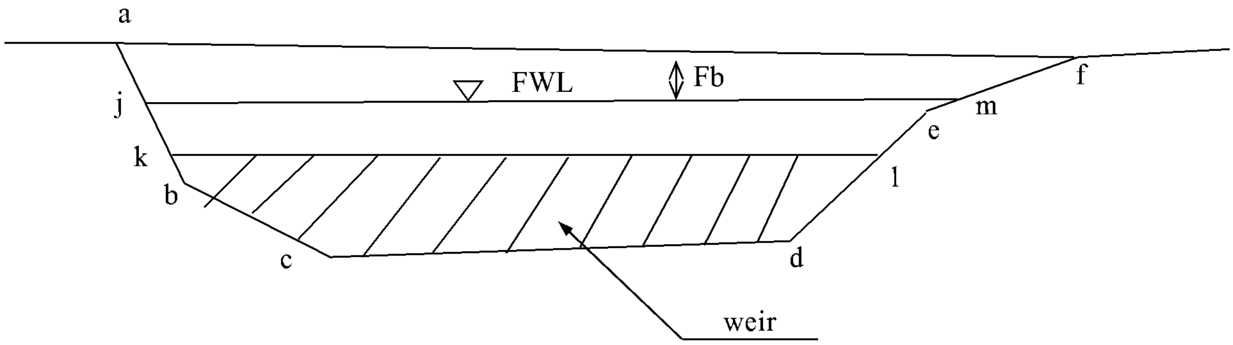


Figure 3-3 Sample Cross Section of a Weir

In case of perfect overflow at the weir, upstream depth of the weir at the design flood discharge is roughly estimated as below.

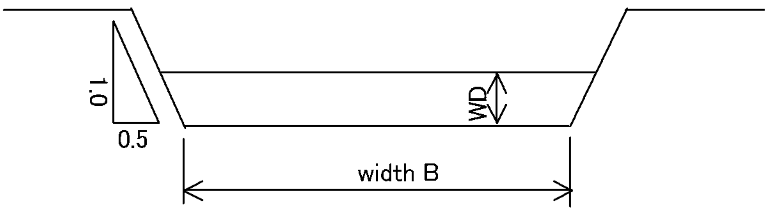
$qw = mo \times bw \times \sqrt{(2g)} \times h1^{3/2} = ko \times bw \times h1^{3/2}$ (m^3/sec)
qw = Discharge (m^3/sec)
mo, ko = Discharge coefficient, mo = 0.385, ko = 1.70 (considering a situation with sedimentation expected to accumulate on the top of the weir)
bw = Weir length (m)
g = Gravity acceleration ($9.8m/sec^2$)
h1 = Upstream head from the top of the weir (m)
$h1 = d1 + V^2 / 2g$
V = qw / A = qw / (d1 x bw)
d1 = Upstream depth

Source: Engineering Manual for Irrigation and Drainage Head Works, The Japanese Institute of Irrigation and Drainage 1989.

Table 3-5 shows referential hydraulic analysis result of perfect overflow at a weir.

Table 3-4 Referential Hydraulic Analysis Results of Uniform Flow

Assumed Cross Section of River



Roughness coefficient n = 0.045

Table Depth – Discharge B = 5.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	1.851	10.179	0.591
1.200	0.010	2.032	13.658	0.593
1.400	0.010	2.195	17.514	0.593
1.600	0.010	2.342	21.733	0.591
1.800	0.010	2.477	26.305	0.590
2.000	0.010	2.602	31.222	0.588
2.200	0.010	2.718	36.480	0.585
2.400	0.010	2.828	42.076	0.583
2.600	0.010	2.931	48.009	0.581
2.800	0.010	3.029	54.279	0.578
1.000	0.005	1.309	7.198	0.418
1.200	0.005	1.437	9.657	0.419
1.400	0.005	1.552	12.384	0.419
1.600	0.005	1.656	15.368	0.418
1.800	0.005	1.751	18.600	0.417
2.000	0.005	1.840	22.077	0.416
2.200	0.005	1.922	25.795	0.414
2.400	0.005	2.000	29.752	0.412
2.600	0.005	2.073	33.948	0.411
2.800	0.005	2.142	38.381	0.409
1.000	0.003	1.069	5.877	0.341
1.200	0.003	1.173	7.885	0.342
1.400	0.003	1.267	10.112	0.342
1.600	0.003	1.352	12.548	0.341
1.800	0.003	1.430	15.187	0.340
2.000	0.003	1.502	18.026	0.339
2.200	0.003	1.569	21.062	0.338
2.400	0.003	1.633	24.293	0.337
2.600	0.003	1.692	27.718	0.335
2.800	0.003	1.749	31.338	0.334
1.000	0.002	0.828	4.552	0.264
1.200	0.002	0.909	6.108	0.265
1.400	0.002	0.982	7.832	0.265
1.600	0.002	1.047	9.719	0.264
1.800	0.002	1.108	11.764	0.264
2.000	0.002	1.164	13.963	0.263
2.200	0.002	1.216	16.314	0.262
2.400	0.002	1.265	18.817	0.261
2.600	0.002	1.311	21.470	0.260
2.800	0.002	1.355	24.274	0.259

Table Depth - Discharge B = 10.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.007	21.071	0.641
1.200	0.010	2.227	28.321	0.649
1.400	0.010	2.426	36.346	0.655
1.600	0.010	2.610	45.097	0.659
1.800	0.010	2.780	54.536	0.662
2.000	0.010	2.938	64.635	0.664
2.200	0.010	3.086	75.370	0.665
2.400	0.010	3.226	86.720	0.665
2.600	0.010	3.358	98.670	0.665
2.800	0.010	3.484	111.206	0.665
1.000	0.005	1.419	14.899	0.453
1.200	0.005	1.574	20.026	0.459
1.400	0.005	1.716	25.700	0.463
1.600	0.005	1.845	31.888	0.466
1.800	0.005	1.966	38.563	0.468
2.000	0.005	2.078	45.704	0.469
2.200	0.005	2.182	53.295	0.470
2.400	0.005	2.281	61.320	0.470
2.600	0.005	2.375	69.770	0.471
2.800	0.005	2.464	78.634	0.470
1.000	0.003	1.159	12.165	0.370
1.200	0.003	1.286	16.351	0.375
1.400	0.003	1.401	20.984	0.378
1.600	0.003	1.507	26.037	0.381
1.800	0.003	1.605	31.487	0.382
2.000	0.003	1.696	37.317	0.383
2.200	0.003	1.782	43.515	0.384
2.400	0.003	1.863	50.068	0.384
2.600	0.003	1.939	56.967	0.384
2.800	0.003	2.011	64.205	0.384
1.000	0.002	0.897	9.423	0.287
1.200	0.002	0.996	12.666	0.290
1.400	0.002	1.085	16.254	0.293
1.600	0.002	1.167	20.168	0.295
1.800	0.002	1.243	24.389	0.296
2.000	0.002	1.314	28.906	0.297
2.200	0.002	1.380	33.706	0.297
2.400	0.002	1.443	38.782	0.298
2.600	0.002	1.502	44.126	0.298
2.800	0.002	1.558	49.733	0.297

Table Depth - Discharge B = 15.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.070	32.091	0.661
1.200	0.010	2.308	43.210	0.673
1.400	0.010	2.527	55.534	0.682
1.600	0.010	2.729	68.985	0.689
1.800	0.010	2.918	83.500	0.695
2.000	0.010	3.095	99.029	0.699
2.200	0.010	3.262	115.527	0.703
2.400	0.010	3.420	132.960	0.705
2.600	0.010	3.570	151.294	0.707
2.800	0.010	3.713	170.504	0.709
1.000	0.005	1.464	22.692	0.468
1.200	0.005	1.632	30.554	0.476
1.400	0.005	1.787	39.269	0.482
1.600	0.005	1.930	48.780	0.487
1.800	0.005	2.063	59.044	0.491
2.000	0.005	2.188	70.024	0.494
2.200	0.005	2.306	81.690	0.497
2.400	0.005	2.418	94.017	0.499
2.600	0.005	2.524	106.981	0.500
2.800	0.005	2.626	120.565	0.501
1.000	0.003	1.195	18.528	0.382
1.200	0.003	1.333	24.948	0.389
1.400	0.003	1.459	32.063	0.394
1.600	0.003	1.576	39.829	0.398
1.800	0.003	1.684	48.209	0.401
2.000	0.003	1.787	57.174	0.404
2.200	0.003	1.883	66.700	0.406
2.400	0.003	1.974	76.764	0.407
2.600	0.003	2.061	87.350	0.408
2.800	0.003	2.144	98.441	0.409
1.000	0.002	0.926	14.352	0.296
1.200	0.002	1.032	19.324	0.301
1.400	0.002	1.130	24.836	0.305
1.600	0.002	1.220	30.851	0.308
1.800	0.002	1.305	37.343	0.311
2.000	0.002	1.384	44.287	0.313
2.200	0.002	1.459	51.665	0.314
2.400	0.002	1.529	59.461	0.315
2.600	0.002	1.597	67.661	0.316
2.800	0.002	1.661	76.252	0.317

Table Depth - Discharge B = 20.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.105	43.152	0.672
1.200	0.010	2.353	58.174	0.686
1.400	0.010	2.583	74.845	0.697
1.600	0.010	2.796	93.059	0.706
1.800	0.010	2.997	112.731	0.714
2.000	0.010	3.186	133.789	0.720
2.200	0.010	3.364	156.173	0.724
2.400	0.010	3.534	179.828	0.729
2.600	0.010	3.697	204.711	0.732
2.800	0.010	3.852	230.781	0.735
1.000	0.005	1.489	30.513	0.476
1.200	0.005	1.664	41.135	0.485
1.400	0.005	1.826	52.923	0.493
1.600	0.005	1.977	65.803	0.499
1.800	0.005	2.119	79.713	0.505
2.000	0.005	2.253	94.603	0.509
2.200	0.005	2.379	110.431	0.512
2.400	0.005	2.499	127.158	0.515
2.600	0.005	2.614	144.753	0.518
2.800	0.005	2.723	163.187	0.520
1.000	0.003	1.215	24.914	0.388
1.200	0.003	1.359	33.587	0.396
1.400	0.003	1.491	43.212	0.403
1.600	0.003	1.614	53.728	0.408
1.800	0.003	1.730	65.085	0.412
2.000	0.003	1.839	77.243	0.415
2.200	0.003	1.942	90.166	0.418
2.400	0.003	2.041	103.824	0.421
2.600	0.003	2.134	118.190	0.423
2.800	0.003	2.224	133.241	0.425
1.000	0.002	0.941	19.298	0.301
1.200	0.002	1.052	26.016	0.307
1.400	0.002	1.155	33.472	0.312
1.600	0.002	1.251	41.617	0.316
1.800	0.002	1.340	50.415	0.319
2.000	0.002	1.425	59.832	0.322
2.200	0.002	1.505	69.843	0.324
2.400	0.002	1.581	80.422	0.326
2.600	0.002	1.653	91.550	0.327
2.800	0.002	1.722	103.208	0.329

Table Depth - Discharge B = 25.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.127	54.232	0.679
1.200	0.010	2.382	73.172	0.695
1.400	0.010	2.618	94.212	0.707
1.600	0.010	2.840	117.220	0.717
1.800	0.010	3.048	142.089	0.726
2.000	0.010	3.245	168.727	0.733
2.200	0.010	3.432	197.057	0.739
2.400	0.010	3.610	227.010	0.744
2.600	0.010	3.781	258.527	0.749
2.800	0.010	3.944	291.556	0.753
1.000	0.005	1.504	38.348	0.480
1.200	0.005	1.684	51.740	0.491
1.400	0.005	1.852	66.618	0.500
1.600	0.005	2.008	82.887	0.507
1.800	0.005	2.155	100.472	0.513
2.000	0.005	2.294	119.308	0.518
2.200	0.005	2.427	139.340	0.523
2.400	0.005	2.553	160.520	0.526
2.600	0.005	2.673	182.806	0.530
2.800	0.005	2.790	206.161	0.533
1.000	0.003	1.228	31.311	0.392
1.200	0.003	1.375	42.246	0.401
1.400	0.003	1.512	54.393	0.408
1.600	0.003	1.640	67.677	0.414
1.800	0.003	1.760	82.035	0.419
2.000	0.003	1.873	97.415	0.423
2.200	0.003	1.981	113.771	0.427
2.400	0.003	2.084	131.064	0.430
2.600	0.003	2.183	149.261	0.432
2.800	0.003	2.277	168.330	0.435
1.000	0.002	0.951	24.253	0.304
1.200	0.002	1.065	32.724	0.311
1.400	0.002	1.171	42.133	0.316
1.600	0.002	1.270	52.422	0.321
1.800	0.002	1.363	63.544	0.325
2.000	0.002	1.451	75.457	0.328
2.200	0.002	1.535	88.127	0.331
2.400	0.002	1.615	101.522	0.333
2.600	0.002	1.691	115.617	0.335
2.800	0.002	1.764	130.388	0.337

Table 3-5 Referential Hydraulic Analysis Results of Perfect Over-flow at a Weir

Perfect Overflow Depth at the Weir

Q	k0	bw	h1	A	V	d1
8.500	1.700	5.000	1.000	3.465	2.453	0.693
11.174	1.700	5.000	1.200	3.840	2.910	0.768
14.080	1.700	5.000	1.400	4.480	3.143	0.896
17.203	1.700	5.000	1.600	5.540	3.105	1.108
20.527	1.700	5.000	1.800	6.235	3.292	1.247
24.042	1.700	5.000	2.000	6.930	3.469	1.386
27.737	1.700	5.000	2.200	7.620	3.640	1.524
31.604	1.700	5.000	2.400	8.315	3.801	1.663
35.635	1.700	5.000	2.600	9.005	3.957	1.801
39.825	1.700	5.000	2.800	9.700	4.106	1.940
17.000	1.700	10.000	1.000	6.930	2.453	0.693
22.347	1.700	10.000	1.200	7.680	2.910	0.768
28.161	1.700	10.000	1.400	8.960	3.143	0.896
34.406	1.700	10.000	1.600	11.080	3.105	1.108
41.054	1.700	10.000	1.800	12.470	3.292	1.247
48.083	1.700	10.000	2.000	13.860	3.469	1.386
55.473	1.700	10.000	2.200	15.240	3.640	1.524
63.207	1.700	10.000	2.400	16.630	3.801	1.663
71.270	1.700	10.000	2.600	18.010	3.957	1.801
79.650	1.700	10.000	2.800	19.400	4.106	1.940
25.500	1.700	15.000	1.000	10.395	2.453	0.693
33.521	1.700	15.000	1.200	11.520	2.910	0.768
42.241	1.700	15.000	1.400	13.440	3.143	0.896
51.608	1.700	15.000	1.600	16.620	3.105	1.108
61.581	1.700	15.000	1.800	18.705	3.292	1.247
72.125	1.700	15.000	2.000	20.790	3.469	1.386
83.210	1.700	15.000	2.200	22.860	3.640	1.524
94.811	1.700	15.000	2.400	24.945	3.801	1.663
106.906	1.700	15.000	2.600	27.015	3.957	1.801
119.475	1.700	15.000	2.800	29.100	4.106	1.940
34.000	1.700	20.000	1.000	13.860	2.453	0.693
44.694	1.700	20.000	1.200	15.360	2.910	0.768
56.321	1.700	20.000	1.400	17.920	3.143	0.896
68.811	1.700	20.000	1.600	22.160	3.105	1.108
82.108	1.700	20.000	1.800	24.940	3.292	1.247
96.167	1.700	20.000	2.000	27.720	3.469	1.386
110.946	1.700	20.000	2.200	30.480	3.640	1.524
126.414	1.700	20.000	2.400	33.260	3.801	1.663
142.541	1.700	20.000	2.600	36.020	3.957	1.801
159.300	1.700	20.000	2.800	38.800	4.106	1.940
42.500	1.700	25.000	1.000	17.325	2.453	0.693
55.868	1.700	25.000	1.200	19.200	2.910	0.768
70.401	1.700	25.000	1.400	22.400	3.143	0.896
86.014	1.700	25.000	1.600	27.700	3.105	1.108
102.636	1.700	25.000	1.800	31.175	3.292	1.247
120.208	1.700	25.000	2.000	34.650	3.469	1.386
138.683	1.700	25.000	2.200	38.100	3.640	1.524
158.018	1.700	25.000	2.400	41.575	3.801	1.663
178.176	1.700	25.000	2.600	45.025	3.957	1.801
199.125	1.700	25.000	2.800	48.500	4.106	1.940

2) Main Weir

Main weir should be made of concrete or stone masonry with mortar. The foundation should have enough bearing capacity and be impervious. The sectional shape of main weir body is trapezoid, being vertical or close to vertical on the upstream face and with a gentle slope on the downstream face, giving some width on the weir crest. Where there is a flow of stones, it may be desirable to make the slope of the upstream face gentle and that on the downstream face steep as in case of debris so as to protect the weir body from damage due to falling stones. Weir should be laid on sound and stable foundation. Surface soil of riverbed such as silt or sand should be removed. Standard cross section of main weir is shown in the **Figure 3-4** and stability condition shown in **Figure 3-5**.

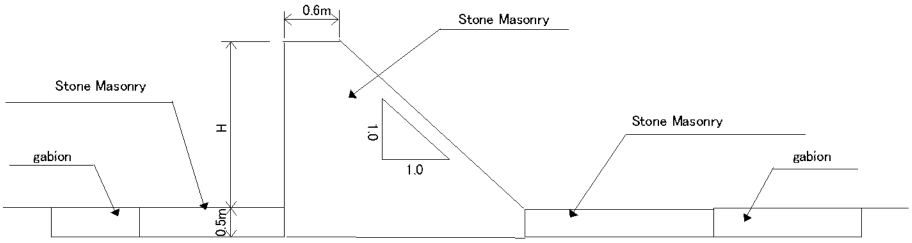


Figure 3-4 Standard Cross-Section of a Main Weir

a. Stability analysis

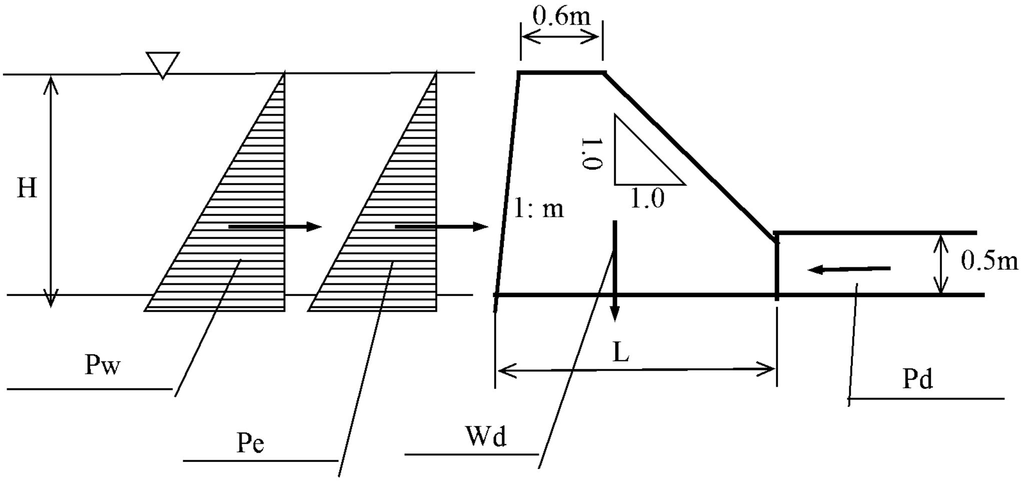


Figure 3-5 Stability Analysis Condition (Main Weir)

Pw: Hydrostatic pressure

$Pw = H^2 / 2$ (t)

Pe: Earth pressure due to sediment

$Pe = (w - wo) \times co \times H^2 / 2$ (t)

w: unit weight of deposited silt (1.8 t/m^3)

wo: unit weight of water (1.0 t/m^3)

co: coefficient of earth pressure co = 0.45

Pd: Downstream resisting pressure against sliding (in case of soil foundation)

$Pp = 0.5 \times La \times (2.3 - w0) \times \alpha$

La: length of apron (m)

α : coefficient of friction against ground (refer **Table 3-2**)

Wd: Dead weight of weir (t)

Condition of stability is;

(i) Safety against overturning

$e \leq 1/6$

$e = |\Sigma M / \Sigma V - 1/2|$

e: Eccentric distance (m)

ΣM : total of moments (t . m)

ΣV : resultant force of vertical force (t)

(ii) Safety against sliding

$Sf = \alpha \times \Sigma V / \Sigma H$

α : coefficient of friction against ground (refer **Table 3-2**)

Sf: safety factor Sf > 1.5

ΣH : resultant force of horizontal force (t)

(iii) Safety against settlement

The compressive strength at the bottom should be within the safe bearing capacity of the foundation.

$p = \Sigma V / A \times (1 \pm 6 \times e / l)$

p: compressive strength caused at both ends of the bottom (t/m^2)

A: bottom area (m^2)

Table 3-6 shows the result of sample stability analysis.

Case-1: Rock foundation, $\alpha = 0.7$, upstream slope: vertical, downstream slope 1:1.0, In case of weir height more than 4.0m, safety factor of sliding is less than 1.5. In this case, providing cut off is effective. There is no problem about safeness against overturning and safeness against settlement.

Case-2: Soil foundation, $\alpha = 0.45$, upstream slope: vertical, downstream slope 1:1.0, Even weir height is 1.0 m, safety factor of sliding is less than 1.5. In this case, providing the downstream stone masonry apron is effective.

Case-3: Soil foundation, $\alpha = 0.45$, upstream slope: vertical, downstream slope 1:1.0, with downstream sliding resistance force. In case that the weir height is more than 2.0m, required length of apron is very long.

Case-4: Soil foundation, $\alpha = 0.45$, upstream slope: 1:0.3, downstream slope 1:1.0, with downstream sliding resistance force. In case that the weir height is more than 3.0m, required length of apron is very long.

Case-5: Soil foundation $\alpha = 0.45$, upstream slope: 1:0.5, downstream slope 1:1.0, with downstream sliding resistance force. Making the upstream slope gentle, the length of apron can be reduced.

In all cases, the safety against overturning satisfies required condition. Maximum required compressive strength is about 10 t/ m^2 and it is smaller than allowable bearing capacity of solid clayey soil.

Table 3-6 Results of Sample Stability Analysis (Weir)

case-1 Stability Analysis of weir α=0.7, Foundation: Rock or semi consolidated clay

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2
1.0	1.100	0.500	0.000	0.180	2.243	1.350	0.680	0.052	0.183	2.308	2.616	1.461
1.5	1.600	1.125	0.000	0.405	4.370	3.724	1.530	0.052	0.267	1.999	3.266	2.196
2.0	2.100	2.000	0.000	0.720	7.073	7.816	2.720	0.055	0.350	1.820	3.899	2.837
2.5	2.600	3.125	0.000	1.125	10.350	14.083	4.250	0.061	0.433	1.705	4.538	3.423
3.0	3.100	4.500	0.000	1.620	14.203	22.983	6.120	0.068	0.517	1.624	5.186	3.976
3.5	3.600	6.125	0.000	2.205	18.630	34.972	8.330	0.077	0.600	1.566	5.841	4.509
4.0	4.100	8.000	0.000	2.880	23.633	50.509	10.880	0.087	0.683	1.520	6.500	5.028
4.5	4.600	10.125	0.000	3.645	29.210	70.051	13.770	0.098	0.767	1.485	7.163	5.537

case-2 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, without downstream horizontal force

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2
1.0	1.100	0.500	0.000	0.180	2.243	1.350	0.680	0.052	0.183	1.484	2.616	1.461
1.5	1.600	1.125	0.000	0.405	4.370	3.724	1.530	0.052	0.267	1.285	3.266	2.196
2.0	2.100	2.000	0.000	0.720	7.073	7.816	2.720	0.055	0.350	1.170	3.899	2.837
2.5	2.600	3.125	0.000	1.125	10.350	14.083	4.250	0.061	0.433	1.096	4.538	3.423
3.0	3.100	4.500	0.000	1.620	14.203	22.983	6.120	0.068	0.517	1.044	5.186	3.976
3.5	3.600	6.125	0.000	2.205	18.630	34.972	8.330	0.077	0.600	1.006	5.841	4.509
4.0	4.100	8.000	0.000	2.880	23.633	50.509	10.880	0.087	0.683	0.977	6.500	5.028
4.5	4.600	10.125	0.000	3.645	29.210	70.051	13.770	0.098	0.767	0.955	7.163	5.537

case-3 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, with downstream horizontal resisting force

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2	La
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2	m
1.0	1.100	0.500	0.146	0.180	2.243	1.350	0.534	0.052	0.183	1.891	2.616	1.461	0.500
1.5	1.600	1.125	0.293	0.405	4.370	3.724	1.238	0.052	0.267	1.589	3.266	2.196	1.000
2.0	2.100	2.000	0.731	0.720	7.073	7.816	1.989	0.055	0.350	1.600	3.899	2.837	2.500
2.5	2.600	3.125	1.170	1.125	10.350	14.083	3.080	0.061	0.433	1.512	4.538	3.423	4.000
3.0	3.100	4.500	1.901	1.620	14.203	22.983	4.219	0.068	0.517	1.515	5.186	3.976	6.500
3.5	3.600	6.125	2.779	2.205	18.630	34.972	5.551	0.077	0.600	1.510	5.841	4.509	9.500
4.0	4.100	8.000	3.803	2.880	23.633	50.509	7.078	0.087	0.683	1.503	6.500	5.028	13.000
4.5	4.600	10.125	5.119	3.645	29.210	70.051	8.651	0.098	0.767	1.519	7.163	5.537	17.500

case-4 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, with downstream horizontal resisting force, upstream slope 1:0.3

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2	La
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2	m
1.0	1.250	0.500	0.000	0.180	2.501	1.708	0.680	0.058	0.208	1.655	2.556	1.446	0.000
1.5	1.900	1.125	0.146	0.405	5.060	5.156	1.384	0.069	0.317	1.646	3.243	2.083	0.500
2.0	2.550	2.000	0.293	0.720	8.366	11.348	2.428	0.081	0.425	1.551	3.910	2.652	1.000
2.5	3.200	3.125	0.585	1.125	12.420	21.052	3.665	0.095	0.533	1.525	4.573	3.190	2.000
3.0	3.850	4.500	1.024	1.620	17.221	35.036	5.096	0.109	0.642	1.521	5.236	3.710	3.500
3.5	4.500	6.125	1.609	2.205	22.770	54.068	6.721	0.125	0.750	1.524	5.900	4.220	5.500
4.0	5.150	8.000	2.194	2.880	29.066	78.916	8.686	0.140	0.858	1.506	6.565	4.723	7.500
4.5	5.800	10.125	3.071	3.645	36.110	110.347	10.699	0.156	0.967	1.519	7.230	5.222	10.500

case-5 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, with downstream horizontal resisting force, upstream slope 1:0.5

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2	La
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2	m
1.0	1.350	0.500	0.000	0.180	2.674	1.994	0.680	0.071	0.225	1.769	2.605	1.357	0.000
1.5	2.100	1.125	0.000	0.405	5.520	6.436	1.530	0.116	0.350	1.624	3.500	1.757	0.000
2.0	2.850	2.000	0.000	0.720	9.229	14.738	2.720	0.172	0.475	1.527	4.410	2.066	0.000
2.5	3.600	3.125	0.146	1.125	13.800	28.075	4.104	0.234	0.600	1.569	5.331	2.336	0.500
3.0	4.350	4.500	0.293	1.620	19.234	47.624	5.828	0.301	0.725	1.564	6.258	2.585	1.000
3.5	5.100	6.125	0.439	2.205	25.530	74.561	7.891	0.371	0.850	1.542	7.188	2.824	1.500
4.0	5.850	8.000	0.585	2.880	32.689	110.063	10.295	0.442	0.975	1.515	8.121	3.055	2.000
4.5	6.600	10.125	0.878	3.645	40.710	155.305	12.893	0.515	1.100	1.525	9.055	3.281	3.000

3) Apron

To prevent scouring downstream of the weir by the overflowing water, a downstream apron is provided. The length of the apron can be obtained from following formula. (Engineering Manual for Irrigation and Drainage Head Works, The Japanese Institute of Irrigation and Drainage 1989).

$$L = 0.6 \times C \times \sqrt{H}$$

Where, L: length of downstream apron (m)

C: Bligh's C, coefficient which varies depending on the type of the foundation. **(Table 3-7)**

H: Height of the weir from downstream riverbed (m)

Table 3-7 Coefficients for Blighs' Method and Lanes' Method

Foundation	Bligh's coefficient C	Lane's coefficient C'
Silty sand or silt	18	8.5
Fine sand	15	7.0
Medium sand	-	6.0
Coarse sand	12	5.0
Gravel	-	4.0
Coarse gravel	-	3.5
Sandy gravel	9	-
Cobble stone with gravel	-	3.0
Rocks with cobble stone and gravel	-	2.5
Rocks with gravel and sand	4 – 6	-
Soft clay	-	3.0
Medium clay	-	2.0
Heavy clay	-	1.8
Hard clay	-	1.6

Table 3-8 below contains computed lengths of aprons for different weir heights and soil conditions, with C for medium clay assumed at 5.0.

Table 3-8 Required Length of Apron

	Required length of apron (m)			
Height of weir (m)	Silty sand or silt	Fine sand	Coarse sand	Medium clay
1.0	7.7	6.4	5.1	2.2
1.5	10.8	9.0	7.2	3.0
2.0	13.3	11.1	8.9	3.7
2.5	15.3	12.8	10.2	4.3
3.0	17.1	14.3	11.4	4.8
3.5	18.8	15.6	12.5	5.2
4.0	20.3	16.9	13.5	5.7
4.5	21.6	18.0	13.4	6.0

4) Riverbed Protection and Slope Protection

Riverbed protection work is provided continuously to the apron to prevent scouring. Riverbed protection work prevent scour by reducing the energy of the high velocity flow that passes the weir gradually using the resistance of riverbed protection, making the flow velocity the same as that of downstream river following the riverbed protection.

The material of riverbed protection work should be gabions or stone pitching . Recommended length of riverbed protection work should be obtained from following Bligh's formula. Slope protection of both sides should be the same length and same material as apron and riverbed protection.

$La = L - Lb$
$L = 0.67 \times C \times \sqrt{\ } (H \times q) \times f$

La: Length of apron
Lb: length of riverbed protection (m)
L: total length of protection including length of apron la (m)
H: height of the weir from downstream riverbed.
q: flow quantity per unit width of design flood discharge (m^3/sec/m)
f: safety factor, 1.5 in case of movable weir, 1.0 in case of fixed weir
C: Bligh's coefficient
Generally, q = 2.0 to 8.0 in small scale irrigation scheme.

From above 1) ~ 2), recommended dimensions of weir are shown in the **Table 3-9.**

Table 3-9 Standard Dimensions of Weir

a. Rock Foundation

Height of weir (m)	Upstream surface slope	Downstream surface slope	Length of apron (m)	Length of riverbed protection (m)	Remarks
1.0	Vertical	1:1.0	0	0	
1.5	Vertical	1:1.0	0	0	
2.0	Vertical	1:1.0	0	0	
2.5	Vertical	1:1.0	0	0	
3.0	Vertical	1:1.0	0	0	
3.5	Vertical	1:1.0	0	0	
4.0	Vertical	1:1.0	0	0	
4.5	Vertical	1:1.0	0	0	Provide cut off

b. Soil Foundation

Height of weir (m)	Upstream surface slope	Downstream surface slope	Length of apron , La (m)	Length of riverbed protection (m)	Remarks
1.0	Vertical	1:1.0	2.5	Lb	
1.5	Vertical	1:1.0	3.0	Lb	
2.0	Vertical	1:1.0	4.0	Lb	
2.5	1:0.3	1:1.0	4.5	Lb	
3.0	1:0.3	1:1.0	5.0	Lb	
3.5	1:0.3	1:1.0	5.5	Lb	
4.0	1:0.5	1:1.0	6.0	Lb	
4.5	1:0.5	1:1.0	6.0	Lb	

In case of rehabilitation of existing weir, the dimensions of the weir, apron and riverbed protection should be modified to meet above table.

5) Intake

The intake should function to make sure that intake design discharge from a river and transfer the flow to the irrigation canal. Generally discharges in rivers are subject to change and at the time of flood, huge amount of soil, sand and floating debris materials are carried by the river flow. Therefore, intake requires such as easy control of intake discharge and prevention of the materials carried from flowing into the canal. The intake is opened in the dry season and closed in the rainy season.

Intake bottom elevation should be higher than the riverbed elevation at least 0.2m to prevent soil and sand flowing into the canal.

Bottom width of intake is decided to meet to required discharge capacity. **Table 3.10** is sample of capacity of intake.

Table 3.10 Main Canal Hydraulic Analysis

Bottom Width = 1.0m, I = 0.002, n = 0.025							
Q (m^3/s)	V (m/s)	A (m^2)	P (m)	R (m)	Water Depth (m)	Freeboard (m)	Canal Height (m)
0.200	0.6109	0.327	1.640	0.200	0.2864	0.114	0.400
0.225	0.6330	0.355	1.689	0.210	0.3080	0.192	0.500
0.250	0.6532	0.383	1.735	0.221	0.3288	0.171	0.500
0.275	0.6717	0.409	1.780	0.230	0.3487	0.151	0.500
0.300	0.6889	0.436	1.823	0.239	0.3679	0.132	0.500
0.325	0.7049	0.461	1.864	0.247	0.3864	0.114	0.500
0.350	0.7199	0.486	1.904	0.255	0.4044	0.196	0.600
0.375	0.7341	0.511	1.943	0.263	0.4219	0.178	0.600
0.400	0.7475	0.535	1.981	0.270	0.4389	0.161	0.600
0.450	0.7723	0.583	2.055	0.284	0.4716	0.128	0.600
0.500	0.7948	0.629	2.124	0.296	0.5027	0.197	0.700

- Slope of side wall shall be 1 : 0.5
- Slope of intake canal (hydraulic gradient) : 1/500
- Thickness of stone masonry lining : minimum 20cm
- Width of top of intake : minimum 60cm

CHAPTER 4 DESIGN OF CANALS AND STRUCTURES

Main canal conveys the diverted water from the intake point to the farming land. An associated problem with main canal is how to align structures according to the topographic condition without using sophisticated survey equipment. Construction, on the other hand, is not so difficult since most of the work required could be done with simple tools such as hoe, shovel, etc.

4.1 Construction Criteria

1) Material

Most of materials for small irrigation schemes should be locally sourced with minimum use of outside materials. Local materials include; sand, stone, bricks, soil etc. and cement, pipes and tools are inputs from outside.

2) Labor

The rehabilitation work should be done by the farmers under supervision of CEOs and TSB officers. Labor force should be provided by the farmers association. Only transportation for materials (if necessary) should be provided from outside.

4.2 Investigation

Field investigations should be carried out at and around the site on necessary items for design, construction, rehabilitation and O&M. Prior to the investigations selecting necessary items for investigation, the appropriate investigation plan should be put in practice. The results of investigation are essential for design of canal system.

1) Meteorological and hydrological investigations

Meteorological and hydrological conditions of the site should be investigated through data collection and observation. Items for meteorological and hydrological investigation include temperature, precipitation, evaporation, wind direction, wind velocity.

2) Soil and geological investigation

Soil tests of geological investigations, including the collection of geological data reconnaissance are important to be carried out along the proposed canal route to understand the geological structure, the physical properties of the soil, the ground water table and other conditions.

3) Topographic investigations

Topography of the site and surrounding area should be clarified through data collection and topographic survey. Topographic investigations are important to determine the alignment of canals and location of gully crossing and road crossing.

i) Plane survey
Plane survey is necessary for design of facilities and planning of construction. The location and route of canals, gully and road should be indicated. It is desirable to draw contour lines on the map.

ii) Longitudinal and cross section
Profile and cross section of the canal are used for determining canal alignment.

iii) Collection of topographic and other related maps
Prior to field investigations and surveys, topographic maps and other related maps around the scheme should be collected in order to prepare the investigation schedule, and to make a preliminary design.

4) Investigation for construction works

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

i) Meteorology, surface water, ground water
Meteorology and surface water should be thoroughly investigated because of their utmost importance for deciding the construction schedule. Especially, temperature is important for work plan of concrete (mortar) works.

ii) Construction equipment and materials
Construction materials include cement, soil, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should be checked. Transportation of materials should be arranged if necessary.

5) Investigation for rehabilitation of existing facilities

In case of rehabilitation of existing facility, following items should be investigated in addition to above items. (Refer to the **Table 4-1**)

i) Present condition of existing facilities
ii) Topographical survey for rehabilitation items
iii) Data on water use management of existing facilities.
iv) Operation and maintenance system of existing facilities

Table 4-1 List of Items to be Investigated (Main and Secondary Canal)

Items	Description	Method	Outputs
1.Meteorological and hydrological investigations	- Collection of meteorological and hydrological data	- Data collection and site observation	- Annual rainfall, temperature, wind direction, wind velocity,etc.
2. Soil and geological investigation (i) Geological data (ii) Surface geological survey	- Collection of existing geological data - To grasp the condition of the field	- Data collection - Site surveying, observation	Topographic map, aerial photographs, geological map, soil texture, soil map Ground water table = Soil character, unstable topography, gully
3. Topographic investigations (i) Plane survey (ii) Longitudinal and cross section (iii) Collection of topographic and other related maps.	- Land topography, boundaries, existing structures, location of gully, location of road - Longitudinal section of canal center line - Cross section of canal center line - Available maps around the scheme	- Site surveying with measuring tape and compass. Plane table - Site survey with tape and level - ditto - Data collection	Plan: scale 1/1000~1/2000 Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50 Various maps
4. Construction works (i) Meteorology (ii) Construction	- Collection of all existing meteorological data - Availability of materials	- Data collection and site observation - Sand, Bricks,	Annual rainfall, Stream condition, temperature, water level = km from the site, = to be

equipment, materials, transportation	- Number of available tools - Available transportation - Number of available labor	Cement - Wheelbarrow, Bucket, Shovel - Truck, tractor, oxcart - Skilled labor, Unskilled labor	procured in___ = units, = pcs DAO, DA, ADD, Farmers = number
5. Rehabilitation of existing facilities (i) Present condition of existing facilities	-Dimensions of existing structures - Cracks - Damage of structures - Water leakage - Freeboard - Water flow condition - Function, capacity of canals - Sediment - Safety	- Site investigation, observation, measuring tape. - ditto - ditto - ditto - ditto - ditto - ditto - ditto - ditto	Length= m, width = m Depth= m, Elevation Location, length, width Location, situation Location, quantity = lit/min Fb= m Stable or not Enough or not Configuration and depth Good or bad
(ii) Topographical survey for rehabilitation items	- Longitudinal section of the structures to be rehabilitated. - Cross section of the structures to be rehabilitated.	- Site surveying with measuring tape and compass. Plane table.	Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50
(iii) Investigation on water use management of existing canals (iv) Operation and maintenance system of existing canals	- Discharge - Irrigation schedule - Water flow depth - Operation and maintenance	- Daily operation record - Operation and maintenance record	Daily discharge for the canal. Depth = Operation and maintenance record.

4.3 Construction Planning/Design

1) Canal Alignment

Recommended way of canal alignment is to use line level. Interval of the two poles should preferably be 5 meter, and one side of the tied points should be 0.5 – 1 cm higher than the other. Pole with higher tied point should always be placed foreside, not like conventional alternate placing. 0.5 cm difference in 5 meter gives 1:1000 gradient suitable for gentle topography, and 1 cm gives 1:500 gradient adaptable for sloped topography. **Figure 4-1** shows the process of canal alignment.

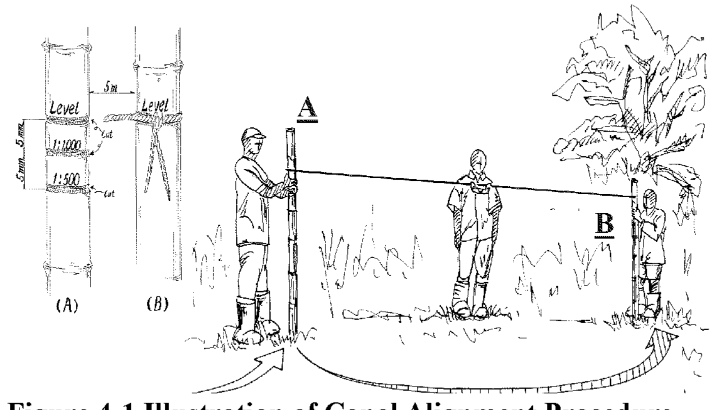


Figure 4-1 Illustration of Canal Alignment Procedure

2) Canal Lining

Canal is categorized into two; either non-lining or lined. Lining is made of brick or stone masonry (concrete lining is sometimes seen but the cost beyond farmers' affordability excludes this option).

Earth canal is the most simple and economical. With simple tools such as hoe, hand shovel, and wheelbarrow, construction is very easy and cheap. However, since this is non-lining, water conveyance loss is high due to seepage/leakage and much maintenance works such as grass cutting, de-silting, reshaping of cross section and so on are needed in every season.

Lining can be done with clay soil, plastic paper, stone, brick, or masonry. These canals reduce the canal conveyance loss and also minimize maintenance works as compared to earth canal. In particular, reducing the canal conveyance loss becomes very important when diversion water is not enough to cover all the prospective service area. Lining can also prevent the canal from being eroded, which in turn minimizes the maintenance work and makes canal life longer.

Investment for lining, on the other hand, is higher than earth canal except for clay, stone and recycled plastic paper linings. Farmers in rural area make bricks by themselves. Therefore, brick lining is cheaper than stone masonry, and damaged parts or bricks can easily be replaced by the farmers. Stone masonry lining is more durable than brick, but requires much cement, which may go beyond the farmers' affordability.

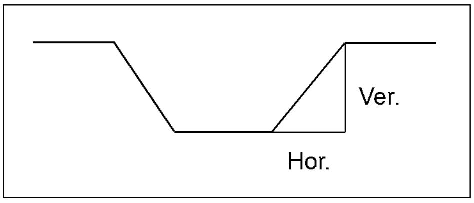
3) Canal Design

i) Cross-section and side-slopes

For earth canals, standard trapezoidal shape is commonly used. Required slope depends on the stability of the soil. Recommendable side slopes for different soils are given in **Table 4-2** below:

Table 4-2 Recommended Side Slopes for Different Types of Soils

Type of Soils	Recommendable Side Slope (Ver.) : (Hor.)
Clay	2 : 1
All other soils	2 : 1
Sand	1 : 1



Generally, rectangular cross section requires less excavation and less quantity of bricks. Considering safety of structure, it is recommendable to adopt trapezoid cross section. However, rectangular cross section may be adopted in case that the depth is less than 0.6 m, due to small soil pressure.

ii) Freeboard

Freeboard acts as a reserve depth in a canal to allow some variations in water flow. The freeboard is decided according to the planned discharge; more discharge, higher free board and less discharge, smaller free board. Irrigation schemes undertaken in this Guideline are small-scale, therefore a minimum 10 cm to maximum of about 20 cm freeboard is recommended.

iii) Allowable flow velocity

The design velocity of canals must be determined within the limits of two factors; namely, 1) the minimum allowable velocity that causes neither accumulation of sediment of soils nor growth of waterweeds, and 2) the maximum allowable velocity that does not produce erosion of canal materials by the flow. Refer **Table 4-3** for Maximum allowable velocities of different types of canals.

The minimum allowable velocity: 0.45 – 0.90 m/sec

Within this range of mean velocity, soil sediments are not accumulated in a canal where the particle size of suspended sediment is not larger than silt. Waterweeds hindering the flow capacity of the canal do not grow when the mean velocity is more than 0.7 m/sec.

Table 4-3 Maximum Allowable Velocity

Type of Canal Material	Maximum Allowable Velocity, (m/s)	Type of Canal Material	Maximum Allowable Velocity, (m/s)
Sandy soil	0.4 - 0.6	Thin concrete (approx.10cm)	1.5 - 2.5
Sand-loam	0.5 - 0.7		
Clay-loam	0.6 - 0.9	Brick masonry with mortar filled	2.50
Clay	0.9 - 1.5		
Rock	1.0 - 2.0		

Table 4-4 Value of Roughness Coefficient

Materials and conditions of canals	Roughness Coefficient		
	Minimum value	Standard value	Maximum value
Concrete (cast-in-place flume, culvert, etc.)	0.012	0.015	0.016
Concrete (shotcrete)	0.016	0.019	0.023
Concrete (with precast flume, pipe, etc.)	0.012	0.014	0.016
Concrete (reinforced concrete pipe)	0.011	0.013	0.014
Concrete block masonry	0.014	0.016	0.017
Cement (mortar)	0.011	0.013	0.015
Asbestos cement pipe	0.011	0.013	0.014
Steel (locked bar or welded)	0.010	0.012	0.014
Steel (revet)	0.013	0.016	0.017
Smooth steel surface (not painted)	0.011	0.012	0.014
Smooth steel surface and pipe (painted)	0.012	0.013	0.017
Corrugated surface (steel sheet)	0.021	0.025	0.030
Cast iron (not painted)	0.011	0.014	0.016
Cast iron sheet and pipe (painted)	0.010	0.013	0.014
Chloride vinyl pipe		0.012	
Reinforced plastic		0.012	
Ceramic pipe	0.011	0.014	0.017
Earth lining		0.025	
Asphalt (smooth surface)		0.014	
Asphalt (rough stone)		0.017	
Masonry (rough stone wet masonry)	0.017	0.025	0.030
Masonry (rough stone dry masonry)	0.023	0.032	0.035
Wood (wooden gutter)	0.010	0.012	0.014
Wood (lined in thin layer, treated with creosote)	0.015	0.017	0.020
Rock tunnel with no lining on overall cross-sectional area	0.030	0.035	0.040
Rock tunnel with no lining except concrete placed on the bottom	0.020	0.025	0.030
Vegetation coverage (turfing)	0.030	0.04	0.050

Source: Engineering Manual for Irrigation and Drainage Canal Works, The Japanese Institute of Irrigation and Drainage 1987.

4) Canal slope (earth)

Steep canal slope creates erosion due to its high flow velocity through it. On the other hand, too gentle slope cause heavy silting in the canal and also enlarges canal section to accommodate the required flow. Canal slope depends on the difference between the elevation at intake and farmland. If the slope is too steep and the water velocity is too high, the slope should be made gentler by setting a drop. If the slope can not be made steeper, frequent maintenance of de-silting should be required.

5) Canal dimension

The minimum canal bed width should be 0.30m considering maintenance work.

The recommended canal dimension; bottom width, water depth and total depth (= water depth + freeboard) for different design discharges and canal slopes and are presented in **Table 4-5** below:

Table 4-5 Recommended Canal Dimension for Various Discharges

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
5	0.30	0.05	0 : 1	0.148	0.113	0.111	0.30
5	0.25	0.10	0 : 1	0.137	0.146	0.111	0.25
5	0.25	0.20	0 : 1	0.105	0.190	0.109	0.25
5	0.25	0.25	0 : 1	0.097	0.206	0.109	0.25
5	0.25	0.33	0 : 1	0.088	0.228	0.109	0.25
5	0.25	0.50	0 : 1	0.076	0.264	0.109	0.20
5	0.25	1.00	0 : 1	0.060	0.336	0.110	0.20

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
5	0.25	0.05	2 : 1	0.135	0.116	0.110	0.25
5	0.25	0.10	2 : 1	0.110	0.150	0.109	0.25
5	0.25	0.20	2 : 1	0.089	0.192	0.108	0.25
5	0.25	0.25	2 : 1	0.083	0.208	0.108	0.20
5	0.25	0.33	2 : 1	0.076	0.230	0.108	0.20
5	0.25	0.50	2 : 1	0.067	0.264	0.108	0.20
5	0.25	1.00	2 : 1	0.054	0.336	0.110	0.20

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
10	0.35	0.05	0 : 1	0.213	0.134	0.116	0.35
10	0.35	0.10	0 : 1	0.164	0.174	0.113	0.30
10	0.30	0.20	0 : 1	0.148	0.226	0.113	0.30
10	0.30	0.25	0 : 1	0.136	0.246	0.113	0.25
10	0.30	0.33	0 : 1	0.122	0.273	0.112	0.25
10	0.25	0.50	0 : 1	0.126	0.319	0.114	0.25
10	0.25	1.00	0 : 1	0.097	0.412	0.115	0.25

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
10	0.35	0.05	2 : 1	0.167	0.138	0.113	0.30
10	0.30	0.10	2 : 1	0.149	0.179	0.112	0.30
10	0.25	0.20	2 : 1	0.135	0.233	0.112	0.25
10	0.25	0.25	2 : 1	0.126	0.253	0.112	0.25
10	0.25	0.33	2 : 1	0.116	0.280	0.112	0.25
10	0.25	0.50	2 : 1	0.102	0.324	0.113	0.25
10	0.25	1.00	2 : 1	0.083	0.415	0.115	0.25

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
15	0.40	0.05	0 : 1	0.253	0.148	0.119	0.40
15	0.40	0.10	0 : 1	0.194	0.193	0.116	0.35
15	0.35	0.20	0 : 1	0.171	0.250	0.115	0.30
15	0.35	0.25	0 : 1	0.158	0.272	0.115	0.30
15	0.30	0.33	0 : 1	0.165	0.303	0.116	0.30
15	0.30	0.50	0 : 1	0.142	0.264	0.113	0.30
15	0.30	1.00	0 : 1	0.110	0.455	0.118	0.25

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
15	0.35	0.05	2 : 1	0.214	0.154	0.116	0.35
15	0.35	0.10	2 : 1	0.173	0.198	0.114	0.30
15	0.30	0.20	2 : 1	0.155	0.257	0.114	0.30
15	0.30	0.25	2 : 1	0.144	0.279	0.114	0.30
15	0.30	0.33	2 : 1	0.132	0.310	0.114	0.25
15	0.30	0.50	2 : 1	0.117	0.358	0.115	0.25
15	0.30	1.00	2 : 1	0.094	0.458	0.117	0.25

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
30	0.50	0.05	0 : 1	0.341	0.176	0.125	0.50
30	0.50	0.10	0 : 1	0.262	0.229	0.121	0.40
30	0.40	0.20	0 : 1	0.253	0.296	0.122	0.40
30	0.40	0.25	0 : 1	0.232	0.323	0.122	0.35
30	0.40	0.33	0 : 1	0.208	0.360	0.121	0.35
30	0.35	0.50	0 : 1	0.205	0.419	0.123	0.35
30	0.35	1.00	0 : 1	0.158	0.543	0.126	0.30

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
30	0.45	0.05	2 : 1	0.279	0.183	0.121	0.45
30	0.40	0.10	2 : 1	0.243	0.237	0.120	0.40
30	0.35	0.20	2 : 1	0.214	0.307	0.120	0.35
30	0.35	0.25	2 : 1	0.200	0.334	0.120	0.35
30	0.35	0.33	2 : 1	0.183	0.371	0.120	0.35
30	0.35	0.50	2 : 1	0.162	0.430	0.121	0.30
30	0.30	1.00	2 : 1	0.144	0.558	0.126	0.30

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
50	0.60	0.05	0 : 1	0.418	0.200	0.131	0.60
50	0.55	0.10	0 : 1	0.350	0.260	0.128	0.50
50	0.50	0.20	0 : 1	0.296	0.337	0.127	0.45
50	0.45	0.25	0 : 1	0.304	0.365	0.128	0.45
50	0.45	0.33	0 : 1	0.272	0.408	0.128	0.45
50	0.40	0.50	0 : 1	0.264	0.474	0.130	0.40
50	0.40	1.00	0 : 1	0.202	0.618	0.134	0.35

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
50	0.50	0.05	2 : 1	0.355	0.208	0.127	0.50
50	0.45	0.10	2 : 1	0.307	0.270	0.125	0.45
50	0.40	0.20	2 : 1	0.268	0.350	0.125	0.40
50	0.40	0.25	2 : 1	0.251	0.380	0.125	0.40
50	0.40	0.33	2 : 1	0.230	0.422	0.125	0.40
50	0.35	0.50	2 : 1	0.221	0.493	0.128	0.35
50	0.35	1.00	2 : 1	0.179	0.635	0.133	0.35

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
100	0.80	0.05	0 : 1	0.526	0.238	0.140	0.70
100	0.70	0.10	0 : 1	0.463	0.308	0.137	0.65
100	0.60	0.20	0 : 1	0.418	0.399	0.137	0.60
100	0.60	0.25	0 : 1	0.383	0.435	0.136	0.55
100	0.55	0.33	0 : 1	0.376	0.484	0.138	0.55
100	0.55	0.50	0 : 1	0.321	0.566	0.139	0.50
100	0.50	1.00	0 : 1	0.272	0.734	0.147	0.45

Discharge (lit./s)	Bed Width (m)	Canal Slope (%)	Side Slope Ver.:Hor	Water Depth (m)	Vmax (m/s)	Freeboard (m)	Canal Height (m)
100	0.70	0.05	2 : 1	0.440	0.247	0.134	0.60
100	0.60	0.10	2 : 1	0.392	0.321	0.133	0.55
100	0.50	0.20	2 : 1	0.355	0.416	0.134	0.50
100	0.50	0.25	2 : 1	0.332	0.452	0.134	0.50
100	0.50	0.33	2 : 1	0.305	0.503	0.134	0.45
100	0.45	0.50	2 : 1	0.287	0.586	0.138	0.45
100	0.40	1.00	2 : 1	0.251	0.760	0.147	0.45

6) Turnout

Turnouts are made to distribute water to secondary and tertiary canals. Turnouts are opened and closed following rotational irrigation schedule. Stop logs are recommended for closing turnout however sand bags or bricks and banana leaves are also acceptable. Interval of turnout depends on a number of factors and should lead water to secondary canal. They are mostly spaced at 40m to 60m.

7) Stream/Gully Crossing

Stream/Gully crossing should consist of brick made boxes and pipe. Boxes should be constructed at each side of stream or gully and connected with a pipe. It is possible to make stream/gully crossing with tree bark, logs, bamboo and plastic paper supported by logs but it should be removed during flood season. Therefore, adoption of stream/gully crossing made of bricks and pipe is recommendable for a small scale irrigation scheme. The length of stream/gully crossing should be less than 6m considering the length and strength of pipe. If the length of stream/gully crossing exceeds 6m, it should be supported. Since the support should be enough strong and durable in order not to be washed away by a flash water, it is costly and requires technical consideration. The location of stream/gully crossing should be determined to make the length as shorter as possible (less than 6m). The flow capacity of pipes is shown **Table 4-6** below.

Table 4-6 Maximum Pipe Flow Quantity of Uniform Flow

Pipe Diameter (Nom. Size)	Gradient 1/300	Gradient 1/500
φ 100	3.9 lit/s	3.1 lit/s
φ 125	6.7 lit/s	5.2 lit/s
φ 150	9.6 lit/s	7.5 lit/s
φ 200	24.4 lit/s	18.9 lit/s
φ 225	32.3 lit/s	25.1 lit/s

8) Road Crossing

Road crossing should consist of brick made boxes and pipes. Boxes should be constructed at each side of the road and connected with pipes. Pipes should be installed at the depth of more than 30cm from the surface of the road. 30 cm soil cover is enough safe for gross weight 14 ton truck load. Pipes should be installed at the height of 10cm from canal bed, refer to the **Figure 4-2**. Siphon type is not recommended due to maintenance problems. It is recommended that the back filling material should be thoroughly compacted without destroying the canal walls.

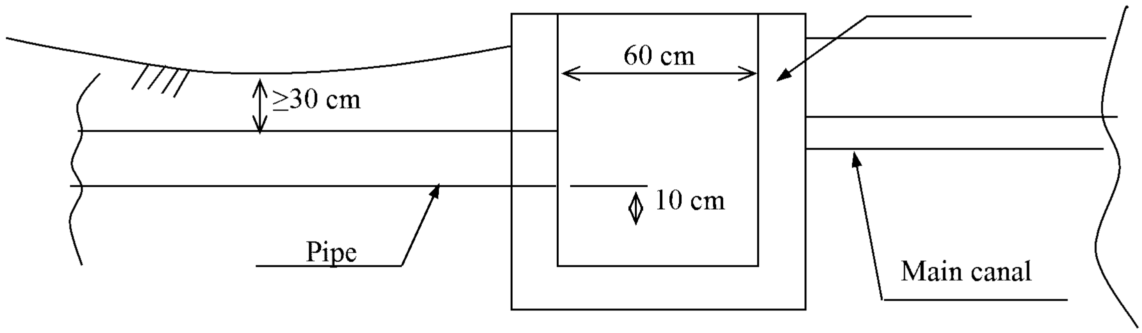
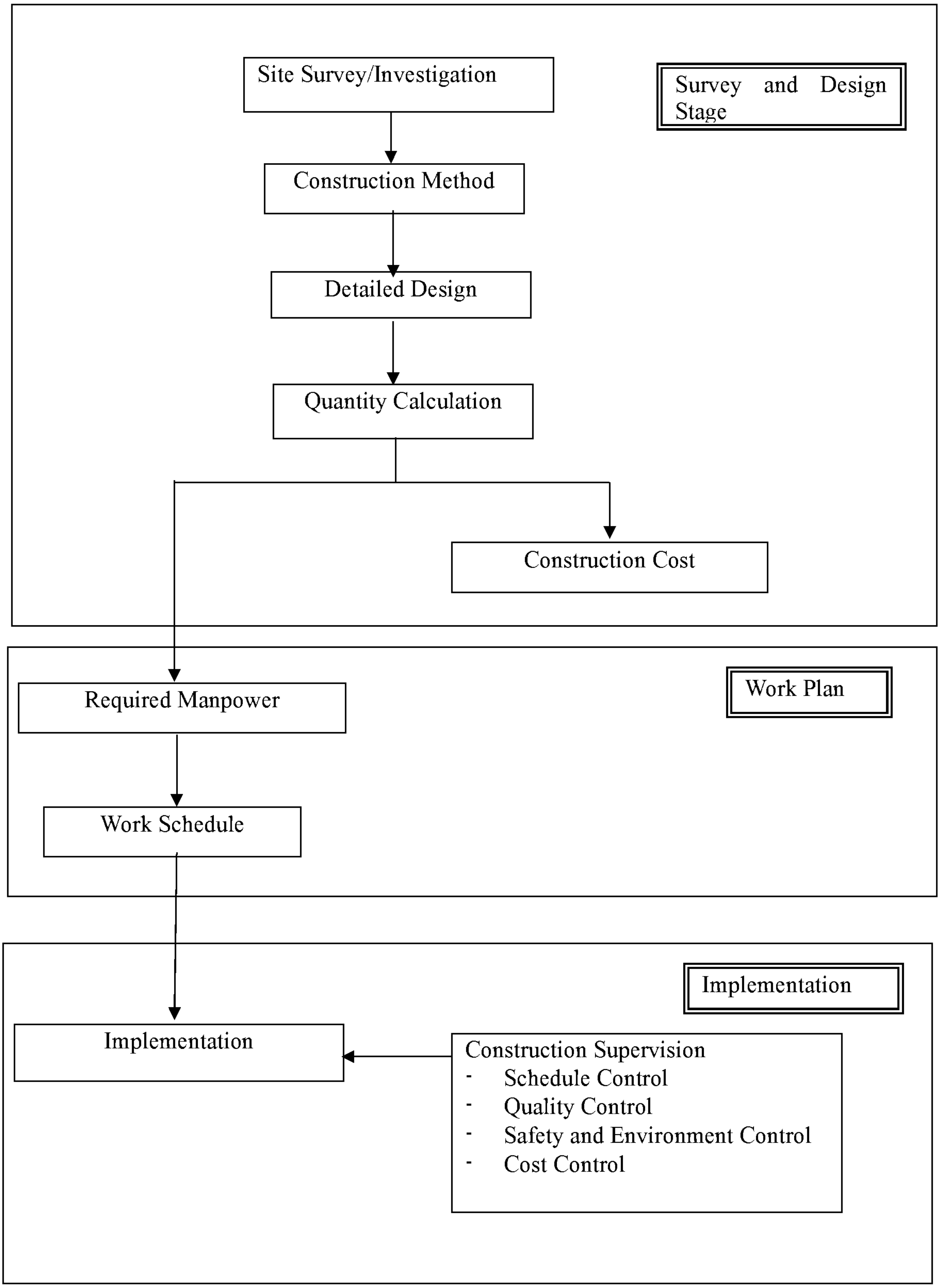


Figure 4-2 Standard Cross Section of Road Crossing

CHAPTER 5 WORK PLAN

5.1 Work Program

Flowchart of work program is shown below.



5.2 Work Plan

(1) General

Construction plan is to establish that the way how the project is implemented safely and within the specified time and cost, and construction method and procedure. Construction work has different types, sizes, and locations and construction conditions are different from one to another. To execute these works in systematic and organized ways, the construction plan appropriate for each work needs to be prepared.

i) Based on design, work method is established.
ii) Based on design, quantity of required materials is calculated.
iii) Based on quantity and work method, required manpower is calculated.
iv) Based on quantity and manpower, construction cost is calculated.
v) Based on manpower, work schedule is drawn up.

(2) Bill of Quantity

Quantity of required materials should be calculated in accordance with drawing. Following items are calculated.

- Excavation
- Embankment
- Stone masonry
- Rubble stones
- Mortar
- Sand
- Cement
- Bricks
- Pipes
- Gabions
- Others

i) Excavation
Quantity of excavation is calculated in accordance with cross section.

Vex = (A1 + A2)/2 x L1 + (A2 + A3)/2 x L2 + ... + (An-1 +An)/2 x Ln

Vex: Excavation volume (m^3)
An: Cross sectional area of excavation at An (m)
Ln: Distance between An-1 and An (m)

or

Vex = A x D (m^3)
A: Excavation area (m^2)
D: Excavation depth (m)

ii) Embankment
Quantity of embankment shall be calculated in accordance with cross section.

Vem = (A1 + A2)/2 x L1 + (A2 + A3)/2 x L2 + ... + (An-1 +An)/2 x Ln
Vem: Embankment volume (m^3)
An: Cross sectional area of embankment at An (m)
Ln: Distance between An-1 and An (m)

iii) Stone masonry
Quantity of stone masonry is calculated in accordance with cross section.

iv) Rubble stone (stone masonry)
Quantity of rubble stone for stone masonry is calculated as follows

Vrs = Vsm x 1.08 (m^3)

1.08: coefficient of loss
Vrs: Volume of rubble stone (m^3)
Vsm: Volume of stone masonry (m^3)

v) Mortar for stone masonry
Quantity of mortar for stone masonry is calculated as follows
Vmo = Vsm x 0.5 x 1.1 (m^3)
Vmo: Volume of mortar for stone masonry (m^3)
Vsm: Volume of stone masonry (m^3)
0.5: coefficient of ratio
1.1: coefficient of loss
vi) Sand for mortar
Quantity of sand for mortar is calculated as follows
Vsa = Vmo x 0.8 (m^3)
Vsa: Volume of sand (m^3)
Vmo: Volume of mortar (m^3)

vii) Cement
Quantity of cement for mortar is calculated as follows
Vc = Vmo x 9.0 (bags)
Vc: Volume of cement (bags)
Vmo: Volume of mortar (m^3)
viii) Bricks
Quantity of bricks is calculated in accordance with drawings.

ix) Gabions
Dimension of gabion wire net is 1.0m x 1.0m x 4.0m or 1.0m x 1.0m x 2.0m.
x) Rubble stones for gabion
Quantity of rubble stone for gabion is calculated as follows
Vrsg = Vga x 0.95 (m^3)
0.95: coefficient of ratio
Vrsg: Volume of rubble stone (m^3)
Vga: Volume of gabion (m^3)

Example of quantity calculation sheet is shown in **Table 5-1.**

Table 5-1 Example of Quantity Calculation Sheet

Site:

No.	Item	Specifoication/ Quality	calculation	Amount	Unit	Remarks
1	Weir	Stone Masonry	standard cross section			
			A1 = (0.6 + 1.9) x 1/2 x 1.3 + 1.9 x 0.5 = 2.575 m^2			
			end cross section			
			A2 = (0.6 + 0.9) x 1/2 x 0.3 = 0.225 m^2			
			V1 = 2.575 x 7.5 = 19.31 m^3			
			V2 = (2.575 + 0.225) x 1/2 x (2.0 + 3.0) = 7.00 m^3			
			V = 19.31 + 7.0 = 26.31			
		rubble stone	26.31 x 1.08 = 28.41m^3	28.4	m^3	
		mortar	26.31 x 0.5 x 1.1 =14.47 m^3			
		sand	14.47 x 0.8 = 11.58 m^3	11.6	m^3	
		cement	14.47 x 450 kg / 50 kg = 130.23 bag	131.0	bag	
		gabion		17.0	pc	
		rubble stone	1.0 x 1.0 x 2.0 x 0.95 x 15 =28.5 m^3	28.5	m^3	
2	Intake	Stone Masonry	A1 = (1.24 + 2.64) x 1/2 x 1.4 = 2.72 m^2			
			A2 = (1.0 + 2.2) x 1/2 x 1.2 = 1.92 m^2			
			V1 = (2.72−1.92) x (1.0 + 0.6 + 1.2 + 1.0) = 3.04 m^3			
			V2 = 1.92 x 0.6 = 1.15 m^3			
			V3 = 1.92 x 1/2 x 1.2 = 1.15 m^3			
			V = 3.04 + 1.15 + 1.15 = 5.34 m^3			
		rubble stone	5.34 x 1.08 = 5.77 m^3	5.8	m^3	
		mortar	5.34 x 0.5 x 1.1 = 2.94 m^3			
		sand	2.94 x 0.8 = 2.35 m^3	2.4	m^3	
		cement	2.94 x 450 kg / 50 kg = 26.46 bag	26.0	bag	
		PVC φ 150		3.6	m	

Box

No.	Item	Specifoication /Quality	calculation	Amount	Unit	Remarks
1	Discharge Box	1.0m x 1.0m x 0.855m (Depth) wall 9 layers				
	Brick	wall	0.215 x 0.855 x (1.43 x 2 + 1.0 x 2) = 0.893 m^3			
		base	1.43 x 1.43 x 0.175 = 0.358 m^3			
		opening	not considered			
		total	0.893 + 0.358 = 1.251 m^3			
			1.251 / (0.235 x 0.115 x 0.095) x 1.1= 536.00 pc	536.0	pc	
	Mortar	wall	0.015 x 0.215 x (1.43 x 2 + 1.0 x 2) x 9 = 0.141 m^3			
			0.015 x 0.215 x (0.08 x 9) x ((1.43 x 2 +1.0 x 2) / 0.235) = 0.048 m^3			
		base	0.015 x (1.43 x 1.43 + 0.175 x (1.43 / 0.235) + 0.175 x (1.43 / 0.115)) = 0.079 m^3			
		opening	not considered			
		inside plastering	1.0 x 1.0 x 0.8 x 0.015 = 0.012 m^3			
		total	(0.141 + 0.048 + 0.079 + 0.012) x 1.3 = 0.364 m^3			
		sand	0.364 x 0.8 = 0.291 m^3	0.291	m^3	
		cement	0.364 x 450kg / 50kg = 3.276 bag	3.276	bag	
2	Box	0.6m x 0.6m x 0.475m (Depth) wall 5 layers				
	Brick	wall	0.215 x 0.475 x (1.03 x 2 + 0.6 x 2) = 0.333 m^3			
		base	1.03 x 1.03 x 0.175 = 0.186 m^3			
		opening	not considered			
		total	0.333 + 0.186 = 0.519 m^3			
			0.519 / (0.235 x 0.115 x 0.095) x 1.1= 222.37 pc	223.0	pc	
	Mortar	wall	0.015 x 0.215 x (1.03 x 2 + 0.6 x 2) x 5 = 0.052 m^3			
			0.015 x 0.215 x (0.08 x 5) x ((1.03 x 2 +0.6 x 2) / 0.235) = 0.018 m^3			
		base	0.015 x (1.03 x 1.03 + 0.175 x (1.03 / 0.235) + 0.175 x (1.03 / 0.115)) = 0.051 m^3			
		opening	not considered			
		inside plastering	0.6 x 0.6 x 0.475 x 0.015 = 0.003 m^3			
		total	(0052 + 0.018 + 0.051 + 0.003) x 1.3 = 0.161 m^3			
		sand	0.161 x 0.8 = 0.129 m^3	0.129	m^3	
		cement	0.161 x 450kg / 50kg = 1.449 bag	1.449	bag	

(3) Man Power and Tools Planning

Standard of required manpower, material and tools for each work is estimated as **Table 5-2**. These were established.

(4) Construction Cost

Construction cost is calculated based on bill of quantity and man power. Example of cost calculation sheet is shown in **Table 5-3**.

5.3 Work Schedule

Based on quantity and required manpower for each item, construction period for each item is estimated. If the available labor per day is enough, putting large manpower into the work, shorten the construction period is shortened. Example of manpower planning is shown in the **Table 5-4.** Based on this man power planning, work progress schedule is drawn up. If man power is enough, work items can be executed simultaneously. Example of work progress schedule is shown in the **Figure 5-1**.

1) Standard Manpower and Quantity Per Unit

Standard manpower and quantity per unit is shown below.

a. Embankment

Embankment (by hand)	per 10m^3	quantity	unit
unskilled labor		7.60	Man*day

Ex. For 100m^3: 76 man*day = 10 days / 7.6 man/day = 20 days / 3.8 man/day

b. Excavation

Excavation (by hand)	per 10m^3	quantity	unit
unskilled labor		7.80	Man*day

Ex. For 100m^3: 78 man*day = 10 days / 7.8 man/day = 20 days / 3.9 man/day

c. Mortar Mixing

1:4 Mortar	per 0.89m^3/day	quantity	unit
unskilled labor (mixing)		2.0	Man*day
unskilled labor (helper)		4.0	Man*day

Ex. For 8.9 m^3 mortar: 10 days / 6.0 unskilled labors = 5 days / 12.0 unskilled labors (2 sets)

d. Stone Masonry (not including mortar mixing)

Stone Masonry	per 1.0 m^3	quantity	Unit
skilled labor		0.6	Man*day
unskilled labor		3.6	Man*day

Ex. For 10 m^3 stone masonry: skilled labor 6 man*day + unskilled labor 36 man*day
=6 days by (1 skilled labor and 6 unskilled labors)/day
=3 days by (2 skilled labor and 12 unskilled labors)/day = 2 sets/day

(Mortar mixing: 0.89 m^3/day/1set. Stone masonry 1.0 m^3 requires 0.5 m^3 mortar.
Stone Masonry 10m^3 requires 5 m^3 mortar
If 6days, mortar mixing 1set/day, If 3days, mortar mixing 2 sets)

e. Gabion Work

Gabion Work	per piece 2.0 m^3	quantity	Unit
skilled labor		0.25	Man*day
unskilled labor		3.5	Man*day

Ex. For 4 gabions: skilled labor 1 man*day + unskilled labor 14 man*day

= 1 day by (1 skilled labor + 14 unskilled labor)

f. Brick Canal (including mortar mixing)

Brick Canal W0.3 x D0.38	per 12m/day	quantity	Unit
Brick layer		1.0	Man*day
unskilled labor		12.0	Man*day

Ex. 60m/day: (1 brick layer +13 unskilled labor) x 5 set/day

g. Pipe Installation

Pipe Installation	per 100m	quantity	Unit
unskilled labor		7.5	Man*day

Ex. For 200m installation: 15 man*day = 2 days by 7.5 unskilled labor
= 1 day by 15 unskilled labor (2sets)

2) Work Group

Work group shall be organized according to work item. Available number of work groups shall be considered in work schedule. Number of work group depends on number of skilled labor or leader. If number of skilled labor is not enough, OJT by skilled labor, leader for another group can be cultivated.

Generally, one group (1 set) has one skilled labor and 10 to 15 unskilled labors.

Standard organization of work item is shown in the Table-1.

Ex. Construction of brick canal 1 set
Brick laying: skilled labor 1, unskilled labor 3
Mortar mixing: unskilled labor 2
Excavation (Shaping): unskilled labor 2
Helper (carry sand, water, mortar, bricks): unskilled labor 4

Generally, following work groups are organized;

- Excavation
- Embankment
- Stone Masonry
- Gabion Work
- Brick Laying
- Brick Molding
- Sand Carrying
- Water Carrying
- Brick Carrying
- Pipe Installation

3) Critical work

Critical work is the work item which directly affects work period. The work that, if the work delayed, total work period will be longer than scheduled. To complete construction work within the period, number of work group for critical work shall be increased and some work items shall be executed simultaneously.

4) Work Schedule

Work schedule shall be developed considering manpower planning (available number of skilled and unskilled labors, work groups) and critical work. Work schedule shall be most efficient. Work schedule is shown in bar chart.

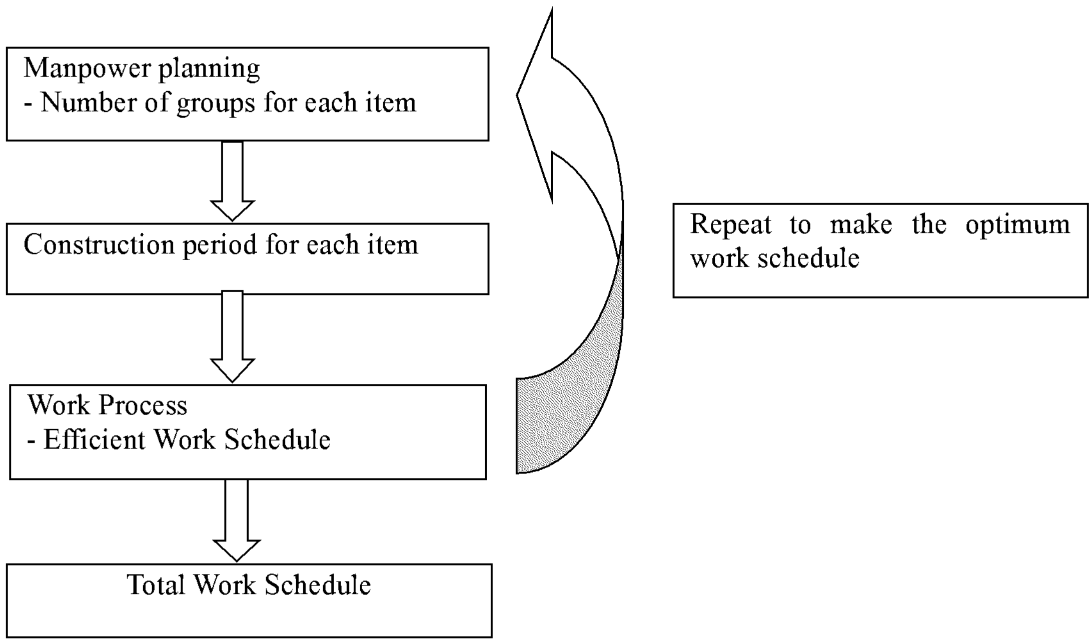


Table 5-2 Standards of Required Manpower, Materials and Tools

Labor Material and Tools

Item	name	specification, quality, shape	quantity	unit			remarks
1-1	Mortar per 1m^3		0.89m^3/day/1set				
	Material						
	Cement	Ordinary Portland	9.00	bags			450kg
	Sand	River sand	0.80	m^3			1.0 x 0.8
	Material Total						
	Labor						
	Mortar mixing	unskilled labor	2.25	man			2 x 9 / 8
	Helper	unskilled labor	4.50	man			4 x 9 / 8
	Labor Total		6.75	man			
	Tools (Daily)						
	Shovel		2.00	pcs			
	Bucket	20 lit	2.00	pcs			
	Wheelbarrow		1.00	pc			
	Mortar box		1.00	pc			
1-2	Mortar per 0.89m^3 / day/ 1 set						
	Material						
	Cement	Ordinary Portland	8.00	bags			400kg
	Sand	River sand	0.71	m^3			0.89 x 0.8
	Material Total						
	Labor						
	Mortar mixing	unskilled labor	2.00	man			
	Helper	unskilled labor	4.00	man			
	Labor Total		6.00	man			
	Tools (Daily)						
	Shovel		2.00	pcs			
	Bucket	20 lit	2.00	pcs			
	Wheelbarrow		1.00	pc			
	Mortar box		1.00	pc			
2-1	Construction of brick canal rectangular W=0.36m, D=0.38m wall 4 layers						
	12m / day / 1 set						
	Material						
	Bricks		730.20	pcs			60.85 x 12
	Mortar	1:3	0.37	m^3			0.031 x 12
	Material Total						
	Labor/day						
	Foreman		1.00	man			
	Mortar mixing	unskilled labor	4.00	man			1 day
	Excavation	unskilled labor	2.00	man			shaping
	Brick laying	skilled labor	1.00	man			
		unskilled labor	3.00	man			
	Helper	unskilled labor	4.00	man			
	Total labor		15.00	man			

Item	name	specification, quality, shape	quantity	unit			remarks
	Tools (Daily)						
	Shovel		2.00	pcs			
	Bucket	20 lit	4.00	pcs			
	Wheelbarrow		3.00	pcs			
	Mortar box		1.00	pc			
	Trowel		4.00	pcs			
	Drum		1.00	pc			
	Hoe		2.00	pcs			
	Line level		1.00	pc			
	String		1.00	roll			
	Brick bolster		1.00	pc			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
2-2	Construction of brick canal rectangular W=0.36m, D=0.475m wall 5 layers						
	10.4m / day / 1 set						
	Material						
	Bricks		730.18	pcs			70.21 x 10.4
	Mortar	1:3	0.37	m^3			0.036 x 10.4
	Material Total						
	Labor/day						
	The same as 2-1						
	Tools						
	The same as 2-1						
3-1	Construction of Brick canal trapezoid W=0.36m, D=0.39m wall 4 layers						
	14.2m / day / 1 set						
	Bricks		731.16	pcs			51.49 x 14.2
	Mortar	1:3	0.53	m^3			0.037 x 14.2
	Material Total						
	Labor/day						
	The same as 2-1						
	Tools						
	The same as 2-1						
3-2	Construction of brick canal trapezoid W=0.36m, D=0.50m wall 5 layers						
	12m / day / 1 set						
	Material						
	Bricks		730.20	pcs			60.85 x 12
	Mortar	1:3	0.47	m^3			0.039 x 12
	Material Total						
	Labor/day						
	The same as 2-1						
	Tools						
	The same as 2-1						

Item	name	specification, quality, shape	quantity	unit			remarks
3－3	Construction of brick canal trapezoid W=0.36m, D=0.62m wall 6 layers						
	10.4m / day / 1 set						
	Material						
	Bricks		730.18	pcs			70.21 x 10.4
	Mortar	1:3	0.45	m^3			0.043 x 10.4
	Material Total						
	Labor/day						
	The same as 2－1						
	Tools						
	The same as 2－1						
4－1	Construction of discharge box 1000mm x 1000mm x 855mm (Depth) wall 9 layers						
	1 location / day / 1 set						
	Bricks		536.00	pcs			
	Mortar	1:3	0.36	m^3			
	Material Total						
	Labor/location 1location / 1 day						
	Foreman		1.00	man			
	Mortar mixing	unskilled labor	4.00	man			
	Excavation	unskilled labor	1.00	man			
	Brick laying	skilled labor	1.00	man			
		unskilled labor	2.00	man			
	Helper	unskilled labor	2.00	man			
	Total labor		11.00	man			
	Tools (Daily)						
	Shovel		1.00	pcs			
	Bucket	20 lit	3.00	pcs			
	Wheel barrow		2.00	pc			
	Mortar box		1.00	pc			
	Trowel		2.00	pcs			
	Drum		1.00	pc			
	Hoe		1.00	pc			
	Brick bolster		1.00	pc			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
4－2	Box	600mm x 600mm x 475mm (Depth) wall 5 layers					
	Bricks		223.00	pcs			
	Mortar	1:3	0.16	m^3			
	Material Total						
	Labor/location 3locations / 1 day						
	Foreman		0.33	man			
	Mortar mixing	unskilled labor	2.00	man			
	Excavation	unskilled labor	0.33	man			
	Brick laying	skilled labor	0.33	man			
		unskilled labor	0.67	man			

Item	name	specification, quality, shape	quantity	unit			remarks
	Helper	unskilled labor	0.67	man			
	Total labor		4.33	man			
	Tools (Daily)						
	Shovel		1.00	pcs			
	Bucket	20 lit	2.00	pcs			
	Wheel barrow		1.00	pc			
	Mortar box		1.00	pc			
	Trowel		2.00	pcs			
	Drum		1.00	pc			
	Hoe		1.00	pc			
	Brick bolster		1.00	pc			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
5	Excavation (by hand)	per 10m^3					
	Labor						
	unskilled labor		7.80	man			
	Tools						
	Shovel		3.00	pcs			
	Pickaxe		2.00	pcs			
	Hoe		2.80	pcs			
	String		1.00	roll			
	Peg						
6	Hauling excavated material per 1.0 m^3 by wheel barrow						
	Labor						
	unskilled labor	～ 20m	0.02	man			
	Wheel barrow	20～ 40m	0.06	man			
		40～ 60m	0.14	man			
		60～ 80m	0.24	man			
		80～ 100m	0.34	man			
		100～ 120m	0.44	man			
		120～ 140m	0.56	man			
		140～ 160m	0.66	man			
		160～ 180m	0.78	man			
		180～ 200m	0.90	man			
		one way distance					
7	Embankment (by hand)	per 10m^3					
	unskilled labor		7.60	man			
	Tools						
	Shovel		2.00	pcs			
	Hoe		3.60	pcs			
	Rammer		2.00	pcs			
	String		1.00	roll			
	Peg						

Item	name	specification, quality, shape	quantity	unit			remarks
8	Finishing slope (cut earth) per 100m^2						
	Labor						
	Foreman		1.40	man			
	Unskilled labor		11.80	man			
	Total labor		13.20	man			
	Tools						
	Shovel		4.00	pcs			
	Hoe		7.80	pcs			
	String		1.00	roll			
9	Finishing slope (embankment) per 100m^2						
	Labor						
	Foreman		1.60	man			
	Unskilled labor		25.80	man			
	Total labor		27.40	man			
	Tools						
	Shovel		4.00	pcs			
	Hoe		21.80	pcs			
	String		1.00	roll			
10	Stone masonry	per 1m^3					
	Material						
	Rubble stone		1.08	m^3			
	Mortar		0.55	m^3			
	Total material						
	Labor (not include mortar mixing)						
	Foreman		0.30	man			
	Skilled labor		0.60	man			
	Unskilled labor		3.60	man			
	Total labor		4.50	man			
	Tools (Daily, not include mortar mixing)						
	Bucket	20 lit	4.00	pcs			
	Wheelbarrow		4.00	pc			
	Trowel		4.00	pcs			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
11-1	Gabion work per piece	2.0m x 1.0m x 1.0m					
	Material						
	Rubble stone		1.90	m^3			2.0 x 0.95
	Gabion wire net		1.00	pc			
	Steel wire						
	Total material						

Item	name	specification, quality, shape	quantity	unit			remarks
	Labor						
	Foreman		0.13	man			
	Skilled labor		0.25	man			
	Unskilled labor		3.50	man			
	Total labor		3.88	man			
	Tools (Daily)						
	Wheelbarrow		2.00	pcs			
	Bucket		2.00	pcs			
	Plier		2.00	pcs			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
11-2	Gabion work per piece	2.0m x 1.0m x 0.5m					
	Material						
	Rubble stone		0.95	m^3			
	Gabion wire net		1.00	pc			
	Total material						
	Labor						
	Foreman		0.10	man			
	Skilled labor		0.20	man			
	Unskilled labor		2.00	man			
	Total labor		2.30	man			
	Tools (Daily)						
	The same as 11-1						
12	Discharge Pipe installation per 100m						
	Material						
	PVC pipe	class 6	16.7	pc			
	Foreman		0.50	man			
	Unskilled labor		7.50	man			
	Total labor		8.00	man			
13	Gathering stones	per 10m^3 distance 50m					
	Unskilled labor		15.00	man			
	Tools (daily)						
	Wheelbarrow		7.00	pcs			
	14 lbs hammer		4.00	pcs			
	4 lbs hammer		2.00	pcs			
	Chisel		2.00	pcs			
14	Tractor trailer loading and unloading						
	4 m^3 / 1 trip, 4 trips / day = 12 m^3 / day						
	unskilled labor		15.00	man			

Table 5-3 Example of Cost Calculation Sheet

Cost Estimation Name of the Site: Example

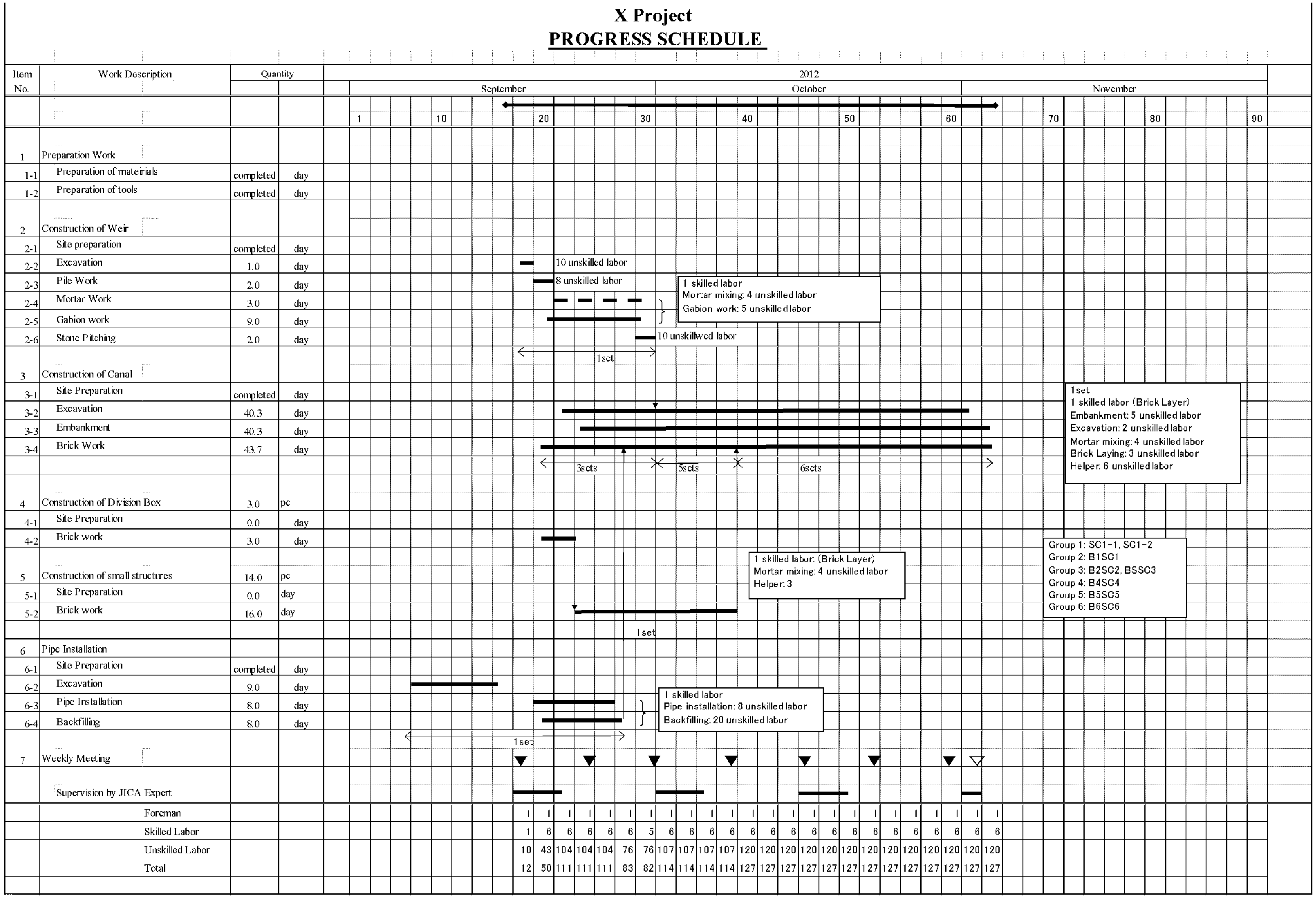
No.	Item	Specification/Quality	Quantity	Unit	Unit Price	Price	Remarks
					ZMK	ZMK	
1	Preparation Work						
	Site clearing	unskilled labor	15.0	m·d		0.0	1day
	Gathering stones	unskilled labor	94.8	man		0.0	63.8/10x15
	Gathering sand	unskilled labor	37.8	man		0.0	25.2/10x15
	labor total					0.0	
2	Stone Masonry Weir	V=	40.0	m^3			
	rubble stone		43.2	m^3		0.0	40 x 1.08
	sand		17.6	m^3		0.0	40 x 0.5 x 1.1 x 0.8
	cement	ordinary portland	198.0	bag		0.0	40 x 0.5 x 1.1 x 9
	material total					0.0	
	excavation	unskilled labor	7.8	man		0.0	10m^3
	mortar mixing	unskilled labor	132.0	man		0.0	40 x 0.5 x 1.1 x 6
	stone masonry	foreman	12.0	man		0.0	0.3 x 40
		skilled labor	24.0	man		0.0	0.6 x 40
		unskilled labor	144.0	man		0.0	3.6 x 40
	labor total						
3	Intake	V=	5.0	m^3			
	rubble stone		5.4	m^3		0.0	5.0 x 1.08
	sand		2.2	m^3		0.0	5 x 0.5 x 1.1 x 0.8
	cement	ordinary portland	24.8	bag		0.0	5 x 0.5 x 1.1 x 9
	PVC	ϕ=140	1.0	pc		0.0	6m
	material total					0.0	
	excavation	unskilled labor	1.6	man		0.0	2m^3
	mortar mixing	unskilled labor	16.5	man		0.0	5 x 0.5 x 1.1 x 6
	stone masonry	foreman	1.5	man		0.0	0.3 x 5.0
		skilled labor	3.0	man		0.0	0.6 x 5.0
		unskilled labor	18.0	man		0.0	3.6 x 5.0
	labor total					0.0	
4	Main Canal Rectangular	W=0.36 D=0.38	300.0	m			
	bricks		18,255.0	pcs		0.0	730.2x300/12
	sand		7.4	m^3		0.0	0.37x300/12x0.5
	cement	ordinary portland	83.3	bag		0.0	0.37x300/12x9
	material total					0.0	
	excavation	unskilled labor	9.6	man		0.0	75m^3/7.8
	mortar mixing	unskilled labor	100.0	man		0.0	4x300/12
	brick laying	skilled labor	25.0	man		0.0	1x300/12
		unskilled labor	225.0	man		0.0	9*300/12
	labor total					0.0	
5	Gully Crossing	Box 600 x 600 x 475	3.0	pcs			
	bricks		669.0	pcs		0.0	223.0x3
	sand		0.4	m^3		0.0	0.16x0.8x3
	cement		4.3	bag		0.0	0.16x3x9
	PVC pipe	ϕ140	3.0	pc		0.0	6m
	material total					0.0	

Table 5-4 Example of Manpower Planning

Manpower Planning Name of the Site: Example

No.	Item	Specification/ Quality	Quantity	Unit	period	day	Remarks
	Available labor						
	skilled labor	2 man / day					
	unskilled labor	20 man / day					
1	Preparation Work						
	Site clearing	unskilled labor	15.0	man・day	1.0	day	15man/day
	Gathering stones	unskilled labor	94.8	man・day	5.0	day	20man/day
	Gathering sand	unskilled labor	37.8	man・day	3.0	day	15man/day
	total				9.0	day	
2	Stone Masonry Weir						
	excavation	unskilled labor	7.8	man・day	1.0	day	8man/day
	mortar mixing	unskilled labor	132.0	man・day	22.0	day	6man/day
	stone masonry	foreman	12.0	man・day			1man/day
		skilled labor	24.0	man・day			2man/day
		unskilled labor	144.0	man・day			8man/day
	total				23.0	day	
3	Intake						
	excavation	unskilled labor	1.6	man・day	1.0	day	2man/day
	mortar mixing	unskilled labor	16.5	man・day	3.0	day	6man/day
	stone masonry	foreman	1.5	man・day			1man/day
		skilled labor	3.0	man・day			1man/day
		unskilled labor	18.0	man・day			6man/day
	total				4.0	day	
4	Main Canal Rectangular	W=0.36 D=0.38	300.0	m			
	excavation	unskilled labor	9.6	man・day	1.0	day	10ma/day
	mortar mixing	unskilled labor	100.0	man・day	25.0	day	4man/day
	brick laying	skilled labor	25.0	man・day			1man/day
		unskilled labor	225.0	man・day			9man/day
	total				26.0	day	
5	Gully Crossing	Box 600 x 600 x 475	3.0	pcs			
	excavation	unskilled labor	1.0	man・day	1.0	day	1man/day
	mortar mixing	unskilled labor	6.0	man・day			6man/day
	brick laying	foreman	1.0	man・day			1man/day
		skilled labor	1.0	man・day			1man/day
		unskilled labor	2.0	man・day			2man/day
	total				1.0	day	
6	Gabion Work	2.0x1.0x1.0	8pcs				
	gabion work	foreman	1.0	man・day	2.0	day	1man/day
		skilled labor	2.0	man・day			1man/day
		unskilled labor	28.0	man・day			14man/day
	total				2.0	day	

Figure 5-1 Example of Work Progress Schedule.



CHAPTER 6 CONSTRUCTION

6.1 Work Method

(1) Surface Preparation

Ground surfaces in areas to be excavated or where facilities are to be located should be cleared of all trees, bush, debris and surface vegetation. Stumps and roots larger than 50 mm in diameter should completely uproot and removed. Matted roots, surface vegetation should be removed regardless of size; they should completely remove with roots to a depth of not less than 10 cm below ground surface. All trees or groups of trees designated should be protected from damage from any construction operations.

(2) Excavation

Excavation should be planned and carried out to minimize adverse effects on the existing facilities and structures, as well as the vehicular and pedestrian traffic of and around the construction site.

Over excavation, below the depths indicated, should, unless otherwise be specified, refilled and compacted. If soft or unsuitable soil is found at the excavated depth, additional excavation should be carried out to depth and filled and compacted. Soil disturbed or weakened and soils deteriorated by exposure to weather should be excavated and excavated areas refilled and compacted.

Generally, all excavations should be kept free from water during construction. If soft or unsuitable soil is encountered after excavation to the designated bottom of the trench or structure, the ground should be excavated to a firm foundation level and filled over the excavated area with backfilling material.

(3) Replacement and Embankment

Material for the replacement and embankment should be placed in horizontal layers of uniform thickness over a width determined and in conformity with the lines, grades, sections, and dimensions. The layer of loose material other than rock should be not more than 30 cm thick. After adjustment of the moisture content, the loose material should be compacted.

(4) Stone Masonry

1) Material

i) Stone
Stone for Stone Masonry should consist of field stone or rough un-hewn quarry stone as nearly rectangular in section as is practical, including such stone or material observed being in use on the existing work. The stone should be sound, tough, durable, dense, resistant to the action of air and water, and suitable in all respects for the purpose intended. The size of the stone should be 10 cm minimum and 30 cm maximum.
ii) Sand
Sand for mortar should be river sand, free from silt, salt and other organic foreign matter.
iii) Water
Water for mortar should be clean and free from harmful matter, such as oil, salts, organic matter, or any material which may have a harmful effect on the mortar. Potable water (except for bacteriological limits and conditions) is suitable for the mixing of mortar under all conditions.
iv) Mortar mix
Standard mixing proportion of cement and mortar is as follows,
Ordinary Portland Cement 1 bucket of cement: 4 buckets of Sand
Mortar should be mixed uniformly with water to the proper consistency for spreading by trowel. Mortar which has been mixed with water for more than 45 minutes should not be used.

2) Construction

Excavation should be made to the required shape and depth, and should be compacted to a firm, even surface. All surpluses, soft and unsuitable material should be removed and replaced with suitable material which should be thoroughly compacted.

Stone should be washed with water before placing. Mortar should be pushed into the interstices of the stone within a short time after placing. The spaces between the stones are then filled with mortar. Sufficient mortar should be used to completely fill all voids, except that the face surface of the stone is left for exposition. The surface of stone masonry should be finished neatly and smoothly. After completion of Stone Masonry, it should be cured with water for more than 10 hours.

(5) Gabion

1) Material

The wire mesh should be made of galvanized steel having a minimum size of 2.7 mm (0.106 inch) diameter. The length and width of bamboo gabion should be less than one meter and the height less than 0.6 meter. The gabions should consist of hard rocks which are durable rock pieces that might not deteriorate when submerged in water or exposed to severe weather conditions. Rock pieces should be generally uniformly graded in sizes ranging from 100mm to 200mm. All Voids should be evenly distributed.

2) Construction

The wire mesh should be twisted to form hexagonal openings of uniform sizes. The maximum linear dimension of the mesh opening should not exceed 110 mm (4 ½ inches) and the area of mesh opening should not exceed 51.6 sq.cm (8 square inches). The mesh should then be fabricated non-raveled. Non-raveling is defined as the ability to resist pulling apart at any of the twists or connections forming the mesh when a single wire strand in a section is cut.

Gabion should be fabricated in such a manner that the side, ends, lid, and diaphragms can be assembled at the construction site into rectangular baskets of the specific sizes. Gabions should be of single unit construction, base, lids, ends, and sides should be either woven into a single unit or one edge of these members connected to the base section of the gabion in such a manner that the strength and flexibility at the point of connection is at least equal to that of the mesh.

The gabion should be equally divided by diaphragms, of the same mesh and gauge as the body of the gabions, into cells the length of which does not exceed the horizontal width. The gabion should be furnished with the necessary diaphragms secured in proper position on the base, such that no additional tying at this junction are necessary.

The gabions are then filled with stone carefully placed by hand to assure alignment and avoid bulges with a minimum of voids. Alternate placing of rock and connection wires should be performed until the gabion is filled. After a gabion has been filled, the lid should be bent over until it meets the sides and edges. The lid should then be secured to the sides, ends and diaphragms with the wire ties or connecting wire in the manner described for assembling.

(6) Brick Masonry

1) Material

Brick for brick masonry should be sound, tough, durable, dense, resistant to the action of air and water, and suitable in all respects for the purpose intended. Standard mixing proportion of mortar should be as follows;

Ordinary Portland Cement 1 bucket of Cement: 4 buckets of Sand

2) Construction

Bricks should be soaked in the water before laying. Brick should be laid straight. Thickness of joint mortar shall be 1 to 2 cm. The joint between the bricks should be filled with mortar completely and the surface of brick masonry finished neat and smooth.

(7) Safety and Environment

1) Safety

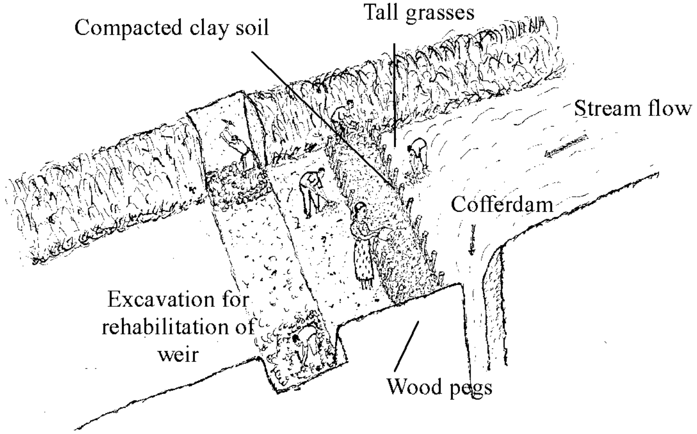
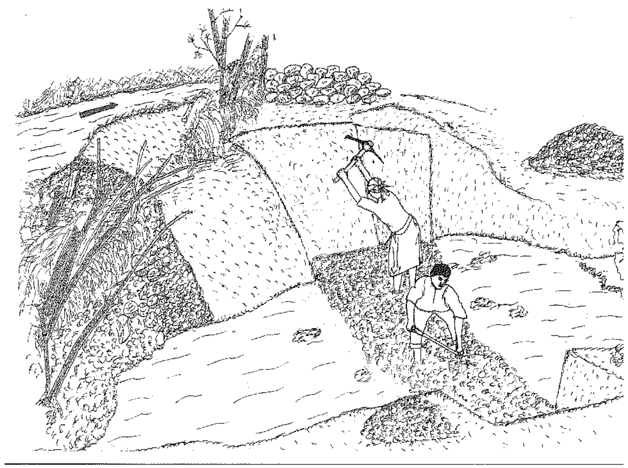
Reasonable precaution to protect persons or property from injury should be exercised and maximum care should also be put in place for people around them.

2) Environment

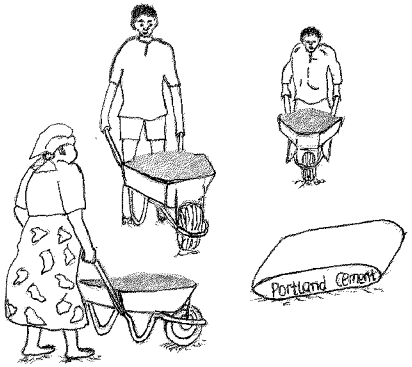
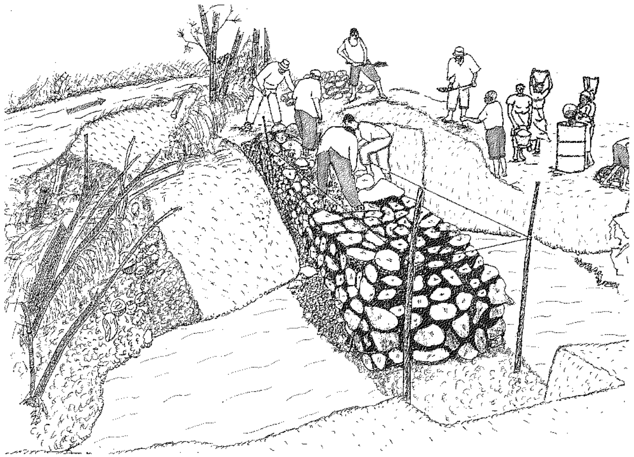
All necessary precautions should be taken to secure the efficient protection of all waterways against pollution, including spillage of oil which may be likely to cause injury to fish or plant life. Waste water from washing tools for mortar work such as mortar box, shovels, buckets and trowels should not be poured into a river directly.

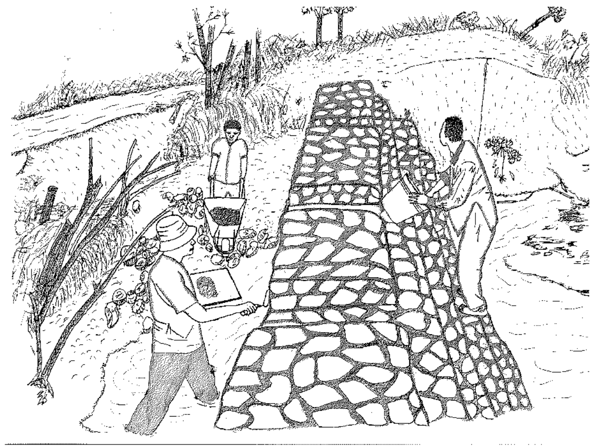
6-2 Construction

(1) Stone Masonry Weir

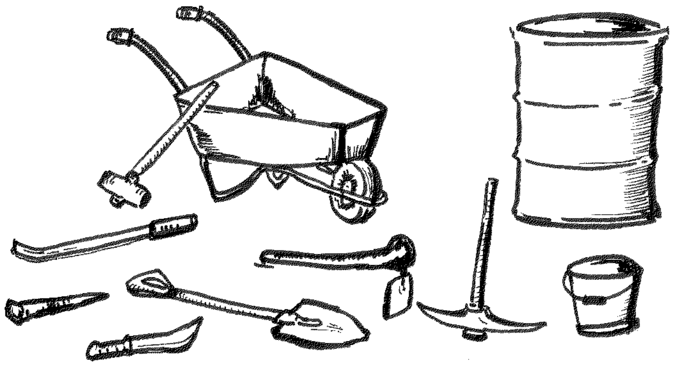
<table>
<tr><th></th><th>Process</th><th>Description</th><th>Remark</th></tr>
<tr><td>1</td><td>
</td><td><u>Cofferdam Construction</u>
(a) Cofferdam with soils
- Position wooden poles at the diversion point
- Weave grass fence to tap the stream flow
- Put clay soil on the grass fence
- Compact the soil using logs
(b) Cofferdam with sand bags
- To fill sand bags with soils
- To place sand bags tight each other at diversion point.</td><td>- Cofferdam is constructed to close the river (upstream of the construction site) so that the weir point is dry throughout the construction.
- Rammers may be used for the compaction when available.</td></tr>
<tr><td>2</td><td></td><td><u>Excavation for Weir</u>
1. The foundation is excavated to bedrock at least 50 cm depth from riverbed.
2. Abutment is excavated 1m horizontal direction into river bank.
3. The line of upstream end, downstream end and abutment shall be indicated with pegs and strings.</td><td>- If soft or unsuitable soil is found at the excavated depth, additional excavation shall be carried out.
Precaution(>1.5m excavation)
- Maximum safety against land sliding shall be ensured when excavating an abutment.
- Elevation of cutting shall be checked.</td></tr>
</table>

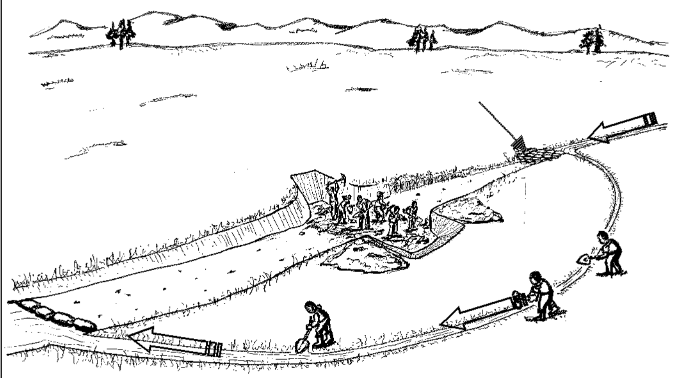
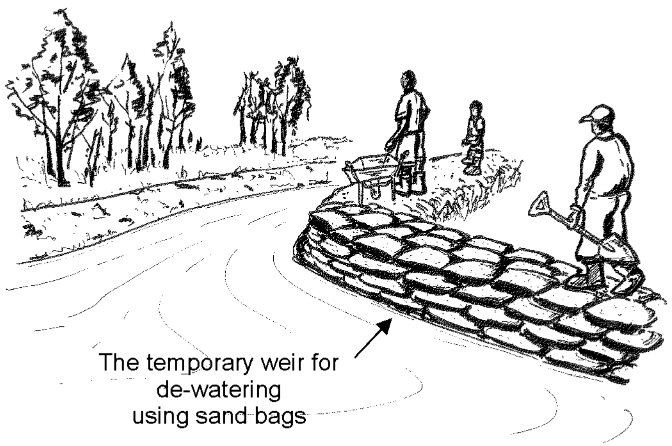
3		**De-watering** 1. During the construction of the base, ensure that foundations are dry by dewatering using buckets.	- If there is a lot of ground water, dewatering shall be carried out continuously with buckets. Drain ditch and drain pit are required to be arranged. - Drainage pumps or treadle pumps may be used when buckets are not sufficient.
4		**Mortar Mixing Place Preparation** 1. Excavate a curved surface on a flat place (1.7m diameter). 2. Compact the surface with rammers or stones. 3. Lay bricks around the curved surface. 4. Place mortar in spaces between the bricks.	- The mixing place shall be as close to the construction place. - Compaction seals off all voids. - The Place can also be used for future rehabilitation.
		Water for Mortar 1. Prepare drum(s) of water for mortar at the site on the day of construction. 2. Water shall be clean water.	- Number of drums depends on the number of mortar mixing place.

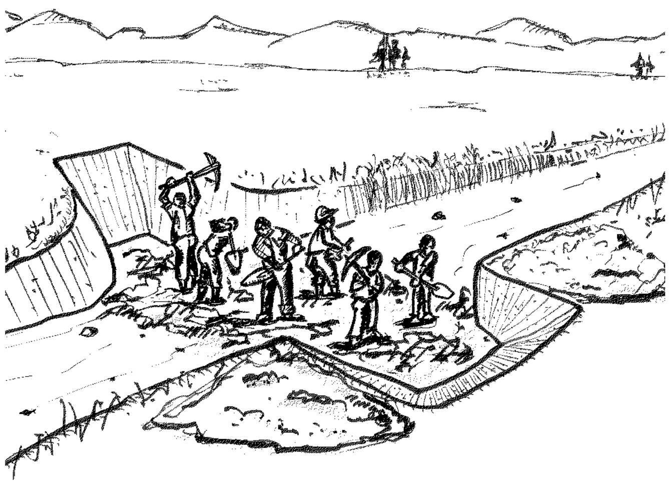
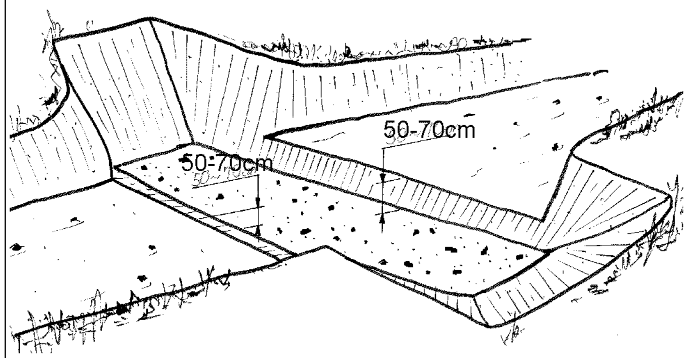
5		<u>Stages of Mortar Mixing</u> 1. Standard mixing proportion of cement: sand is; ***1:4*** 2. Measure one 50kg bag of Cement and six buckets of sand. If the sand is dry, 20 liter of water is poured and mixed first. Then additional water is sprayed and mixed to the proper consistency. 3. 1 bag of cement will be used with sand at the standard mortar mixing place at the same time.	
6		<u>Weir Construction</u> 1. Make sure that the closed river is dry, if not keep on dewatering. 2. Wash stones before used for construction. 3. Line the stones with the flat surface facing outside the structure (use a builders' level when constructing). 4. Mortar is pushed into the interstices and spaces between the stones. 5. Stones are placed layer by layer.	- Washing removes all debris thereby increasing the bond strength. - Voids shall be filled with mortar completely so that leakage may not happen and strength is secured. - Crest elevation and dimension shall be checked.

7		**Finishing and Curing** 1. The surface of stone masonry needs to be finished neatly and smoothly. 2. After completion of stone masonry, it needs to be covered with grasses or straw mats for curing mortar. 3. Water shall be sprayed from time to time.	

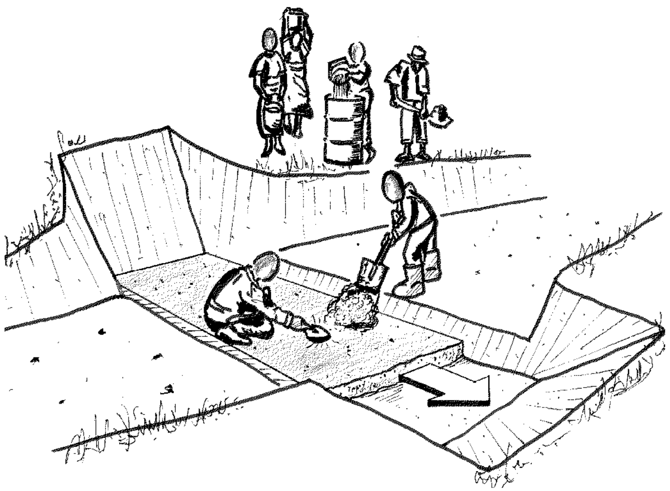
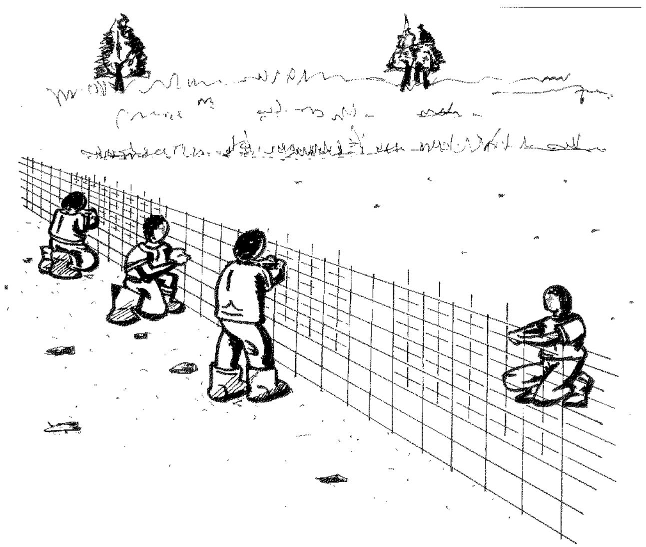
(2) Construction of Permanent Weir: Concrete Wall type

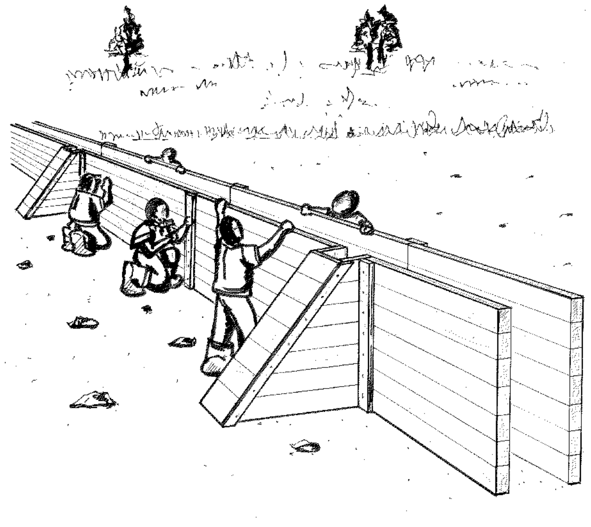
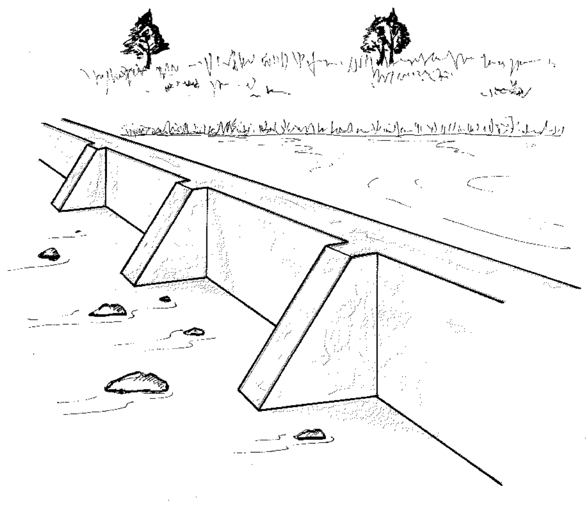
Step	Process	Description	Remarks
1		**Tools Required:** For the construction of permanent weir, the major tools required are: - Wheelbarrows - Hoes - Panga knives - Pickaxes - Chisels - Hammers - Buckets - Drum - Slashers - Shovels - Trowel	
2		**Tools Required;** For the construction of permanent weir, the major material required are: - Cement - Crushed stones - River sand - Reinforcement bars - Mesh wire - Paint	

Step	Process	Description	Remarks
3		**De-watering:** During the construction of weir, it is necessary to keep the foundation of construction site dry. To this end, de-water the site by piling sandbags at an upstream point from the site. Then, dug a drain ditch to convey the river/stream water downstream of the construction site.	If you see a plenty of seepage at the construction site, dewatering should be carried out continuously with buckets. Drain ditch and drain pit are required to be arranged. Drainage pumps or treadle pumps may be applicable, when buckets are not sufficient.
4		**Material for Temporal Weir:** For setting up the temporal weir to divert stream/river water, sandbags are appropriate.	

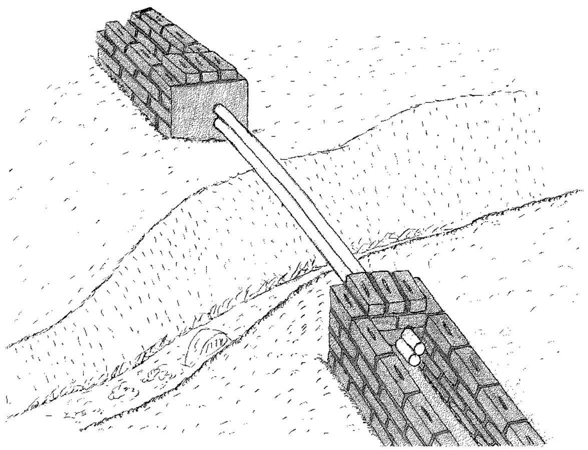
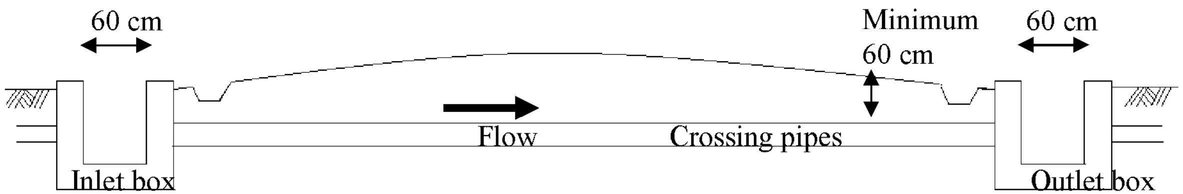
Step	Process	Description	Remarks
5		**Excavation of River foundation:** While keeping construction site dry, excavate the foundation of construction point down until the bedrock. Abutment should be also excavated at least 2 m to the horizontal direction into river bank on both sides.	
6		**Further Excavation:** River/stream bed should be further excavated 50 cm to 70 cm in depth from river/stream bed.	If soft soil or unsuitable soil is exposed, additional excavation should be carried out. **Attention:** To prevent landslide, shape of the wall at abutment should be in slope, if the depth of excavation is expected to be deeper than 1.5m.

Step	Process	Description	Remarks
7		**Chipping Rocky Foundation:** If there is rock on the bottom of river bed, chipping should be done to make concrete to contact with foundation well.	To chip the rocks, you use hammer, and chisel if you have.
8		**Concrete Mixing:** In order to get proper concrete for weir construction, standard mixing proportion of cement to sand and crushed stone is: 1 : 2 : 4, which is equivalent to 1 bag of cement (50kg), 2 wheelbarrows of sand and 4 wheelbarrows of crushed stones. Reference: For canal construction, the standard mixing proportion of cement to sand and crushed stone is: 1 : 3 : 3 or 1 : 3 : 6.	Prepare drums of water for concrete mixing at the site on the day of construction. The water should be clean. If the sand is dry, pour 1 jerrican (20 liter) of water and mix it in advance. Then, additional water should be sprayed and mixed to keep proper consistency. Stones should be crushed in advance with a diameter of 15-20 mm. The mixing should be carried out on a steel plate or an exposed rock foundation, otherwise soil could be mixed up, making the concrete quality poor.

Step	Process	Description	Remarks
9		**<Weir Construction>** **<u>1) Placing the base concrete</u>** The base concrete with weir mesh is placed on the bottom of construction space (excavated area). The thickness of the base concrete is at least 5cm. Wait until concrete dries up while giving it proper curing.	Unless de-watering is kept continuously, never close the construction site completely.
10		**<u>2) Assembling Reinforcement bars</u>** Assemble the reinforcement bars on the base concrete after the concrete dried up. It is recommended to assemble the bars at intervals of 25-30cm. (usually 30cm). As for the size of reinforcement bar, Y12 (12mm) and Y16 (16mm) of diameter are usually used for weir construction. Y means deformed bar.	Y12 and Y16 are used for horizontal and vertical members respectively. Make sure that the persons who deal with the reinforcement bars should wear gloves for safe.

Step	Process	Description	Remarks
11		**3) Assembling Framework (Shuttering)** Assemble framework (Shuttering) to place the concrete while covering reinforcement bars assembled. The inside of frame works should be coated with a bit of oil; it helps smooth removal of the framework after concrete is ready.	Make sure that the persons who deal with the reinforcement bars should wear gloves for safe.
12	 Concrete wall weir supported several buttresses	**4) Placing Concrete** Pour concrete into the framework layer by layer. Split level is helpful to see the level of the layer depending on the preparation of frame work (shuttering). (30cm thickness is recommended for each layer). Interstices and gaps inside of the frame work should be filled thoroughly with concrete by poking the concrete with sticks.	Concrete should be gently placed not to disturb reinforcement bars assembled properly. Voids in the weir body should be filled with concrete entirely to stop water leakage and strength the weir body. After completion of placing concrete, the top of weir should be covered with wet grasses or wet straw mats to prevent sunshine. This type of weir is applied for the weir having more than 2.0 m of weir height.

(3) Gully Crossing and Road Crossing

	Process	Description	Remark
1		<u>Gully Crossing</u> 1. A gully crossing is constructed to convey water across a gully. 2. The length of pipe is normally less than 6m. 3. The pipe is required to be installed at the height of 10cm from canal bed.	- Considering the strength of pipe and necessity of support, the length is less than 6m. - Since the length of pipe is limited, the location of gully crossing is decided considering the length.
2	<u>Road Crossing</u>  1. Pipes are installed under ground and soil covering depth shall be more than 60cm. 2. The pipes are installed at the height of 10cm from canal bed.		- Road crossing is constructed to convey water across the road.

CHAPTER 7 O&M OF IRRIGATION FACILITIES

7.1 Irrigation System's Operation Plan

(1) Types and Selection of Irrigation Methods

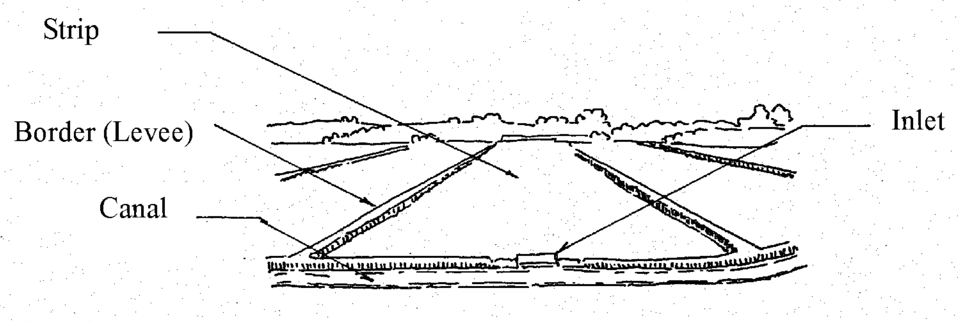
In general, irrigation methods applicable for upland crops could be divided into following four types;

- Surface irrigation – basin, furrow and border strip (see **Figure 7-1**),
- Overhead irrigation – watering-can/bucket and sprinkler,
- Micro-irrigation – drip, micro-sprinkler, mini-sprays and mini-sprinkler, and
- Sub-surface irrigation – shallow ground water or active control of groundwater to permit cropping in the dry season.

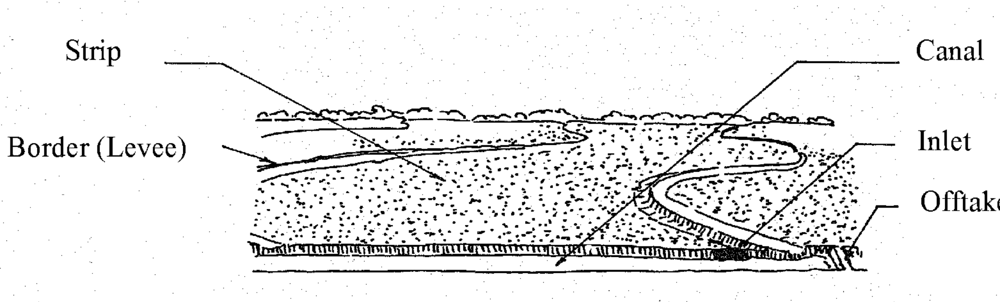
Each irrigation method has advantages and disadvantages that should be taken into consideration when choosing the most suitable irrigation method. The factors influencing selection of the type of irrigation methods are listed below;

- Natural conditions (soil type, slope, climate, water quality and quantity),
- Type of crops to be grown,
- Farmers' previous experience of irrigation, and
- Capital and operational costs,

The subsequent discusses more details on the surface irrigation methods such as basin and furrow (ridge) irrigation methods, which are widely and commonly applied.

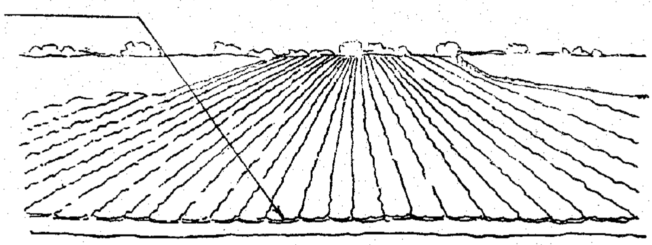


Basin Type with Level Border of Surface Irrigation



Basin Type with Contour Levee of Surface Irrigation

Canal



Basin Type with Level Furrow (Ridge) of Surface Irrigation

Figure 7-1 Typical Layout of Surface Irrigation Methods

a) Basin Irrigation Methods (Flat Bet, Raised Bed, Ridged Bed)

Basin is a leveled area of land with strips enclosed by earthen border ridges of levees, witch is totally flooded during irrigation. Water is held on the surface of the basin until it goes into the soil. Water is normally brought to the basin in earth canal using gravity. Where water is pumped from the water source, it should be pumped to a high portion and distributed in canals under gravity. Basins could be flat, either sunken or raised or ridged. In all cases good basin irrigation requires the ground surface to be level.

Basin irrigation is suitable for many crops. The advantages are; a) right amount of water can be given with a minimum amount of labour if the beds are well leveled, b) water losses could be kept low by minimum run-off, and c) basins last for a long time once they are constructed.

On the other hand, the basin irrigation needs a good water supply to fill the basin quickly. This in turn requires accurate land leveling and field layout from the start, which may need a lot of manual labour. Prolonged ponding and crop damage could occur in poorly managed flat beds. There is also the risk of soil erosion in the supply canal as a result of the high speed of the water.

The systems on level strips are classified as the level system. The classification of the surface level system is summarized as follows;

- Level border : Basin type with level border
- Contour level : Basin type with contour levee
  Basin type with level furrow (ridge)

Level Border

The level border type of surface system consists of a level area enclosed by earthen border ridges of levees. When irrigating, designed amount of water is turned on the strip and allowed to spread until it is absorbed.

For a uniform distribution of water, the rate at which the water is turned onto each strip should be at least twice as the succeeding one as along as soil can absorb it. This rate gets water over the entire strip as quickly as possible. Otherwise, more water than the necessary is absorbed near the head ditch. For this reason, level border system must be constructed so that at least 3.5 lit/sec/ha of water is available for strip. Another feature that will increase the speed of water flow across the strip is to construct a slight grade. It may also help prevent water from pounding in low spot.

Contour Levee

The contour levee type of surface system is similar to the level border system except that it is adapted to the sloping land. The strips should be graded until they are level. Instead of rectangular fields bordered by dikes or levees, the fields are bound on the contour by levees at the lower edge of the strip.

When watering, the procedure is the same at that for the level border system. Water is applied from farm ditch at one ends of the strip. It spreads rapidly over the area where it remains until water becomes absorbed, unless extra water is applied for weed control.

Since contour levee systems are leveled areas on the side of a slope. There are often two or more such strips below the highest one. In that case, water can be released from the higher strips to the lower strips. Water is held at the desired level on each strip by small spillways in the levees. They allow excess water from one strip to spill over onto the strip immediately below. If there is too much water for the lowest strip, it is drained into a farm drain at the lower edge of the field.

Level Furrow (Ridge)

The level type of surface system is the same as the level border type except for the addition of furrows. There is a little slope. The size and shape of the furrow depends on the crop grown, equipment used and spacing between the rows.

When irrigating, a stream as large as the furrow can withstand is turned into each furrow by siphon tubes or pipes. It is allowed to flow until the amount needed is obtained. The water stands in the furrow until it would be absorbed into the root zone below the furrows and in the ridges between the furrows. It is said that with this type of system, about 15 percent more than that is needed to obtain enough water on the entire strip will generally be required. The reason is that more water is absorbed by the area next to the farm ditch where the water is applied.

b) Furrow Irrigation Methods

Furrow irrigation is generally used on farms having large uniform fields, where long furrows can be formed, usually using a tractor. They are not appropriate for very small-scale irrigation where farmers' plots are small and irregular in shape.

Under furrow irrigation water is taken to the plant through long, narrow canals (furrows) formed in the soil at regular intervals, between the crop rows (ridges). It is important to use the right shape of furrow, furrow spacing and length. Good water management is important for the method to work well. If managed well, furrow irrigation has the following advantages;

- Moderate and high irrigation efficiency,
- Less danger of leaching nutrients from the soil than with basin method,
- Crop stems are not wetted, and
- Even soils, which form a surface crust when flooded, can be irrigated as water moves laterally from the furrow into the ridge, below the level of plant growth.

The disadvantages of furrow irrigation are listed as follows;

- Erosion could occur if slope is two steep,
- Labour requirement may be high as the streams must be carefully regulated to achieve uniform water distribution,
- Salts from the soil or water supply may concentrate on the top of the ridge and eventually cause damage to young crops planted there,
- Lateral spread of water in coarse textured soils may not be enough to wet the soil between the furrows, and
- Careful land leveling is required for uniform furrow slope an shape.

(2) Distribution of Irrigation Water and Plan of Irrigation Schedule

a) General Methods of Water Distribution

Following two types of water distribution methods are generally applied at present;

- Simultaneous distribution, and
- Rotational distribution

1) Simultaneous Distribution

This method involves simultaneous supply of water to all the canals.

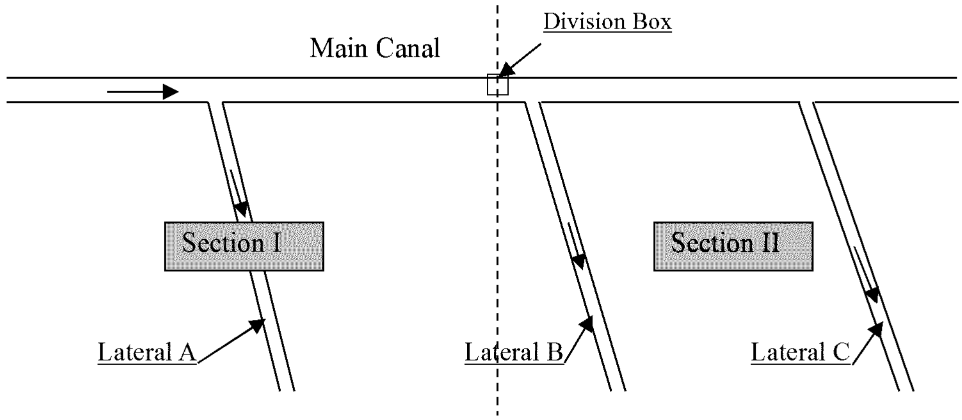
2) Rotational Distribution

Rotational distribution is practiced by rotating the supply of water to different areas. Under this method there are three practices as shown below, namely:

- Rotation by section in main canal
- Rotation by section or turnouts in the lateral/feeder canals
- Rotation by section in the farm ditch

Rotation by Section in Main Canal

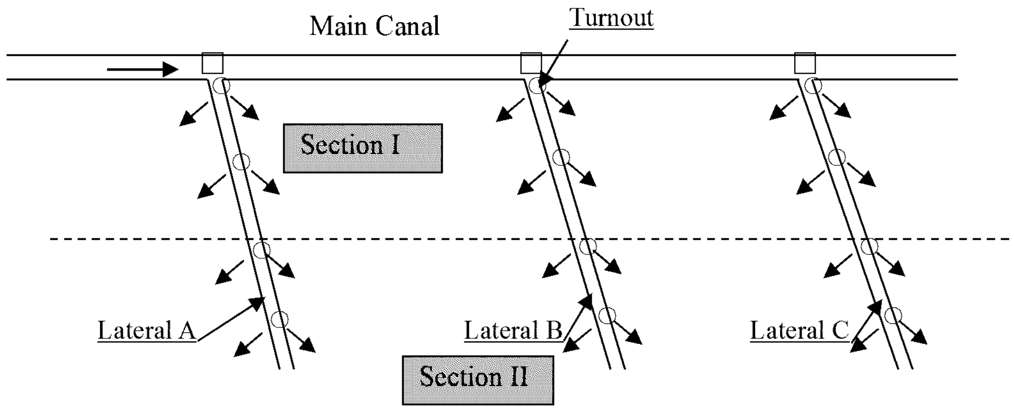
Irrigation water is conveyed by rotation to different sections in the main canal (refer to the following figure). This method requires bigger capacities for both conveyance and distribution systems.



Generally, 3-day to 7-day rotational water supplies are adopted in the small scale irrigation schemes, so that irrigation interval in each scheme should be carefully checked and determined, based on the soil characteristics, estimated crop water requirement, canal and pump capacity, etc.

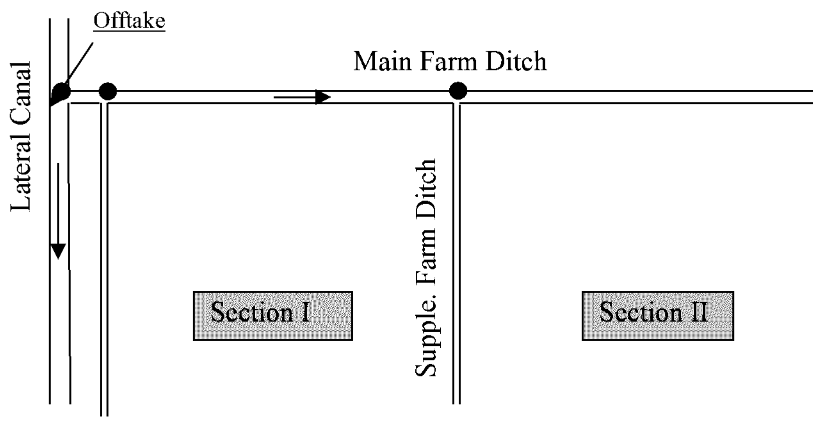
Rotation by Section or Turnouts in Lateral/Feeder Canals

The main canal conveys a continuous flow while the water is rotated by the section or turnouts of the lateral/feeder canal (refer to the following figure)



Rotation by Section in Farm Ditch

Water is rotated only in rotation area in the farm ditch, and conveyance of water in the main canal and lateral/feeder canals are continuous.



b) Comparison on the Water Distribution Methods

1) Advantages of Rotational Distribution Methods

Advantages of rotational water distribution are as follows;

- Water can be reasonably regulated and evenly distributed over the upper, middle and lower reaches of canal systems to meet the requirements for reducing and/or eliminating the droughts in the spot areas, when the water resources is scarce.
- It may save water which can be used for either extension of new irrigation areas or can be supplied for fish culture uses.
- Furthermore, the farmers will retain confidence in getting timely delivery of a limited amount of irrigation water during dry (summer) season and drought year.

2) Advantages of Simultaneous Water Distribution Methods

When the water resource is abundant, this method has the following advantages.

- The investment in the irrigation system is less because of fewer water control structures and measuring devices in the system.
- Less labour is used in simultaneous irrigation as compared with rotational irrigation.

c) Examination of Irrigation Schedule

In order to properly manage and operate the irrigation facilities, an irrigation schedule should be prepared. Irrigation schedule shows an irrigation interval, date and water supply duration of time, when the farmer may irrigate. Irrigation interval should not exceed a permissible maximum irrigation interval, which will be determined based on soil holding capacity of the soil. Though the maximum irrigation interval depends on the soil characteristics, it can be said that the interval, in general, would be preferable within a week in the most cases.

To examine the optimal irrigation interval for selected sites, the irrigation schedule inclusive of irrigation schedule, date and water supply duration of time should be studied considering the concepts of Readily Available Soil Moisture (RAM). For optimum growth of crops, the crops will be losing water at a rate equivalent to Crop Water Requirements (ETc). The number of days for crops to deplete available soil moisture (irrigation interval : Id) can be obtained from the following equation;

$$Id = RAM / ETc$$

Where ;
- Id = Irrigation interval (day)
- RAM = Sa x P x D x C
- Sa = Available soil moisture (mm/m)
- P = Fraction of available soil moisture
- D = Rooting depth (m)
- C = Correction for ETc
- ETc = Evapo-transpiration by crop (mm/day)

Irrigation interval for selected schemes should be examined based on the above equation.

On the other hand, water supply duration of time for each crop was calculated on the basis of following equation.

$$Sd = Di \times A \times 10 / (Qw \times 3{,}600)$$

Where ;
- Sd = Water supply duration (hr)
- Di = Depth of irrigation (mm)
- A = Irrigation area (ha)
- Qw = Available water (lit/sec)

(3) Operation and Maintenance and Water Management Plans at Farm Level

a) Water Allocation and Distribution Schedule to Target Farm Area

According to the rotational irrigation schedule as discussed in the above, water supply amount, supply duration and irrigation interval to the terminal rotation unit should be determined in each scheme as outputs in the irrigation schedule. The terminal rotation unit (TRU) is here defined as a group of fields to which irrigation water is supplied as a rotation unit by a supplemental farm ditch as shown in **Figure 7-2**.

Figure 7-3 shows an output example wherein the terminal irrigation unit is the area served by supplementary farm ditch (SFD). The final output of operation plan for crops should therefore, answer specific questions raised by farmers in each field or water distribution unit (refer to the following figure).

Expected Farmer's Questioned on Crop Irrigation Operation

Although farm level irrigation schedule should be prepared in the planning/design stage, the schedule would be based on a representative field size and crops. The specific operation schedules, thus, should be made considering the design components such as; the design irrigation efficiency, the maximum permitted length of furrow or border to maintain the level of the design irrigation efficiency, and the design furrow rate of discharge/border stream size.

b) Water Management Parameters

Terminology Definitions of Parameters

Terminology definition for the following parameters should be cleared;

- Number and size of terminal rotation unit (TRU),
- Design flow rate of discharge (Qd) = gross irrigation water requirement (GWR) x whole Irrigation area (A),
- Water supply rate at the inlet (Qs),
- Furrow discharge or Stream Size (q)
- Design furrow rate of discharge or border stream size (qd)
- Irrigation interval (In),
- Design irrigation duration for crops (Tud), (Tpd),
- Design maximum permitted length of furrow or border (Lmax), and
- Design irrigation efficiency (IE) ,

Parameters Determination Principles

Considering the size of the programmed are which is small and the real conditions of farm level practices, the following principles will be adopted to simplify the procedures;

- Terminal rotation unit (TRU) is divided into irrigation blocks to simplify the operation. Simultaneous irrigation is applied within each block.
- Earthen off-take is applied to simplify the regulation of water. Thus, Qs value is used as the supply volume ay each unit.
- Bar-chart presentation of cropping pattern or schedules is applied, because the size of each unit

may suggest early completion of farming activities such as seedling, transplanting, and harvesting

- The design irrigation efficiencies (IE) is applied for calculating the amount of water supply (irrigation water requirement, IWR) considering the size of the irrigation area.

Parameters given from the Planning/Design Stage

The following parameters should be defined;

- Amount of water supply at the inlet (Qs) (lit/sec),
- Supply duration of on upland crops (Tud) (hr),
- Supply duration of paddy rice (Tpd) (hr),
- Irrigation Interval (In) (day)
- Design furrow rate of discharge or border stream size (qd) (lit/sec) per furrow or unit border strip width,
- Design maximum permitted length of furrow or border (Lmax) (m)
- Design irrigation efficiency (IE) (%)

Actual Maximum Length (Lmax) of Furrow or Border and Minimum Furrow Rate of Discharge or Border Stream Size (qmin)

By analyzing the map or through reconnaissance field survey, identify the longest furrow length or border strip length (Lmax) within the TRU. Considering the flow direction, the actual discharge or stream size (q) should be calculated during the preliminary blocking. The largest block is applied to estimate the minimum q (qmin).

For the furrow irrigation, if total number of furrow is equal to Nmax;

qmin = Qs /Nmax (lit/sec/furrow)

Where; Nmax = maxim number of furrow for furrow irrigation or maximum distance in meter of border width for border irrigation

Example: If the total numbers of furrows are estimated to be 50, and Qs = 41 lit/sec, qmin is calculated as:

Qmin = 41 lit/50 x 60 sec= 49 lit/min/furrow

Block Hectare (Ai) and Consumptive Use (CU)

Dividing TRU into blocks is done considering the cropping pattern, land topography and block size for operation. The blocks and corresponding hectarage should be delineated in the map. Consumptive use (CU) is applied only to upland crops. For paddy rice, this is referred to as the water requirement in depth.

Required Irrigation Water Supply per Application (V)

For upland crops, V is given as:

V = CU x In x A x10 /IE

Where;
V = Volume of water irrigated per application (cu.m)
CU= Daily consumptive use (mm)
In = Irrigation interval (day)
A = Irrigation area (ha)
IE = Design irrigation efficiency (%)

Water Supply Duration (Td)

Water supply duration is given as:

Td = V / 3.6Qs

Where; Td = Water supply duration (hr/application)

c) Crop Hectarage and Cropping Pattern

In accordance with the crop allocation, crop hectarage should be decided. The draft of blocking the area (dividing the terminal rotation unit (TRU) area into a number of blocks should be finalized with specific crop allocation. The following criteria should be considered in the blocking design:

- Same crops or crops with similar water consumption are planned in a block to ease up simultaneous application of a uniform irrigation depth over the same block,
- Same irrigation method is applied within a block, and
- Based on experiences at each irrigation scheme, the water supply duration is summarized. shown below per application to avoid wet damage on crops.

Figure 7-2 Schematic Illustration of Terminal Rotation Unit (TRU)

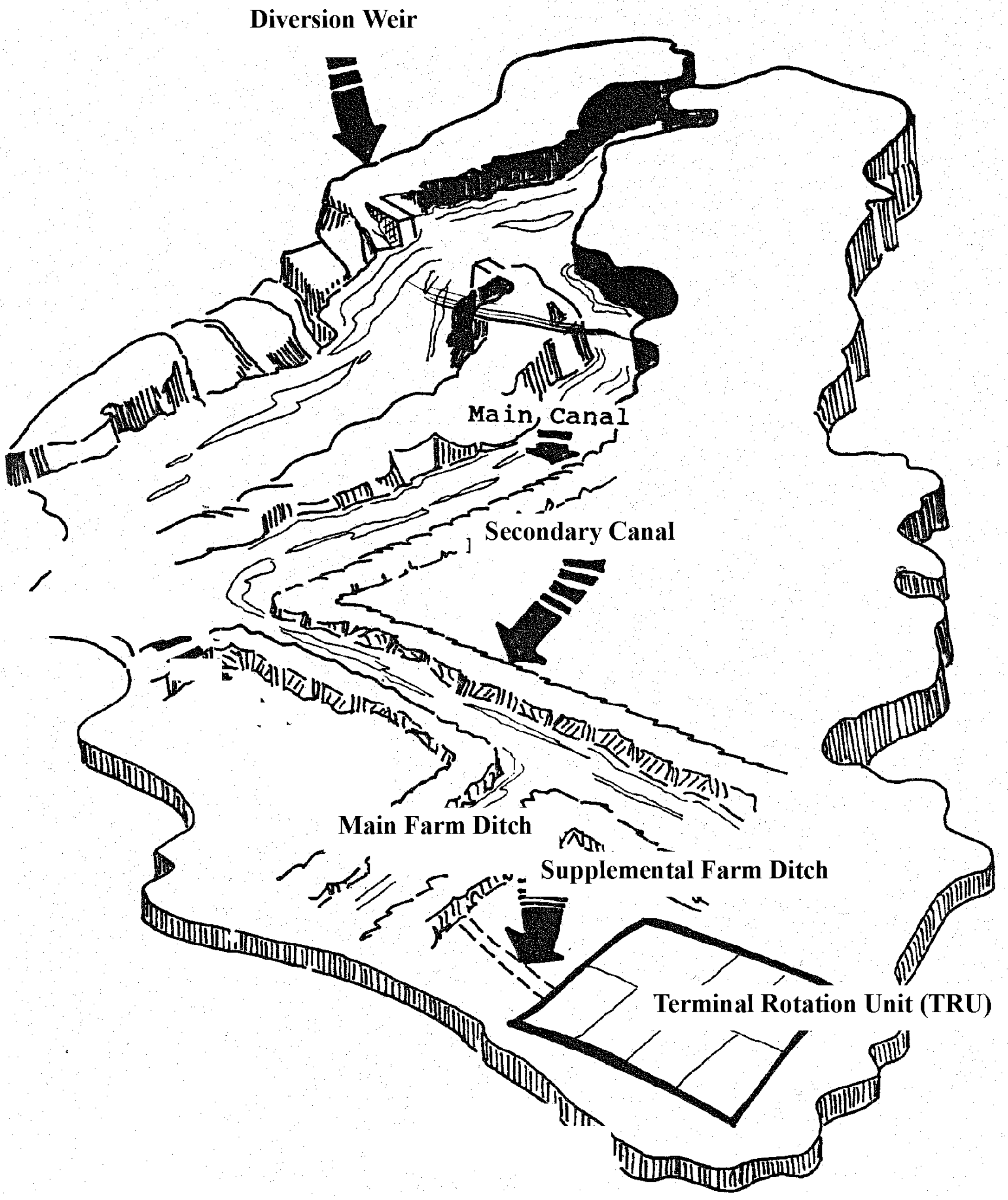
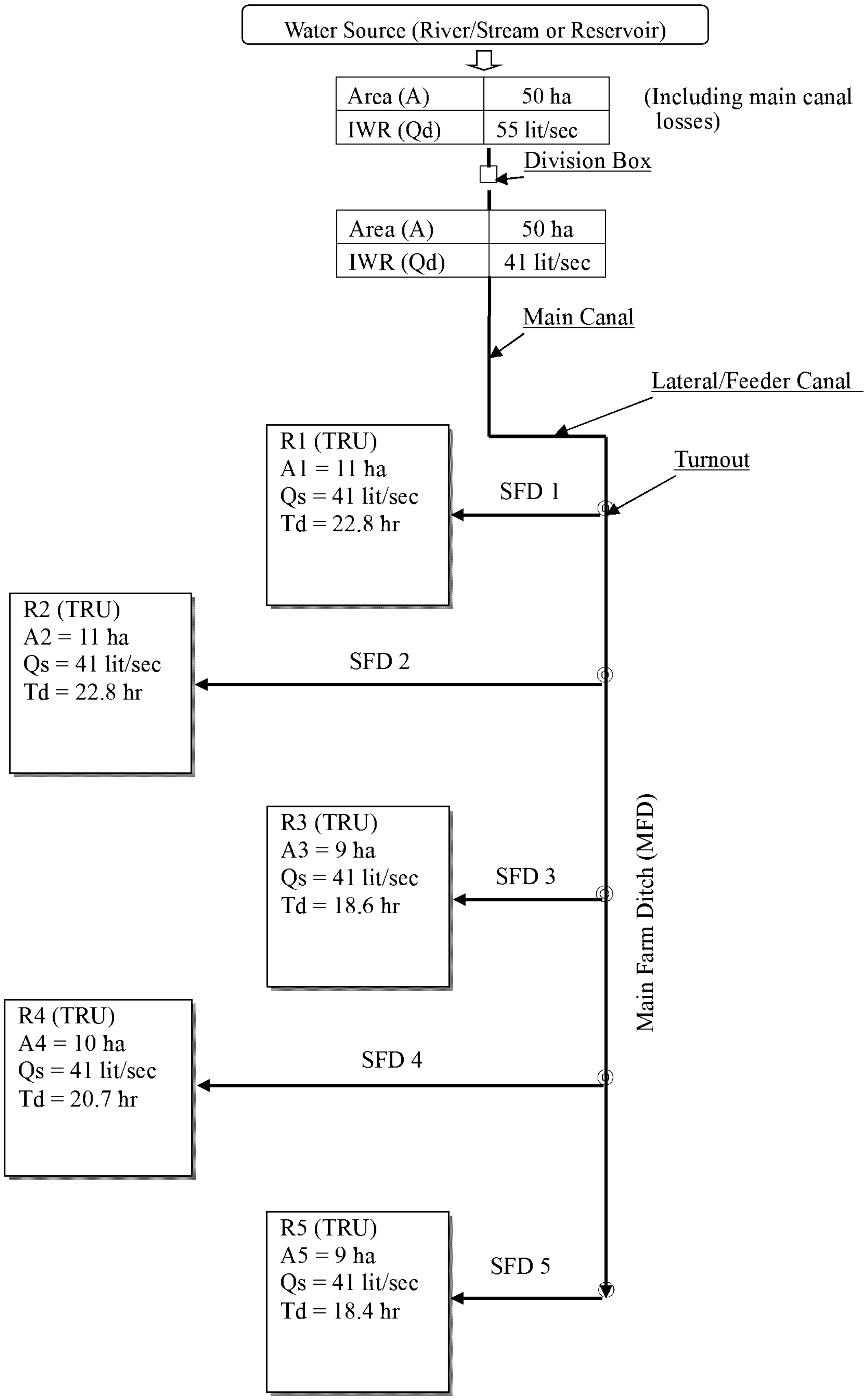


Figure 7-3 Example of Irrigation Network Diagram for Rotational Irrigation



d) Water Allocation and Delivery Schedule

The scheduling includes following five steps, namely; a) defining the designing stage parameters, b) preliminary blocking and evaluation, c) deriving crop hectarage, pattern and blocking terminal rotation unit (TRU), d) calculating water supply durations (Td), and e) determining water allocation/delivery schedule and dissemination.

Step-1. Defining the Design Stage Parameter

Define the following parameter, namely; TRU, Qd, Qs, q, qd, In, Td, Lmax and IE.

Step-2 Preliminary Blocking

Preliminarily, divide the fields in the TRU into a number of blocks considering the existing farming conditions, topography and other physical features. Blocking is done by firstly analyzing the map. If there are doubts in the topography, reconnaissance survey should be undertaken.

Step-3 Determining Cropping Hectarage and Pattern and Blocking TRU

Review the design cropping pattern, hectarage and crop water requirements (CWR) values for crops. If different cropping patterns are suggested from the design, re-determine the new hectarage, cropping pattern and CWR values. Then the specific planting area allocation would be obtained in the map and check with the preliminary blocking draft to assign single cropping pattern to one block.

An example of blocking draft is shown in the following table;

Summary of Crop Hectarage and Cropping pattern within a TRU

Block No	Crop/ CWR(mm/month)	Wet Season					Total Hectarage (ha)
		Nov.	Dec.	Jan.	Feb.	Mar.	
1 - 6	Maize CWR(mm/day)	2.5	3.0	4.5	4.5	4.5	8
7 - 11	Tobbaco CWR	2.5	2.5	3.5	4.0	4.0	6
						Total	14

Step-4. Calculating Water Supply Duration

Based on the blocking draft, water supply duration of each block would be determined by the following calculation and evaluation procedures;

- Maximum flow length of run,
- Paddy rice irrigation area with night time irrigation,
- Discharge rate per furrow or unit border width,
- Total water supply duration, and
- Individual block water supply duration

Step-5. Determining Water Allocation/Delivery Schedule and Dissemination

Based on the required water supply durations, determine the time table of water delivery in each block for each month considering the followings;

- Rotational irrigation schedule,
- Allocating water for paddy farm during night time,
- Allocating water from upper farms to lower farms,
- Farming activities,
- Weather conditions,
- Plant conditions, and
- Others.

7.2 Maintenance of Irrigation Facilities

(1) River Diversion Weir

As per fixed type weir of stone masonry or gabion, no routine maintenance work is usually required. Inspection around the weir should be carried out periodically and after every flood and every year before starting dry season irrigation. Following items should be inspected,

- Damaged part of stone masonry.
- Damaged part of gabion.
- Scouring at downstream of the weir.
- Sediment at upstream.
- Scouring at both side abutments.

Damaged part of stone masonry should be repaired with mortar and damaged part of gabion should also be considered for rehabilitation. Scoured part at downstream of the weir should be protected by gabion or stone pitching. Scoured side abutment should be replaced with stone masonry or gabion, or reinforced with gabion or sand bags. In the case that sediment accumulated to inflow to canal, it should be removed. Maintenance check list is shown in the **Table 6-2.**

(2) Canals

1) Main and Secondary Canals

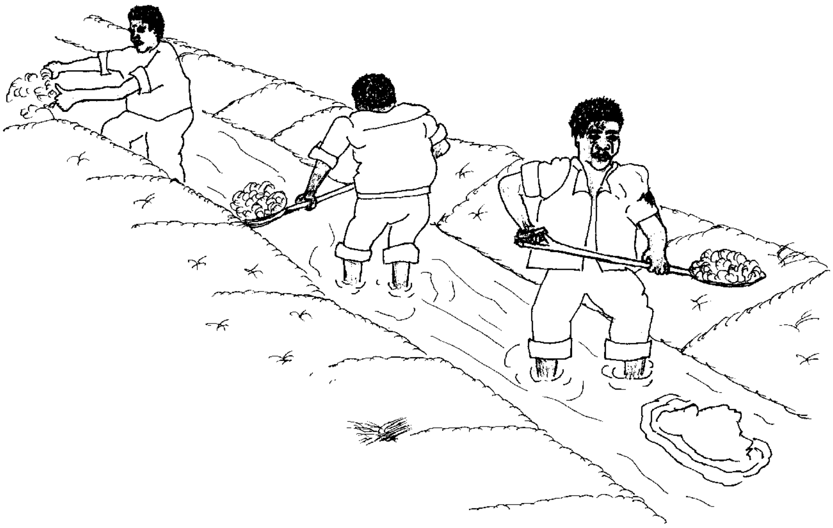
Stream water usually contains certain amount of suspended particulars, causing sedimentation in the canal. Eroded soil loss from field also gets into canal, resulting in the sedimentation in the canal. Maintenance work for canal should be done at least once before the irrigation season starts. Maintenance works required for the canal are; cleaning, weeding, de-silting, re-shaping, and also minor repairs as described below;

1) Earth canal

- Bushes and trees on the canal embankments should be removed. They may obstruct the water flow and their roots open the banks and develop leakages.
- Grasses, sediments and debris in the canal should be removed. While cleaning the canal, care must be so taken that the original shape of the cross-sections is kept. For this, a wooden frame with exact dimensions of the designed cross-section can be of great help.
- Crossing sections by people and animals (livestock) along the canal should be strengthened by hard compaction or lined with stones, bricks or masonry.
- Holes/cracks in the canal should be filled with sticky clay soil, and eroded sections should be rebuilt to the original shape.

2) Brick lined canal

- Grasses, sediments and debris in the canal should be removed.
- Cracks and water leaking point should be repaired with mortar.



2) Division Box, Discharge Box and Turnout

Division box, discharge box and turnout are made of brick masonry and the same maintenance work as brick masonry canal is required. In addition, maintenance on stop-log grooves is required. Damaged stop-log grooves should be repaired and reshaped with mortar to meet to stop-log. In case the connection part to earth canal is scoured, the part should be reinforced with gravel laying. Maintenance check list is shown in the **Table 7-2.**

(3) Maintenance Cost

Maintenance cost for each item is estimated as shown in **Table 7-3**.

Table 7-2 Maintenance Check Lists

Maintenance Check List for River Diversion Weir

Item	Frequency	Point to be checked	Findings
1. River conditions	Daily	Water level	Enough or not.
	Daily	Water flow conditions	Stable or not. Flood, rich or drought.
	Daily	Sediment	If it is a lot to affect intake, it shall be removed.
		Others	Water quality, flotage etc.
2. Weir	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	At after	Erosion at abutment	Need repair or protection or not
	Annually	Water leakage	Small scale or large scale. Need repair or not
	Annually	Riverbed scouring at downstream	Need protection or not
	Daily	Sediment	If it is a lot to affect intake, it shall be removed.
	Annually	Damage of gabion	Small scale or large scale. Need repair or not
	Annually	Subsidence and deformation of gabion	Stable or not. Need repair or not.
		Others	
3. Intake	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	Daily	Sediment	If it is a lot to affect intake pipes, it shall be removed.
	Daily	Trash	If it is a lot to block intake pipes, it shall be removed
	Daily	Water level	Enough or not
	Monthly	Damage of pipes	Need repair or not.
	Daily	Function	Functioning or not.
		Others	
4. Others	Monthly	Conditions of stop log	Need repair or not.
	Monthly	Conditions of gate	Need painting, reapir or not.
		Protection bund	Collapse or erosion. Need repair or not.

Maintenance Check List for Water Impounding Dam

Item	Frequency	Point to be checked	Findings
1. Reservoir	Daily	Water level	Elevation
	Annually	Sediment	Depth
		Others	
2. Spillway	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	At after every flood	Erosion at abutment	Need repair or protection or not
	At after every flood	Erosion at downstream	Need repair or protection or not
	At flood time	Flow capacity	Enough or not (at flood time)
	At flood time	Flow condition at flood	Stable or not
	Annually	Conditions of channel	Damage, weeds etc.
		Others	
3. Dam embankment	Monthly	Crack at embankment	If there is, consult with irrigation engineer.
	Monthly	Erosion of embankment	Small scale or large scale. need repair immediately or not.
	Monthly	Collapse of embankment	Small scale or large scale. need repair immediately or not.
	Monthly	Water leakage at down stream	Small scale or large scale. expanding or not. Need repair immediately or not.
		Others	
4. Intake and outlet	Annually	Sediment	If it is a lot to affect intake pipe, it shall be removed.
	Daily	Trash	If it is a lot to affect intake pipe, it shall be removed.
	Daily	Function	Functioning or not.
		Others	
5. Others	Daily	Water quality	Affect to crops or not.

Maintenance Check List for Canal System

Item	Frequency	Point to be checked	Findings
1. Brick or	Daily	Water flow conditions	Smooth or not
concrete	Monthly	Crack or damage	Small scale or large scale. Need repair or not
lined canal	Annually	Conditions of drain ditch (along the main canal)	Functioning or not. Need excavation or not.
	Monthly	Sediment	Small scale or large scale. Need removal or not
	Monthly	Weeds	A lot or a few. Need clearing or not.
		Others	
2. Earth canal	Daily	Water flow condition	Smooth or not
	Monthly	Cross section area	Enough cross section or not
	Monthly	Erosion	Need repair or not
	Monthly	Weeds	Need clearing or not
		Others	
3. Road	Daily	Water flow conditions	Smooth or not
crossing and	Monthly	Sediment	Small scale or large scale. Need removal or not
gully crossing	Monthly	Crack or damage	Small scale or large scale. Need repair or not
	Daily	Trash	If it is a lot to block pipe, it shall be removed
		Others	
4. Structures	Daily	Water flow conditions	Smooth or not
(division box,	Monthly	Sediment	Small scale or large scale. Need removal or not
drop box	Monthly	Crack or damage	Small scale or large scale. Need repair or not
turnout)	Monthly	Conditions of stop log	Need repair or not
		Others	
5. Others			

Maintenance Check List for Pipeline System

Item	Frequency	Point to be checked	Findings
1. River	Daily	Water flow conditions	Stable or not, flood, rich or drought
conditions	Daily	Water level	Elevation
	Daily	Conditions of intake point	Enough depth or not, Any obstruction.
		Others	
2. Pipes	Monthly	Crack or damage	Small scale or large scale. Need repair or replacement.
	Monthly	Water leakage	Small scale or large scale. Need repair or replacement.
		Others	
3.. Discharge	Daily	Water flow conditions	Smooth or not
box	Monthly	Sediment	Small scale or large scale. Need removal or not
	Monthly	Crack or damage	Small scale or large scale. Need repair or not
	Monthly	Conditions of stop log and groove	Need repair or not
		Others	
4. Others			

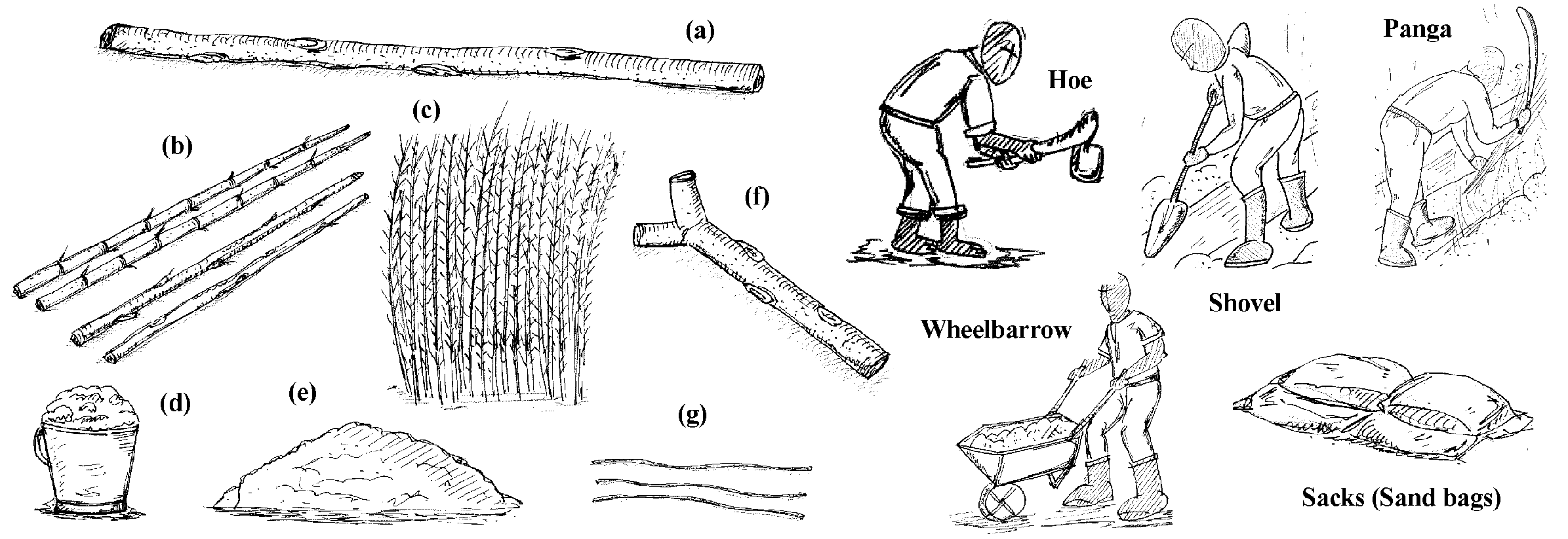
Table 7-3 Maintenance Cost for Each System

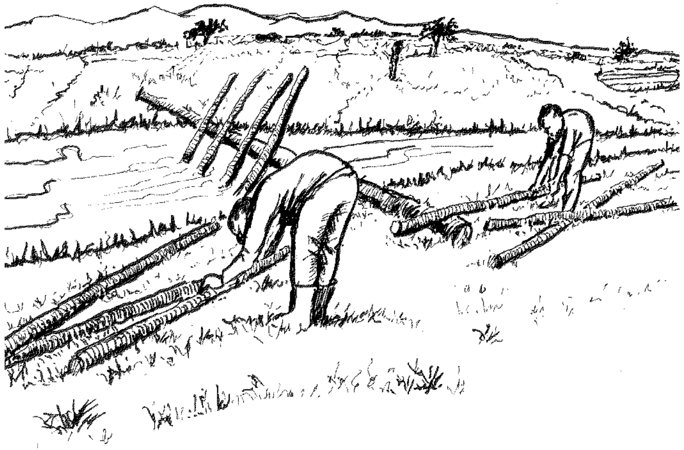
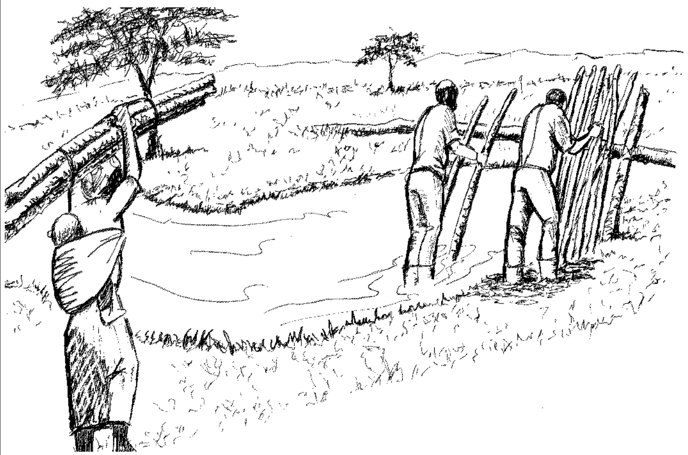
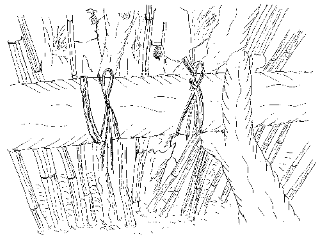
		Maintenance Cost Estimation						
	No.	Item	Specification/Quality	Quantity	Unit	Unit Price	Price	Remarks
						ZMK	ZMK	
	1	**River Diversion Weir**						
	1-1	Annual maintenance						
	(1)	Removal of sediment	unskilled labor	10.0	man		0.0	2man x 5 days
		Total		10.0	man		0.0	
	1-2	Every 5 years						
	(1)	Repair of stone masonry	weir, intake	1.00	m^3			
		rubble stone		0.54	m^3		0.0	
		sand		0.40	m^3		0.0	
		cement	ordinary portland	4.50	bags		0.0	
		material total					0.0	
		mortar mixing	unskilled labor	6.0	man		0.0	1day
		stone masonry	foreman	1.0	man		0.0	1day
			skilled labor	1.0	man		0.0	1day
			unskilled labor	5.0	man		0.0	1day
		labor total					0.0	
	(2)	Repair of gabion						
		rubble stone		1.0	m^3		0.0	
		steel wire		1.0	kg		0.0	
		material total					0.0	
		gabion work	skilled labor	1.0	man		0.0	1day
		gabion work	unskilled labor	3.5	man		0.0	1day
		labor total					0.0	
		Every 5 years Total	material				0.0	
			labor				0.0	
	2	**Open Canal System**						
	2-1	Annual maintenance						
	(1)	Cleaning canal	300m					
		unskilled labor		20.0	man		0.0	
	(2)	Repair of earth canal						

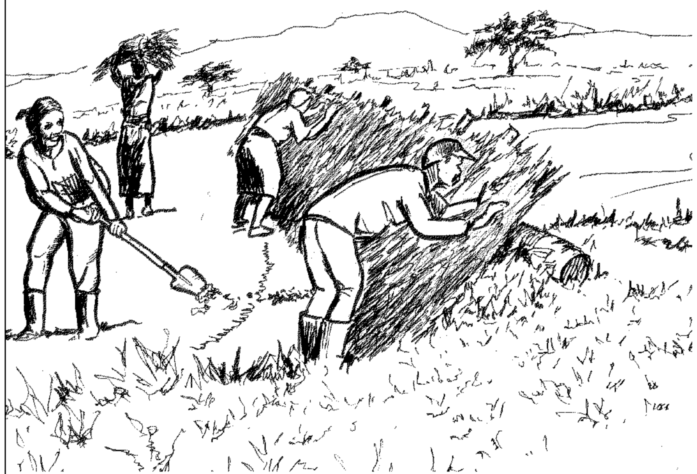
		Re-shaping	unskilled labor				0.0	each plot owner
	2-2	Every 3 years						
	(1)	Repair of brick lining						
		equivalent to 10m construction		10.0	m			
		Bricks		608.5	pcs		0.0	730.2x10/12
		Sand		0.2	m^3		0.0	0.34x10/12x0.5
		Cement	ordinary portland	2.6	bag		0.0	0.34x10/12x9
		material total					0.0	
		mortar mixing	unskilled labor	4.0	man		0.0	
		brick laying	skilled labor	1.0	man		0.0	
			unskilled labor	7.5	man		0.0	
		labor total					0.0	
	(2)	Repair of structures						
		equivalent to 1 box construction		1.0	box			
		bricks		223.0	pcs		0.0	223.0x1
		sand		0.1	m^3		0.0	0.15x0.8x1
		cement		1.4	bag		0.0	0.15x1x9
		material total					0.0	
		mortar mixing	unskilled labor	4.0	man		0.0	
		brick laying	foreman	0.3	man		0.0	0.33x1
			skilled labor	0.3	man		0.0	0.33x1
			unskilled labor	0.7	man		0.0	0.67x1
		labor total					0.0	
		Every 3 years Total	material				0.0	
			labor				0.0	

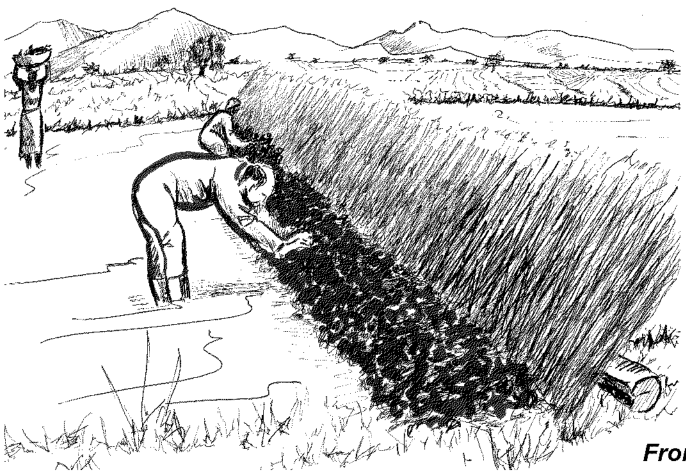
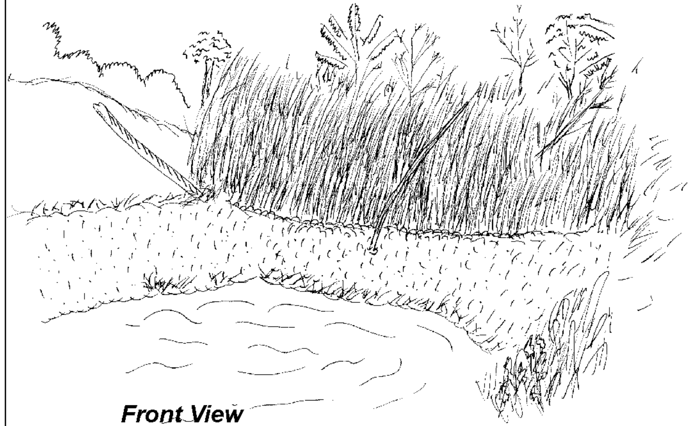
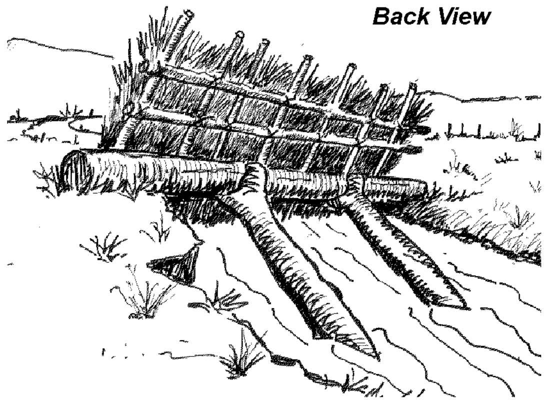
CHAPTER 8. Construction of A Temporary Weir

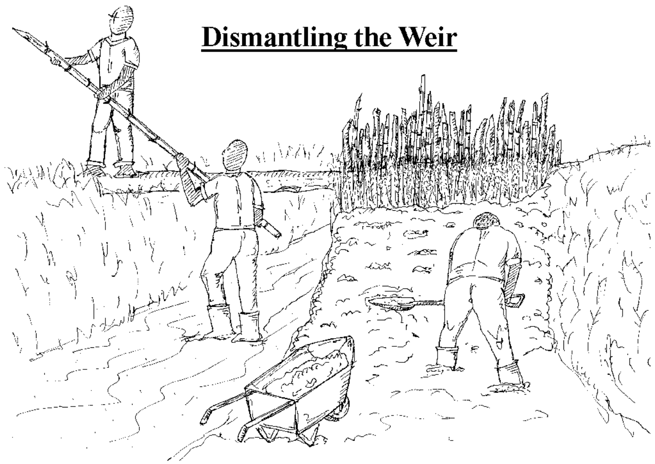
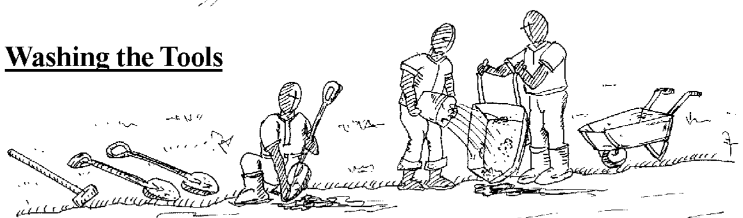
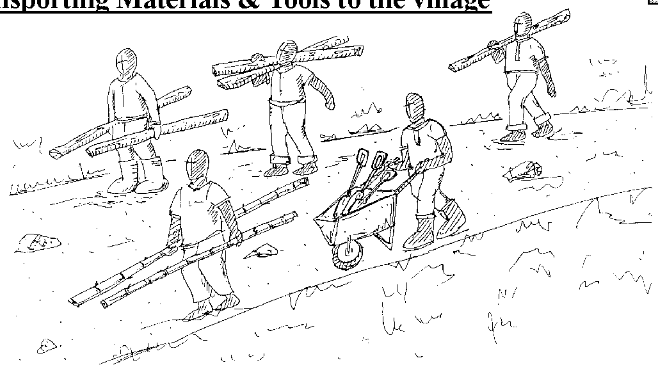
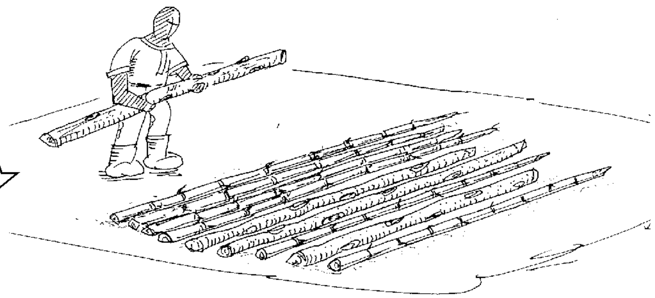
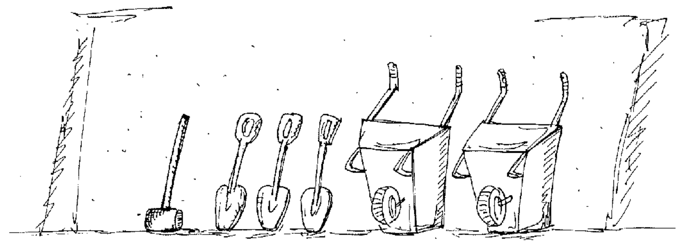
8.1 Inclined Wall Type (best suited at narrower streams)

Step	Materials to be collected
0	**Collect all the following materials (refer to the illustration below)**; (a) A log: to be put horizontally on the stream bank across the diversion point (Quantity: 1 nos., Refer to Step-1) (b) Bamboo/Twigs: to stand in front of the horizontal log (Quantity: 8 – 10 nos. per 1 meter width of the dam, Refer to Step-2) (c) Grasses (Elephant grass): to be put in front of vertical members (Quantity: depend on the size of the dam, Refer to Step-3) (d) Clay soil: to patch on the grasses. And, if necessary, the clay soil is put in the streambed to replace the sand foundation (Quantity: depend on the size of the dam, Refer to Step-5) (e) Ordinary soil: to patch on the clay soil patched on the grass (Quantity: depend on the size of the dam, Refer to Step-6) (f) Log: to support the brush dam (Quantity: depend on the size of the dam) (g) Creeper: to fix the bamboo/twigs to the horizontal log (Refer to Step-2) **Implements;** Hoe, Shovel, Panga knife, Wheelbarrow, Watering can, Sacks (Quantity of these implements depends on the number of participants for construction of the Dam).
	

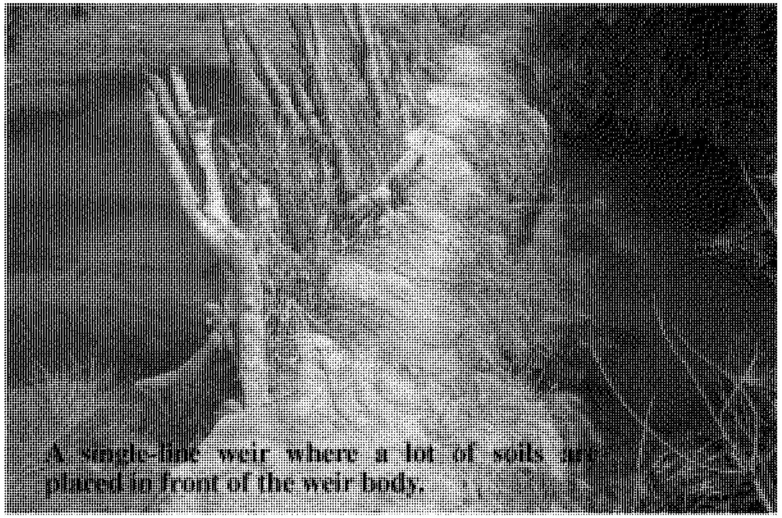
Step	Process	Description	Remarks
1		**<u>Put A Log Horizontally;</u>** Put a horizontal supporting log at the diversion point across the stream. It is advisable that the horizontal log is put on a place where there are tree stump/rock for support of the log. If there are no objects for support, put something such as stone to keep the log from moving by water pressure and weight of the brush dam itself. Length of the log is selected depending on the site condition such as width of the stream.	In case of such site where the material of stream bed is composed of thick sand layer, there is a need to replace the sand layer with imported clay soil. To make replacement work easy, a cofferdam may be constructed using sandbags. If the sacks are not available at the site, banking (soil filling) can be applied.
2		**<u>Stand the Vertical Members;</u>** The vertical members composed of bamboo/twigs are put in front of the horizontal supporting log as seen in the illustration.	To put grasses and soil easily, the vertical members such as bamboo/twigs should be put as close as possible together. These vertical members are placed into the foundation, which in cases has been replaced by clay soil, and again connected to horizontal support log at the top, using materials such as runner (see below). 

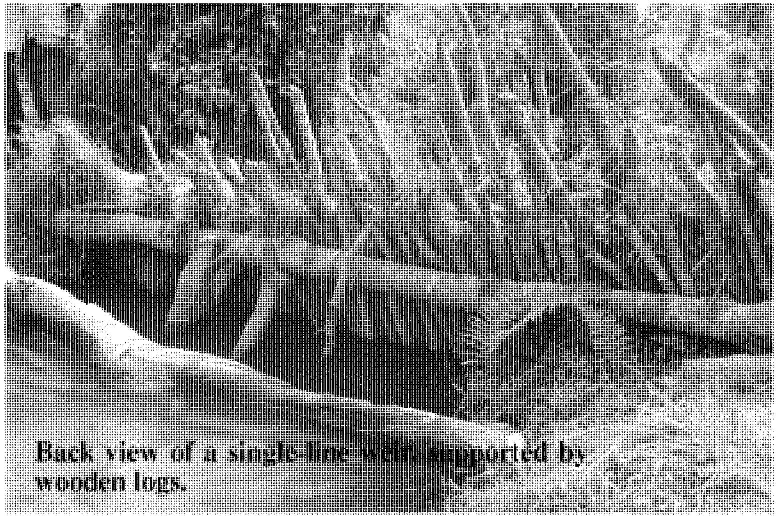
Step	Process	Description	Remarks
3		**<u>Placing the Grasses;</u>** Grasses are placed or fixed in front of the vertical members.	To prevent swelling out of grasses, the grasses are bound by horizontal members such as bamboo and tied together with the vertical members as shown in the illustration. 
4		**<u>Pile the Grasses</u>**; Grasses are piled horizontally on vertical standing grasses. See the illustration at the left.	To make the structure less porous to water, the horizontal layers of grass are placed in front of vertical layers of grasses in a criss-crossing way. This pattern helps in making the weir very much water tight. To prevent swelling out of grasses, the grasses may be bound by a vertical member (bamboo) once again.

Step	Process	Description	Remarks
5		**<u>Patch the Clay Soil;</u>** The clay soil is patched on the grasses as shown on the illustration in the left hand. Furthermore, to significantly prevent water leakage, the layer of clay soil constructed may be covered by soil existing around the brush dam.	To prevent water leakage, clay soil is patched tightly on the grasses. The clay soil is put not only on grasses as a part of dam but also on the stream banks in contact with the weir to minimize water leakage passing through banks.
6		**<u>Completion of Construction;</u>** The weir is then completed. See the illustrations in the left hand and below. 	**<u>Note; Maintaining the Weir</u>** During operation of the irrigated farming, the diversion weir should be maintained carefully. For instance, if a hole is found at the weir, immediately stop it by sealing with clay soil. This process will restore the weir its former good shape, as the hole will be a source of weakness whereby the structure can fail.

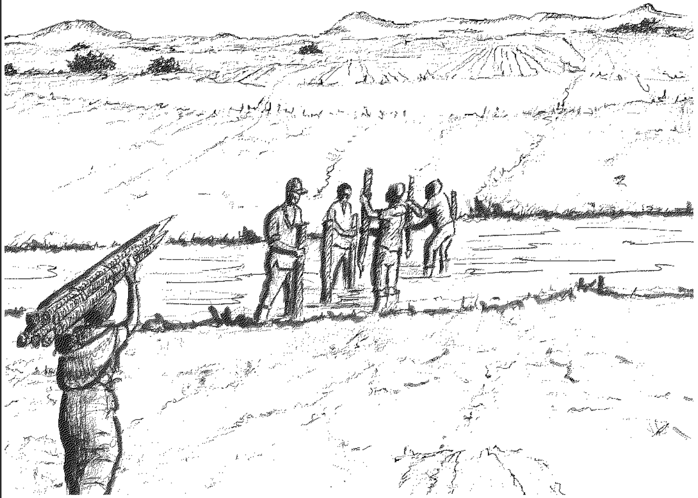
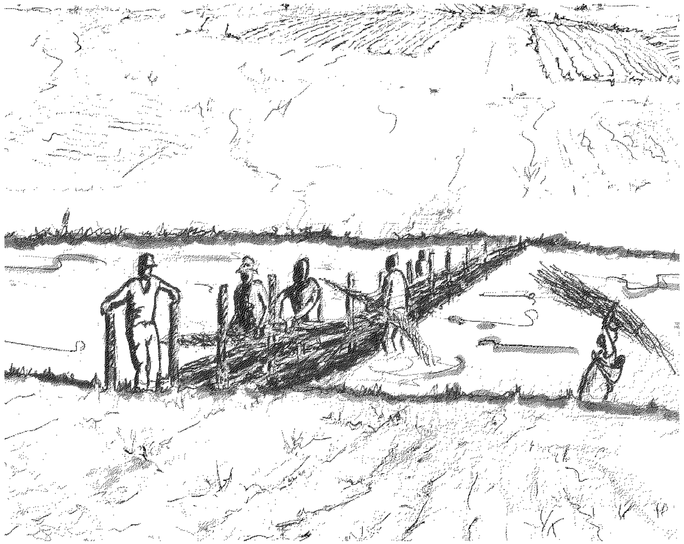
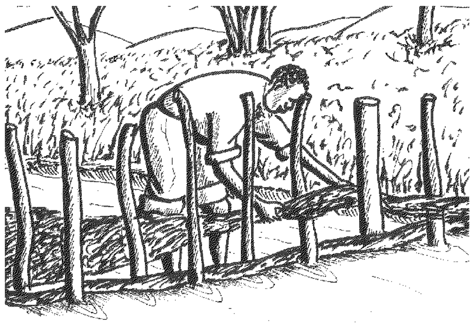
Step	Process	Description
7	**Dismantling the Weir**  **Washing the Tools**  **Transporting Materials & Tools to the village** 	**Note; Dismantling the Weir and Set Aside the Main Materials** These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. **Setting aside the Materials & Tools**  

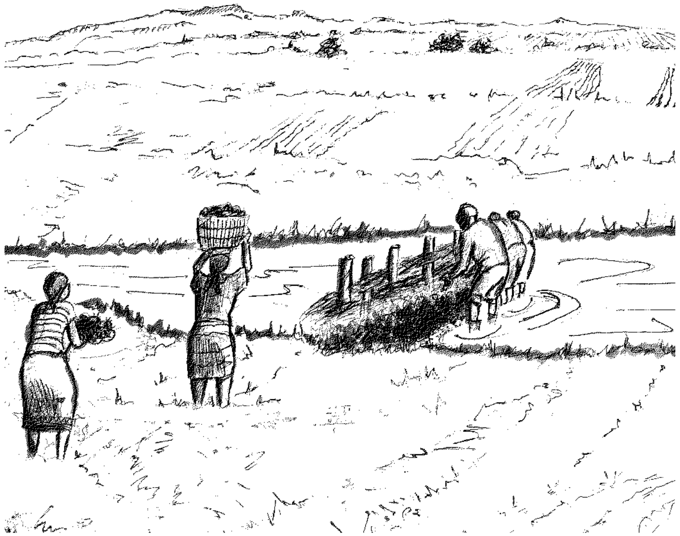
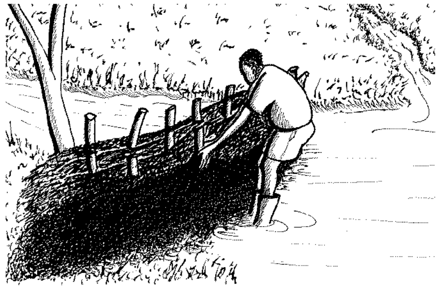
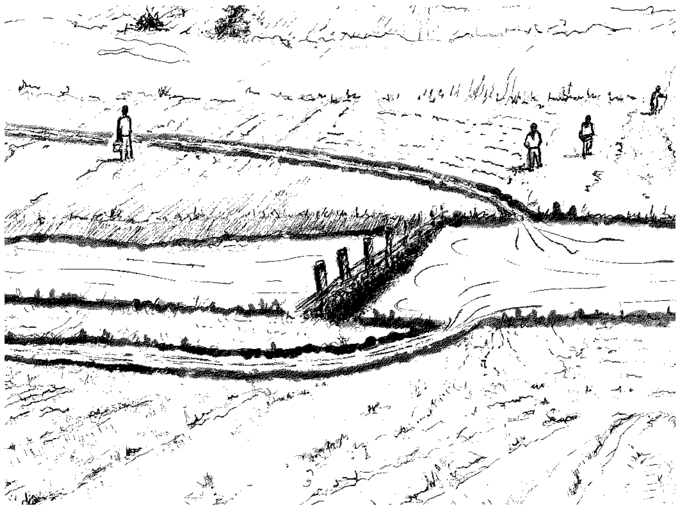
Examples of Inclined Weir (Kawambwa District, Luapula Provicne)

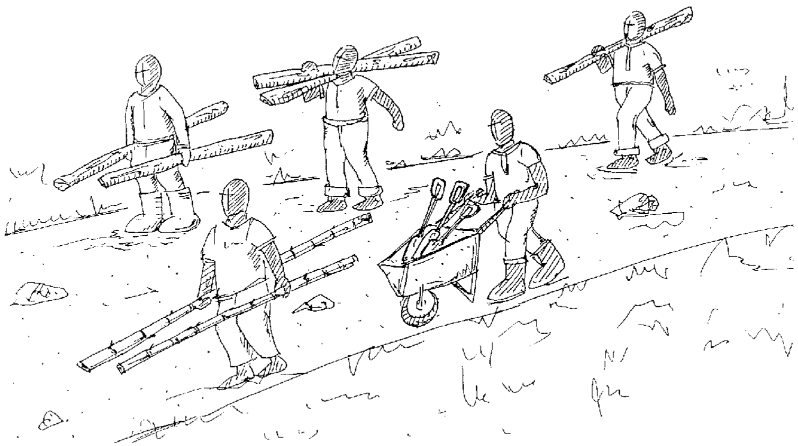
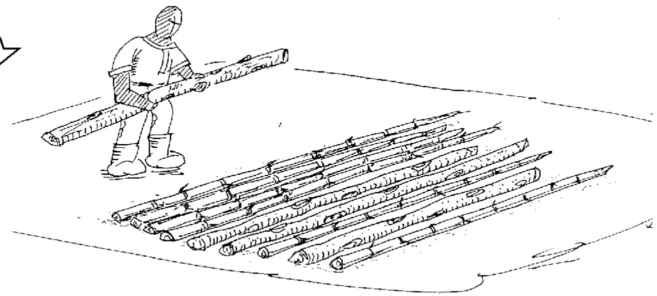
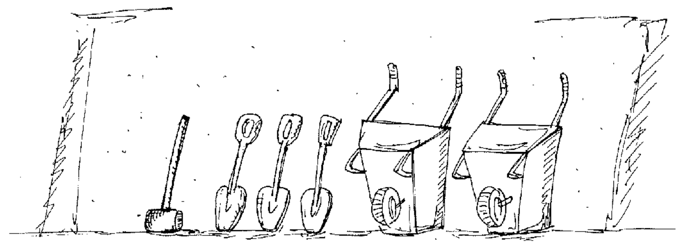

A single-line weir where a lot of soils are placed in front of the weir body.


Back view of a single-line weir supported by wooden logs.

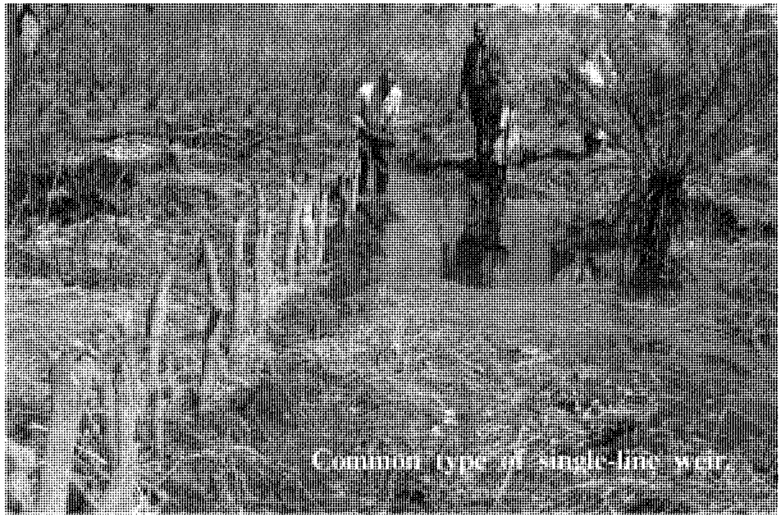
8.2. Construction of A Temporary Weir: Single-line Wall Type (best suited at wider streams whose foundations are not rock)

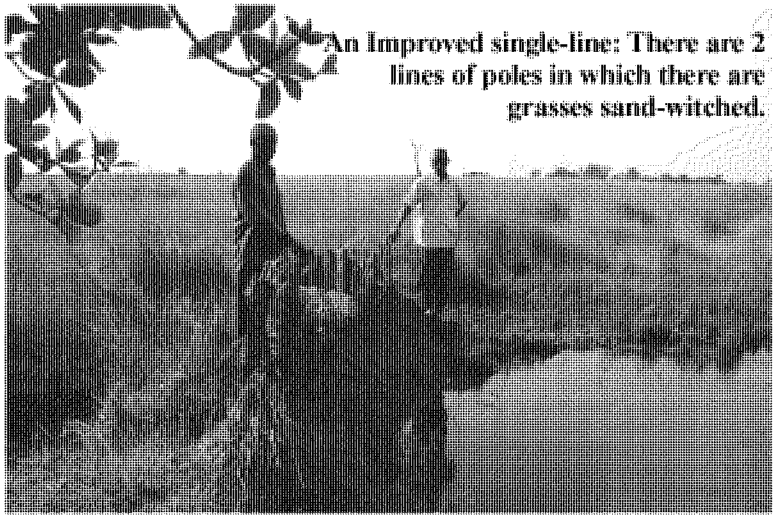
Step	Process	Description	Remarks
1		<u>**Position the Wooden Poles;**</u> Position the wooden poles at the diversion point across the stream with an interval of 20 – 30 cm. In short, there should be 3 to 5 numbers of wooden poles per one meter. The poles are driven into the ground at a depth of more than 0.3m, below soft foundation if any. Length of the pole depends on the site condition, more especially in relation to the design tapping water level.	In case of a certain site in Kasama District, width of the stream at diversion point was about 6m. About 20 wooden poles were piled with 0.2 - 0.3m of interval. Good straight poles with a sizable diameter should be the ones to be used in this step. The hammering of the poles into 0.3 m below the bed level should be done in order to overpass sand foundation if any, which would be prone to scouring effect if placed above 0.3m.
2		<u>**Weave the Grasses through the Poles;**</u> To tap the stream flow, grasses (elephant grass etc.) are woven horizontally through the poles. See the illustration in the left hand. 	A good chunk of grasses is taken, and then is twisted and finally it is woven between the poles. The bundled woven grasses are treaded layer by layer as they are put criss-crossing on upright logs. This kind of compaction is required in order to achieve water tight situation. When the bundle has reached the end, the next bundle should not start at the very end of the last bundle, but rather, it should start at midway in order to minimize gaps.

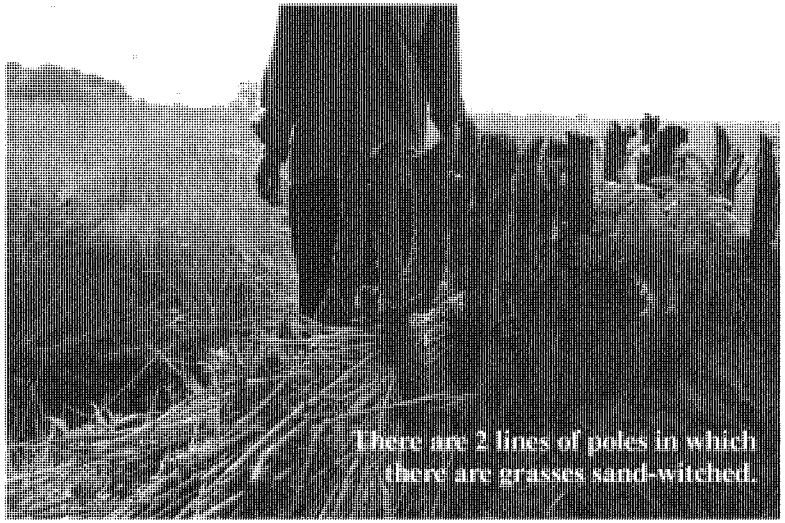
Step	Process	Description	Remarks
3		**<u>Put the clay soil on the Grass Fence;</u>** Put the clay soil on the grass fence. To prevent water leakage from the grass fence and boiling due to sand bed material of the stream, clay soils are put on the grass fence and the bottom of the stream up to certain level. 	It may not be effective to use sandbags as a measure of preventing leakage by boiling/piping on the bottom of the stream. Rather using clay and ordinary soil to seal the gaps in the grass fence and the bottom of stream is effective because the gaps would be clogged with particles of clay and soil. After putting the clay soil on the grass fence and the bottom of stream, soils (stream bed material where appropriate) are thrown to the grass fence.
4		**<u>Completion of Construction;</u>** The weir is completed after following all the steps above.	During operation of the irrigated farming, the diversion weir should be maintained carefully. For instance, if a hole at the weir is found, it should be immediately sealed with clay/ordinary soil. This process will restore the weir its former good shape.

Step	Process	Description
5	**<u>Dismantling the Weir</u>** ***Washing the Tools***  ***Transporting Materials & Tools to the*** 	**<u>Note; Dismantling the Weir and Set Aside the Main Materials</u>** These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. ***Setting aside the Materials &***  

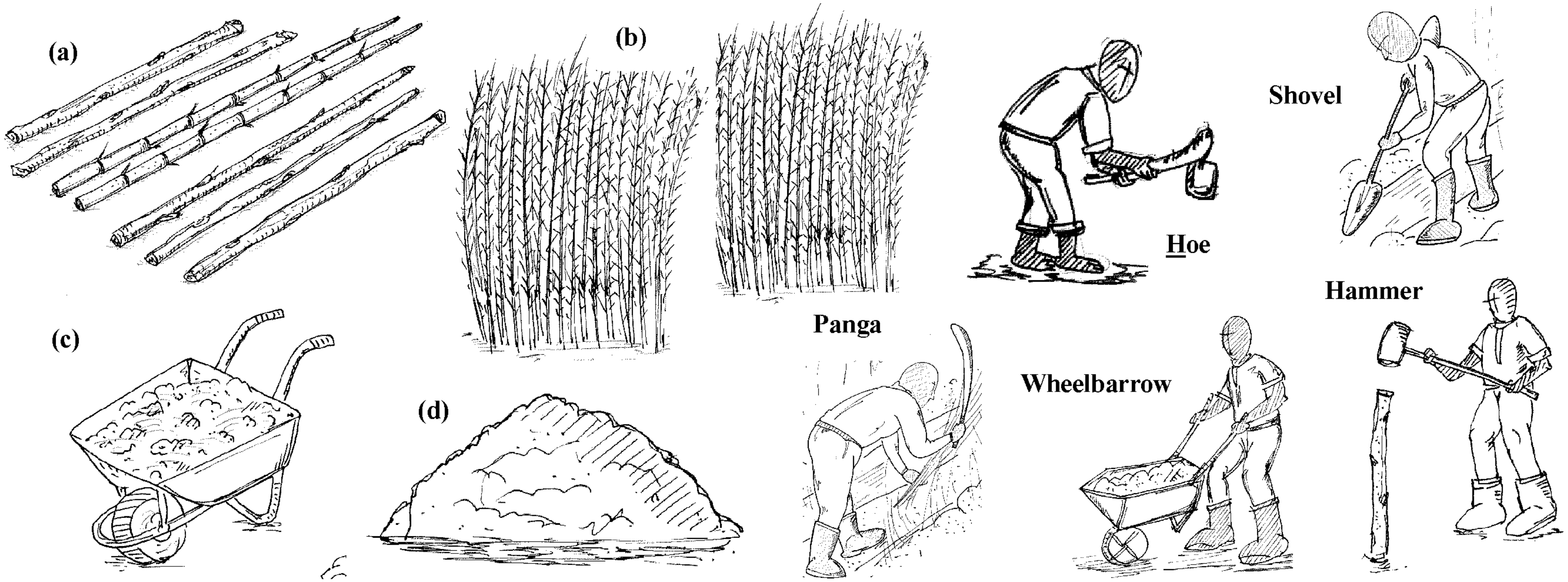
Examples of Single-line Weir (Mbala District (left), Mporokoso District (right), Northern Provicne)

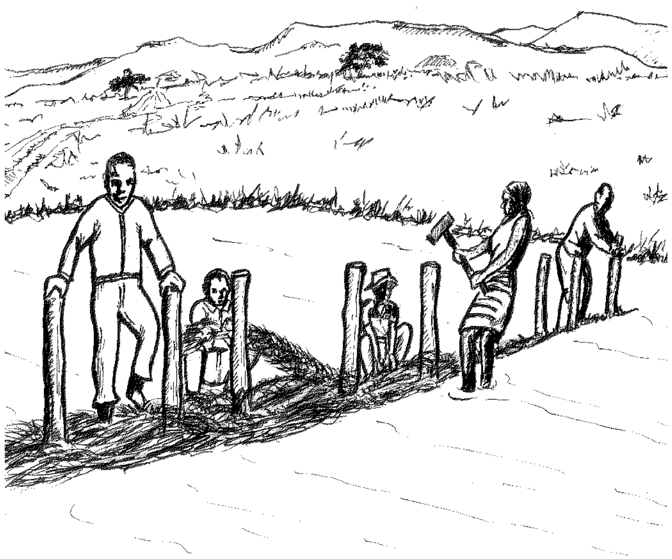
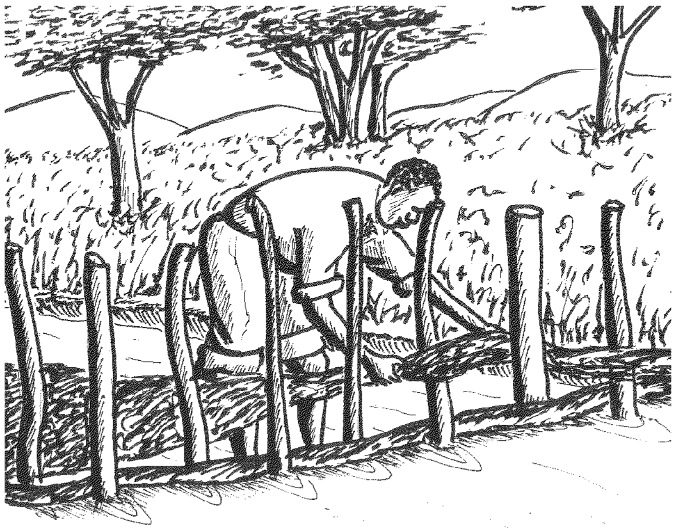


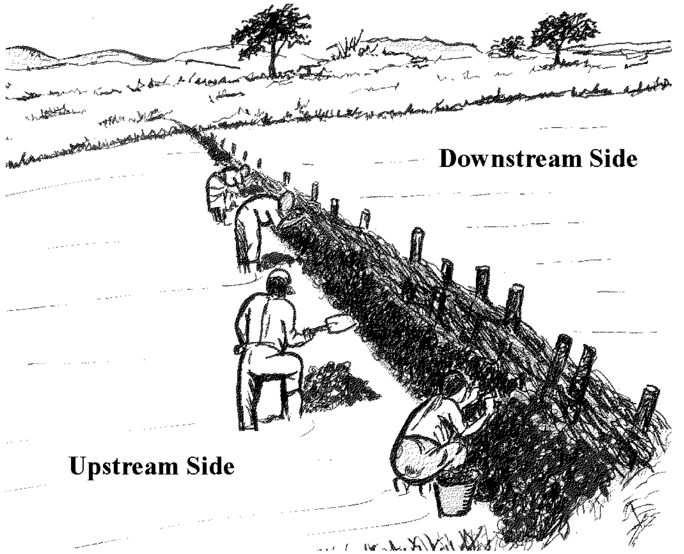
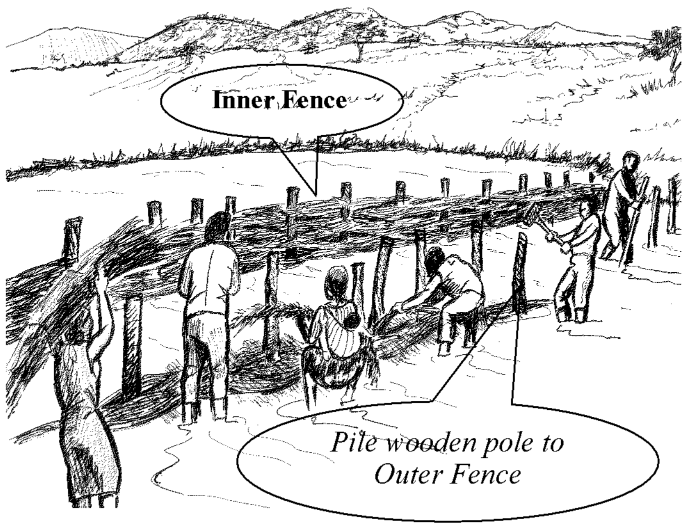


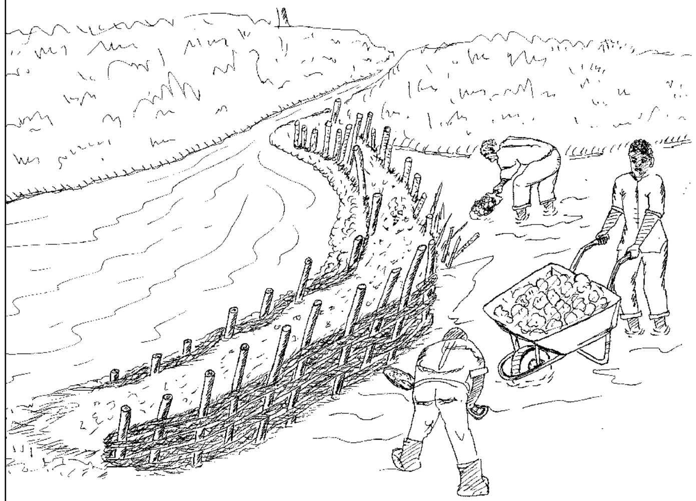
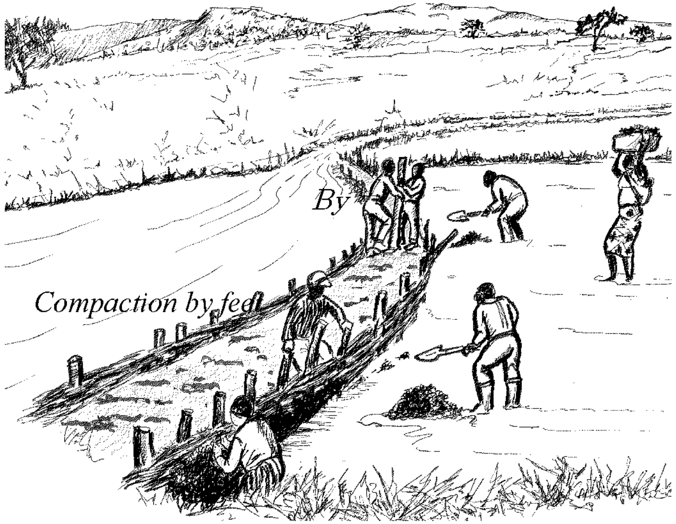
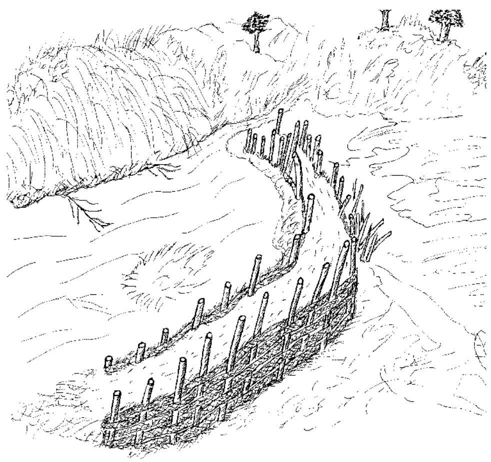


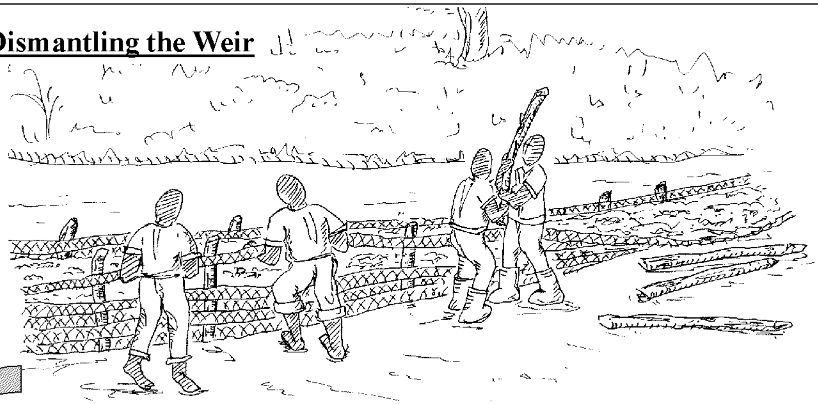
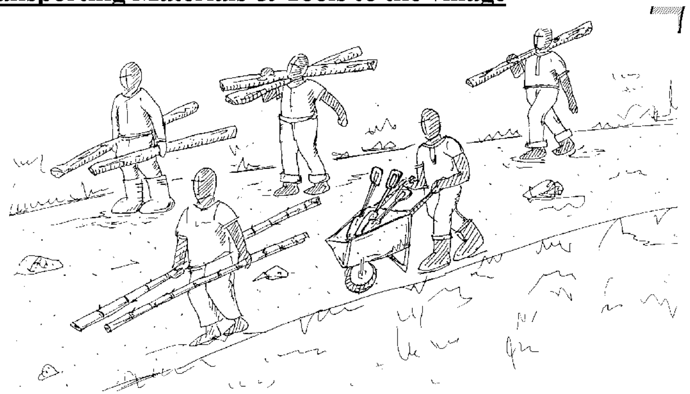
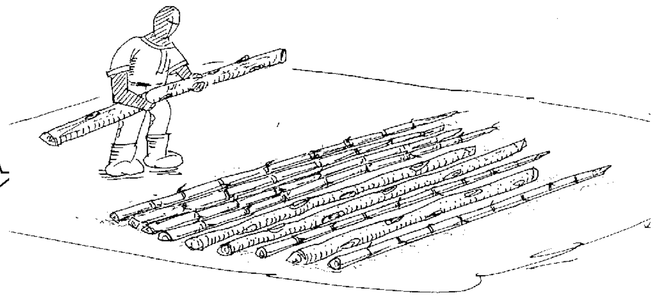
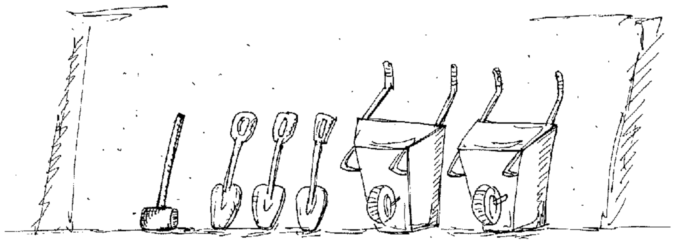
8.3 Construction of A Temporary Weir: Double-line Wall Type (best suited at wider streams whose foundations are not rock)

Step	Materials to be collected
0	**Collect all the following materials**; (a) Log/Bamboo/Twigs: to make the fence both inner and outer (Quantity: 30-35nos. per 10 meter length of the dam, Refer to Step-1 & 5) (b) Grasses (Elephant grass): to weave into the fences (Quantity: depend on the size of the dam, Refer to Step-2 & 6) (c) Clay soil: to patch in front of inner fence (upstream side) and stuff into the opening of the fences (Quantity: depend on the size of the dam, Refer to Step-4 & 7) (d) Ordinary soil: purpose is same as clay soil **Implements;** Hoe, Shovel, Panga knife, Wheelbarrow, Hammer (Quantity of these implements depends on the number of participants for construction of the dam)
	

Step	Process	Description	Remarks
1		**<u>Pile Wooden Poles to the Inner Fence (Upstream Side);</u>** To make the inner fence, the wooden poles such as log, bamboo and twigs are piled every 30-50cm interval on the line crossing the stream. When the poles are properly positioned, they are driven into the streambed by a hammer.	In fact, this process of putting inner fence is just same as that of single-line weir construction. As single-line weir may hardly be able to stop water due to the leakage through the weir body, this double-line weir was devised. Therefore, one may say this weir is best suited at a site whose width is relatively wider, so that it is impossible to construct inclined type weir, whose foundation is formed with soil (not rock), so that we can drive poles into the foundation, and where we need to minimize water leakage probably due to a fact that there is little water flowing in the stream.
2		**<u>Weave Grasses into the Inner Fence;</u>** To tap the stream flow, grasses (elephant grass etc.) are woven horizontally into the inner poles following Step-1. Then, the grasses woven are compacted by feet. The moment any grass is weaved between the poles, press it tightly with feet. Continue doing this until a required height of this weir is obtained. The weaving of grass should be done to both fences, so that a space is left in between the parallel fences.	The grasses are bundled and woven horizontally between the wooden poles. A good chunk of grass twisted is taken and finally it is woven between poles. When the bundle has reached the end, the next bundle should not start at the very ending of the last bundle but it should start at midway in order to minimize creating gaps. The bundled grasses which are woven between the poles are treaded layer by layer so as to compact it in order to achieve a water tight situation.

Step	Process	Description	Remarks
3		**<u>Put Clay/Ordinary Soil on the Inner Fence;</u>** Furthermore, clay/ordinary soils are put on the upstream side of inner fence to prevent water from passing through the weir body as leakage. To protect water leakage through the gap of grass fence and boiling due to sand bed material of the stream, the clay soils are put on the upstream side of inner fence and the bottom of stream up to a certain level.	The above Steps-1, 2 and 3 are exactly same as those of single-line weir construction. There may be a difference from the single-line weir; that is the interval of the poles. Since this is to be a double-line weir, a wider interval than that of single-line weir may be accepted, say 50 to even as wide as 70cm interval.
4		**<u>Pile Wooden Poles to the Outer Fence (Downstream Side);</u>** The outer fence is constructed following the Step-3. As first step of making the outer fence, the wooden poles are piled on the line of outer fence such as that of Step-1, preferably 50cm to 1m downstream from the inner fence. Then, being same as Step-2, grasses (elephant grass etc.) are woven horizontally into the outer poles. The grasses should, of course, be compacted by feet/ or using a log in order to achieve a water tight situation.	The poles are hammered into the ground with double lines (namely at outside of inner fence). The whole essence of hammering is to make the structure strong, and to make the poles go beyond sand deposits. The interval between the poles can be 50cm – 70cm, a little wider than that of single-line weir.

Step	Process	Description	Remarks
5		**<u>Stuff Clay/Ordinary Soils;</u>** Put the soil which exist around the site into the opening between the inner fence and outer fence. To prevent water leakage from the grass fences, clay/ordinary soils are put into the space between the inner fence and outer fence. The clay soil and ordinary soil can be collected around the diversion site.	It should be noted that the wider the space between inner and outer fences, the more soils should be prepared and put into. The wider the space, the less leakage we can expect but the harder the job of putting soils in between becomes.
6		**<u>Compact the Soils;</u>** The clay and soil ordinary soil thrown into the space between the inner and outer fences should be compacted heavily by feet or with a wooden log. After all the process above is followed, the weir is now completed and water starts backing up on the upstream of the weir, then the water starts getting into the diversion canal to flow.	Completion ! 

Step	Process	Description
7	<u>**Dismantling the Weir**</u>  <u>**Washing the Tools**</u>  <u>**Transporting Materials & Tools to the village**</u> 	<u>**Note; Dismantling the Weir and Set Aside the Main Materials**</u> These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. <u>**Setting aside the Materials & Tools**</u>  

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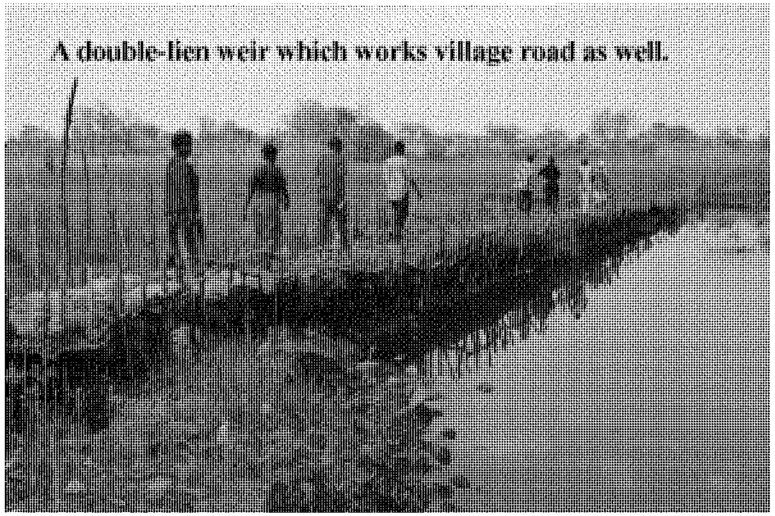
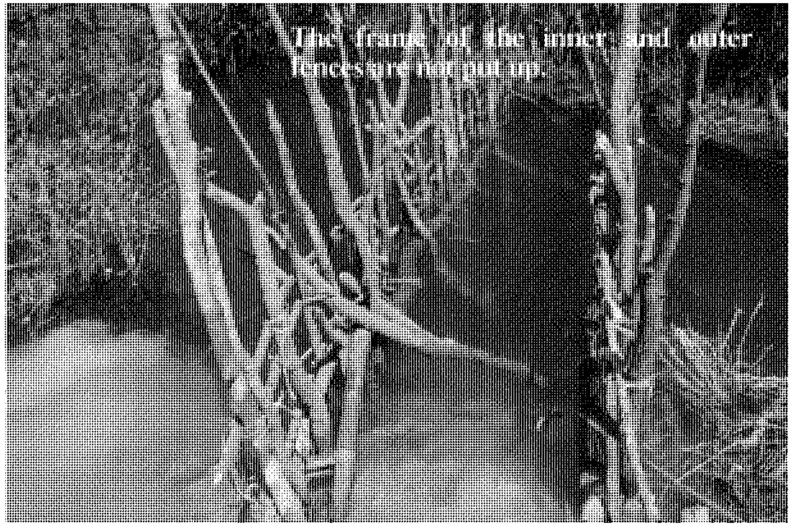
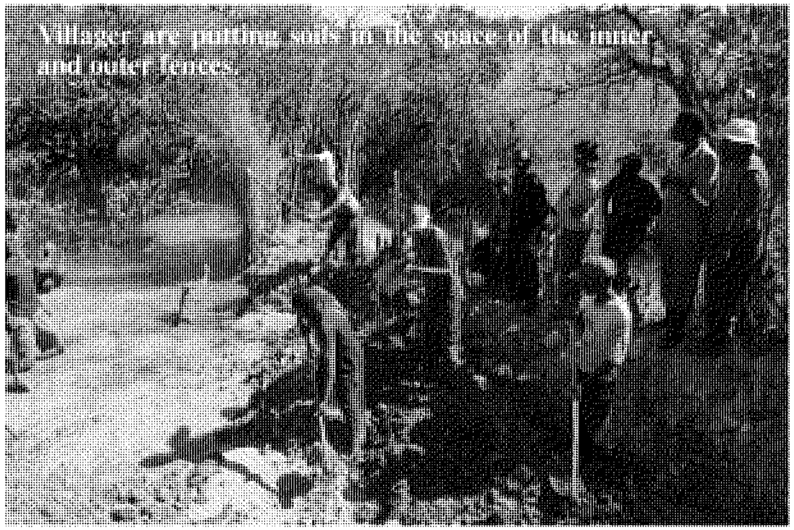
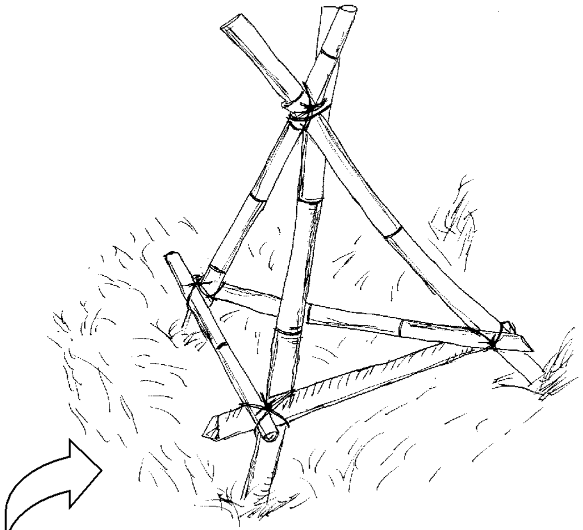
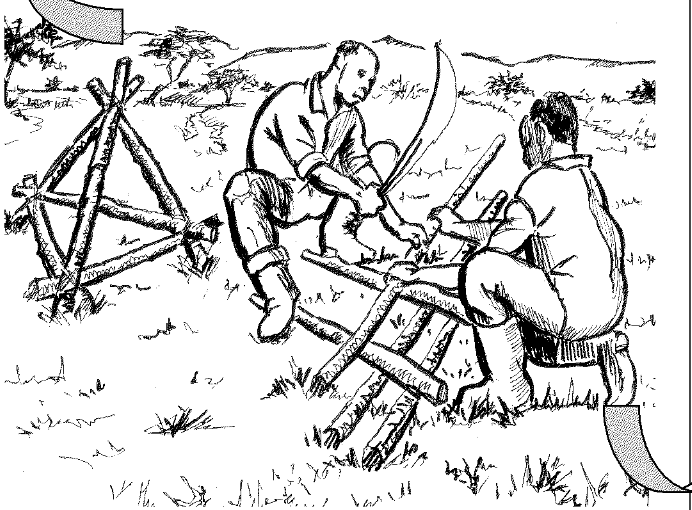
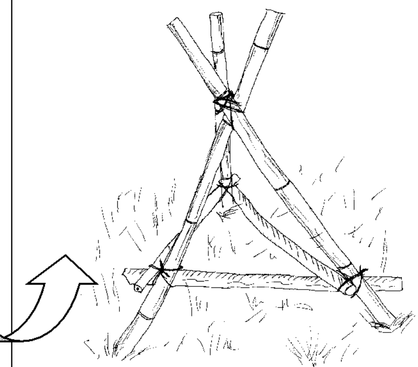
Examples of Double-line Weir (Mansa District (Left), Luapula Provicne, Mungwi District (Right), Northern Province)

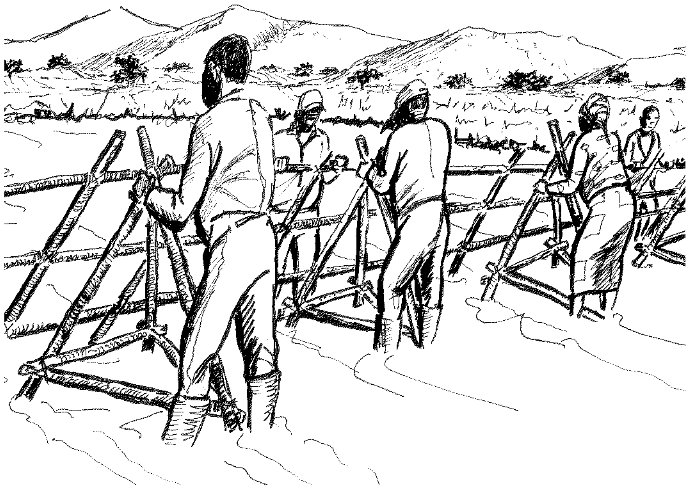


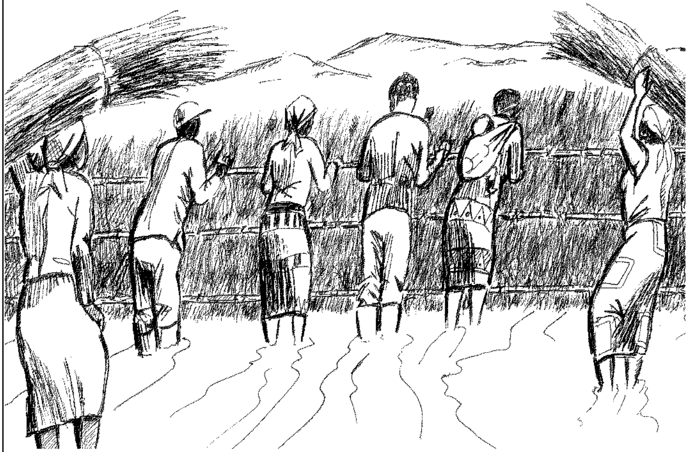


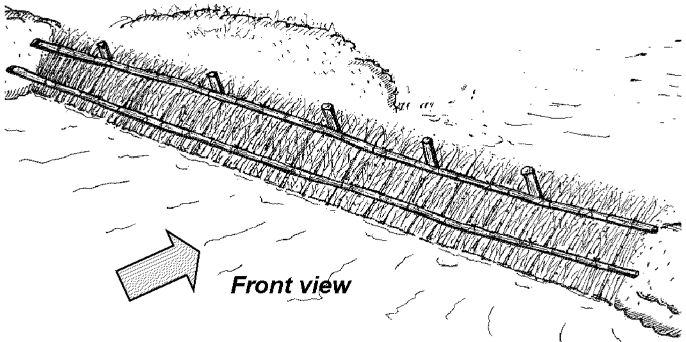
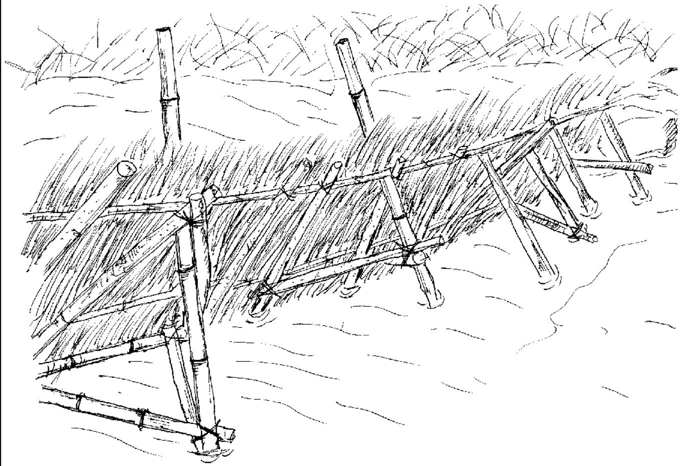


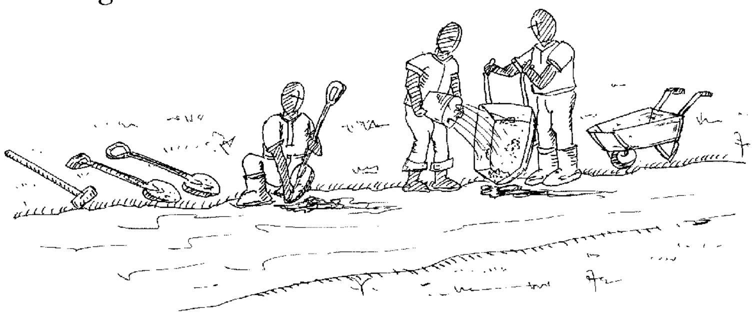
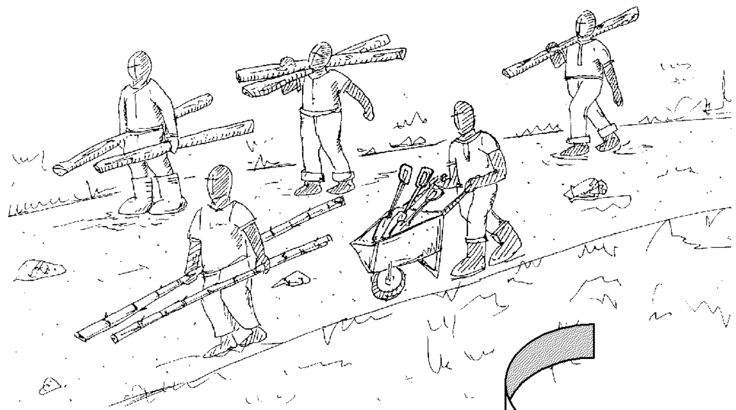
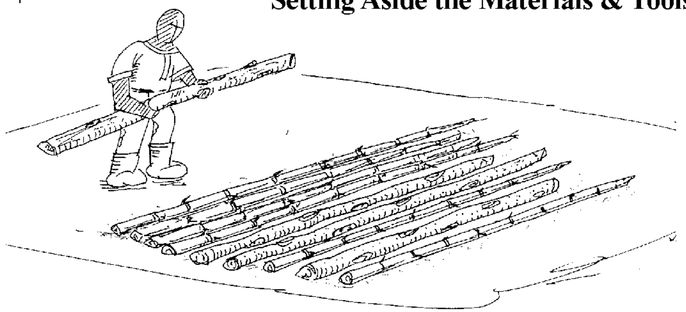
8.4 Construction of A Temporary Weir: Trigonal Supported Wall Type (can be installed on a rock foundation where wooden logs can't be driven)

Step	Process	Description	Remarks
1		**<u>Assemble the Trigonal Prop (Standing Structure);</u>** To support the brush dam made of grasses/clay soil, the trigonal prop standing structures are assembled as shown in the left illustration.	The trigonal prop can be made of log/bamboo. The size of this structure is adjusted depending on the site condition with reference to the design tapping water level. As an example, each member is cut with a length of 1.3m for 0.5m of tapping water depth design. The diameter can be of the log's/bamboo's one for the trigonal prop; around 7cm - 15cm each. The front of this structure, namely the upstream side, has an inclination to act as support for the fence made of logs, bamboos and grasses with clay soil, and lastly, to stand against the water pressure.
		<u>Refer to the Illustrations</u> Cutting of trigonal prop members and assembling of this structure. 	An angle of inclination of the front face is around 70 - 80 degrees. To tie the members to each other, local materials such as runners/grass/sisal can be used. The horizontal 3 members of the prop, forming the horizontal triangular, should be placed outside of the inclined members, so that it can stand more against water pressure.

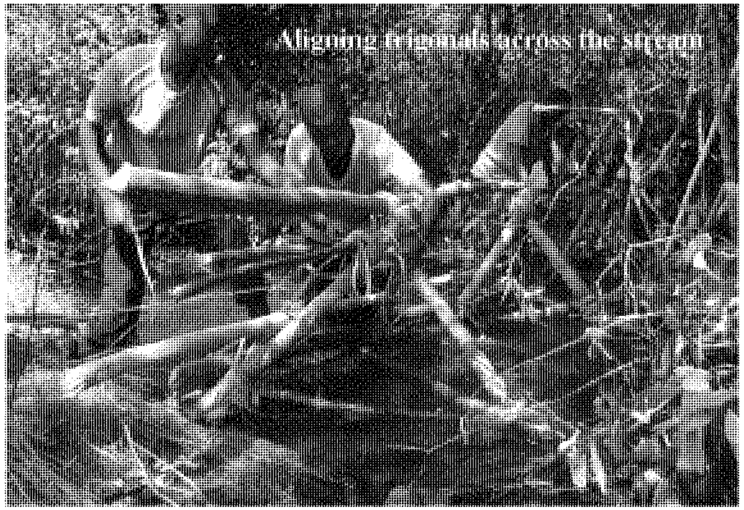
Step	Process	Description	Remarks
2		**<u>Set up the Trigonal Props across the Stream;</u>** The trigonal props are set at the diversion point across the stream. Then, horizontal members are fixed to the trigonal props to keep them in place and in line to each other. At least, 3 horizontal members i.e. upper, middle and lower members should be fixed on the trigonal props. As a result, all of the trigonal props are connected by the horizontal members and will withstand the water pressure as one structure.	The trigonal props are placed at a proper interval in order to prevent this structure from falling down by water pressure. In case of a site in Mungwi district, the width of the stream at the diversion point was about 15m, and 10 trigonal props were set up giving an interval of 1.5m apart. The diameter of fixed horizontal members can be around 3cm - 10cm each. The materials can be wooden poles and bomboos.
3		**<u>Place the Grasses on the Trigonals;</u>** To tap the stream flow, the grasses are placed vertically in front of the trigonal props touching the bed level of the stream.	To reduce the water leakage, it is better to put the grasses very closely. In particular, at the bottom portion of stream, a lot of grasses should be used and should be placed tightly. The horizontal member to be fastened on the top of the grass is the bottom one. Then the second and finally third on top. This helps to keep the grass very tight to the trigonal prop and indeed reinforces the trigonal prop.

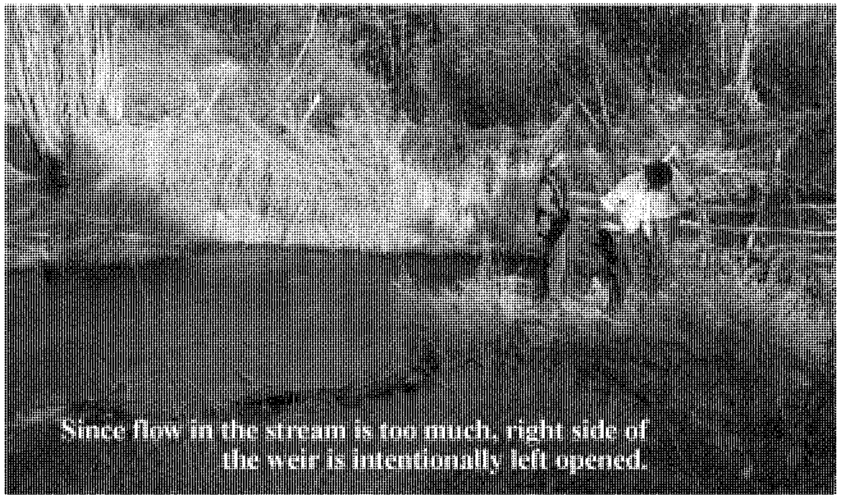
Step	Process	Description	Remarks
4		**<u>Tie the Standing Grasses to the Trigonal Structure;</u>** To prevent swelling out of the standing grasses, these grasses should be pressed against the trigonal prop by using horizontal members again tied with runners. Three horizontally parallel members, at the bottom, at the middle and at the top, are finally fastened with the props or otherwise with the horizontal members already set behind the grasses. The grasses are thus sandwiched by those horizontal members set in front and behind.	To press down the grasses on the trigonal prop, another layer of horizontal members are put in front of grasses which are made to run parallel with the first horizontal members already placed at beginning but at a specified interval between each other and these are tightly tied to the first layers of horizontal members. In so doing, grass is tightly sandwiched between horizontal members. The number of layers of horizontal members is dependent on the height of the trigonal weir. In general, 3 lines of horizontal members are placed.
5		**<u>Put the Clay Soil on the Grass Fence;</u>** Clay soil is placed on the grass fence starting from the foundation or streambed level. To prevent water leakage, the clay soil is patched on the grass fence. The clay soil is put not only on the grasses as a part of brush dam but also on the gap between the bottom edge of the grass fence and the natural ground/exposed rock foundation.	Putting of clay soil should be started at the bottom, and much attention should be put at this stage. This is because this area is very critical in reducing water leakage and thus where the water pressure is the highest. A lot of clay soil should be placed at the bottom in order to make it water tight as much as possible to prevent leakage.

Step	Process	Description	Remarks
6	 *Diversion Weir in a Wide Stream: Rock Foundation*	**<u>Completion of Construction;</u>** <u>The front / Upstream of the Weir</u> Water finally backs up at the upstream of the weir and the duration of backing up depends on the stream width. The weir is finally completed. 	With this trigonal supported weir, water depth stored could reach over 1.0 m or even more than 1.5 m. However, the higher the water level is, the riskier it is and therefore it may fall down. Therefore, it is not recommended to store water over 1.0m.
		<u>The back / Downstream of the Weir</u> 	Check the inclination of the weir. The bamboos supporting the trigonal prop, which is at an inclined angle, is clearly seen / shown in the pictures with its horizontal support. The water level in the downstream is lower than the upper stream of the weir. The trigonal props also help resisting the water pressure which is greater at the bottom, hence the unique design the trigonal prop.

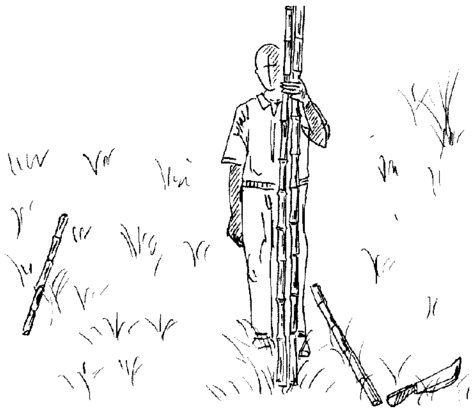
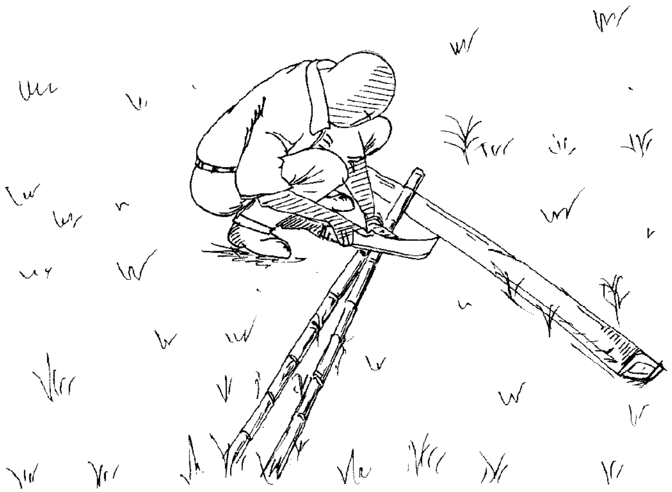
Step	Process	Description
7	**Dismantling the Weir** *Washing the Tools*  **Transporting Materials & Tools to the village** 	**Note; Maintaining the Weir** During operation of the irrigated farming, the diversion weir should be maintained carefully. For instance, if a hole is found on the weir, it should be immediately sealed with clay/ordinary soil. This process will restore the weir its original good shape. **Note; Dismantling the Weir and Set Aside the Main Materials** These types of weirs are constructed as temporary facility for the intake of stream water for irrigation farming in dry season. Therefore, the weir should be dismantled before the start of the rainy season because such kind of structures are constructed across the river/stream and as such, the diversion weir becomes an obstruction for safety flow of floods. Main materials such as logs, bamboos and twigs are then set aside at a suitable place in the village. If properly stored, these materials will be reused for few years to come. **Setting Aside the Materials & Tools** 

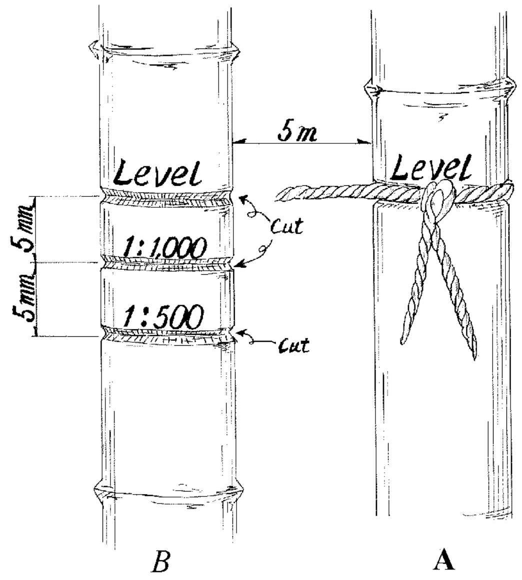
Examples of Trigonal Supprted Wall Type (Mungwi and Mpila Districts, Northern Province)





8.5 Canal Alignment with Sprit Line-level (Section 1; Assemble Line-level)

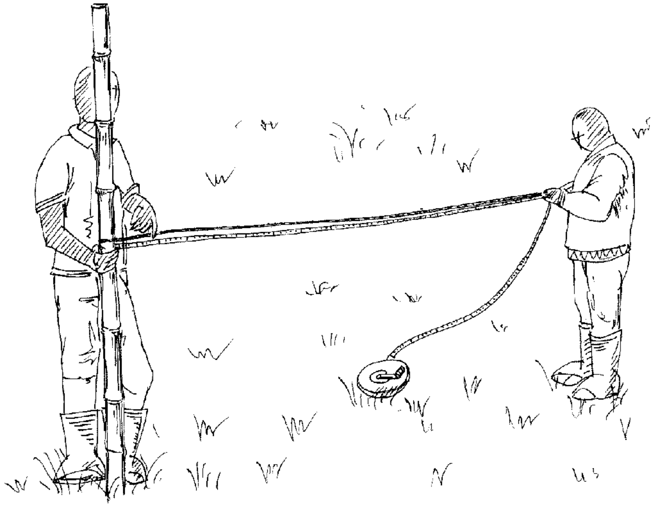
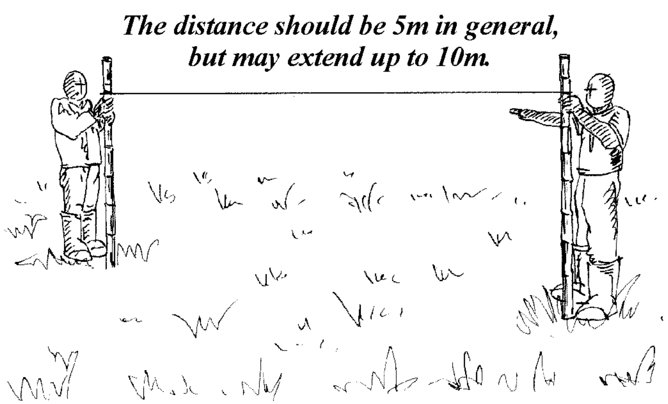
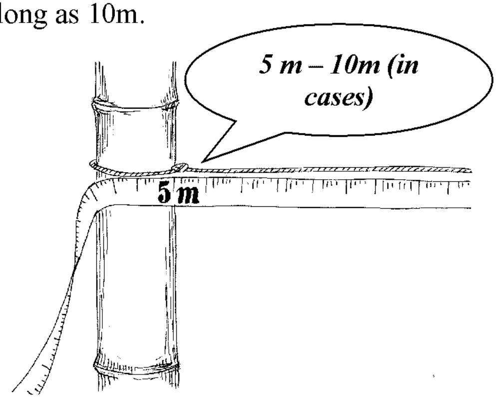
Step	Process	Description	Remarks
1		**<u>Adjust the Poles;</u>** Two (2) poles should be prepared and are cut in the same length. 	Local materials such as bamboo/wooden poles are applicable. The lengths of poles should be adjusted to the height of pole holders. Usually, the poles are about 1.7m to 1.8m in height. The poles should have a sizable diameter so that they are easy to hold. Bigger poles with bigger diameters would be difficult to handle.
2		**<u>Make Groove on the poles (to know gradient on field);</u>** To tie and fix a string, make circular groove around the poles at the same height of both poles—around 1.0-1.3 m from the bottom.	The position of the groove should be set in accordance to the height of the reader of the spirit level. Usually, the height of the groove is from 1.0m to 1.3m from the bottom of the poles. When measuring the level point on field, the grooves should be marked with same height of both poles. However, when measuring a particular slope, grooves should be set at different heights. The table on the next page shows an example of positioning groove on each pole according to a required slope.

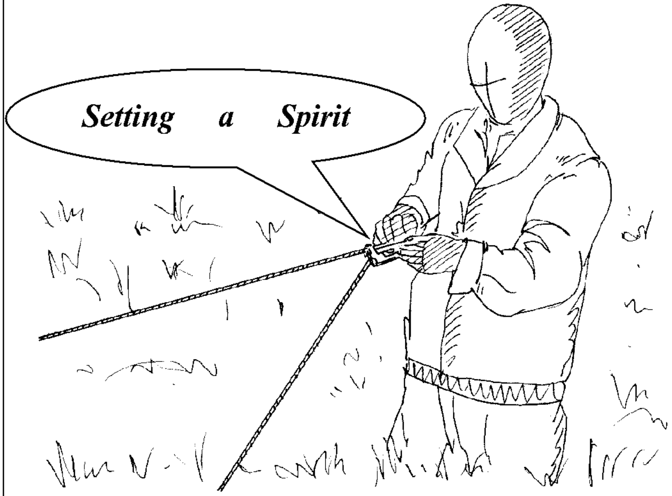
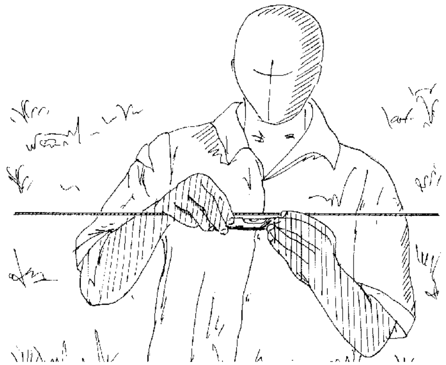
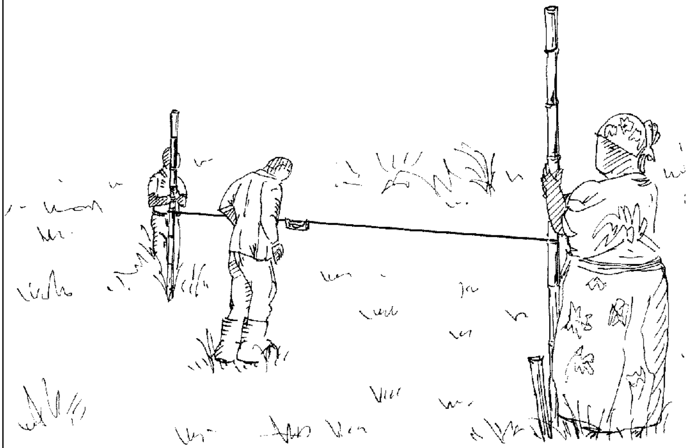
Step	Process	Description	Remarks
3		**<u>Put Grooves at Different Heights on One of the Poles:</u>** Take one of the poles and make grooves on the pole as shown in the illustration. The position of the groove is 5mm lower than the first one (top one), and another 5 mm from the first one. The pole at the right side has a groove fixed at 1.3m from the bottom of the pole as an example. On the other hand, the pole standing at the left hand side has 3 groves. These grooves indicate the level line, 5mm lower than the level line and 10mm lower than the level line.	In conventional way of using a sprit line level, the 2 grooves should be put on the same height in order to know the same elevation points at the 2 poles. However, to align a canal with a designed gradient, we need to make a difference of the elevation in between the grooves of the 2 poles. As an example, 5 mm difference over a distance of 5m gives 1/1,000 (5mm/ 5,000mm) gradient, and 10 mm difference over the same 5m distance gives 1/500 (10mm/5,000mm) gradient. If the 2 poles are placed over a distance of 10m, 10mm difference gives 1/1,000 (10mm/ 10,000mm) gradient and 20mm difference gives 1/500 (20mm/ 10,000 mm) gradient.

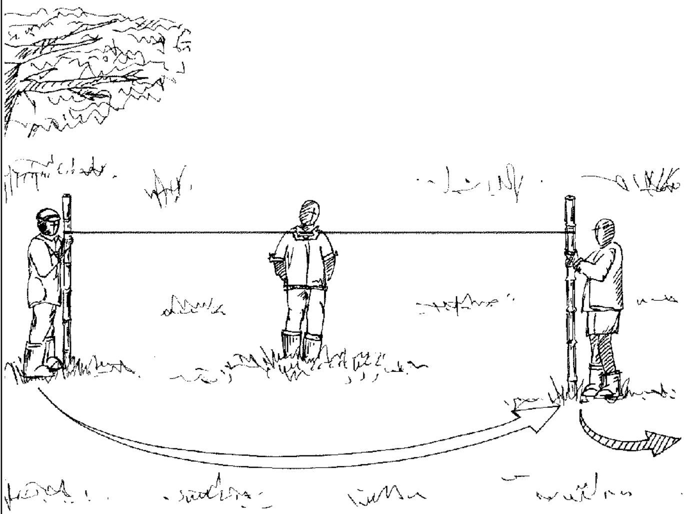
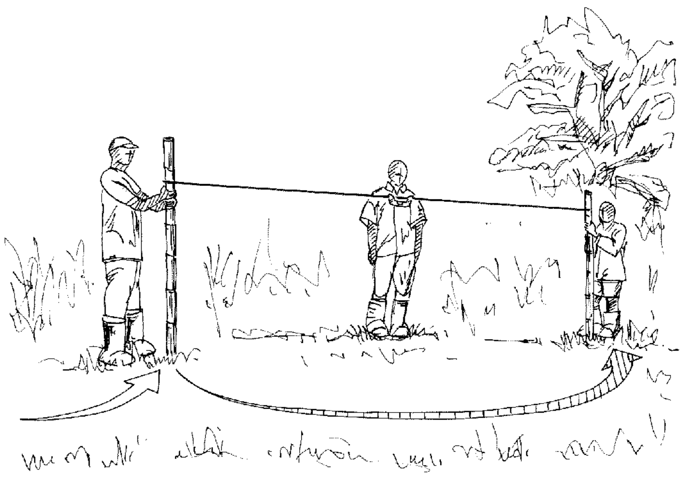
Design gradient of canal	Elevation difference of 2 grooves	Distance between the 2 poles	The position of grooves from the bottom	
			Stick-(A)	Stick-(B)
1/1,000	5.0 mm	5 m	1.3 m	1.295 m
1/500	10.0 mm	5 m	1.3 m	1.290 m
1/1,000	10.0 mm	10 m	1.3 m	1.290 m
1/500	20.0 mm	10 m	1.3 m	1.280 m

The table shown on the left gives an example for the position of the grooves (tying position of string for the 2 poles) to set the designed slope of canal on the site.

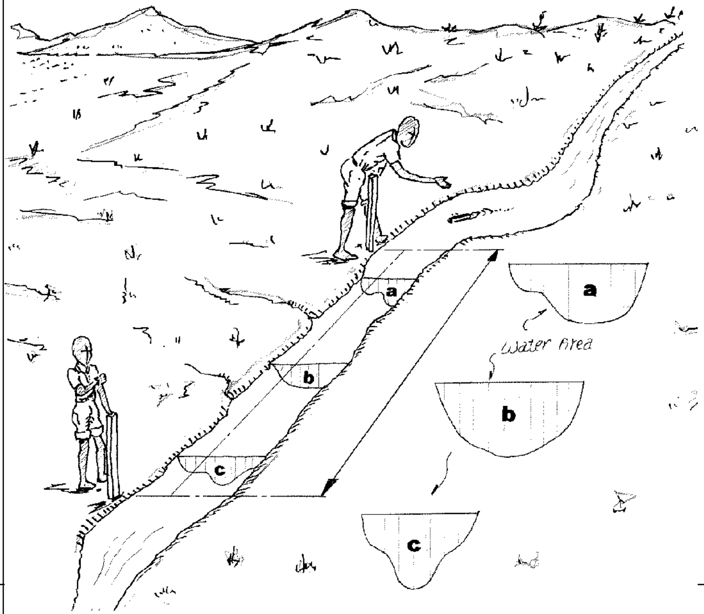
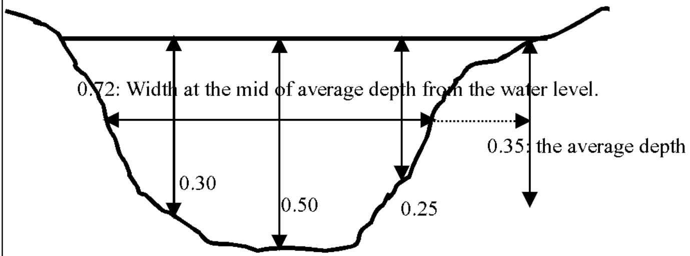
On a gentle topography, 1/1,000 is recommended while on a sloped topography, 1/500 slope is recommended.

Step	Process	Description	Remarks
4		**<u>Fix the String;</u>** Tie the string on a grove marked on the above steps. 	
5		**<u>Testing the line-level;</u>** The length of the string, same as the distance of the 2 poles, should be 5m in most cases but in some cases it can be as long as 10m. 	The length of string depends on the site condition. Usually, 5m length of string is ideal as it is easy to handle. However, if the topography is too gentle and difficult to find an appropriate point within the 5m distance, extend the string up to 10m. Elevation difference of 10-20 mm could be found within the 10m distance.

Step	Process	Description	Remarks
6		**<u>Set a Spirit Level (completion of assembling the line-level):</u>** After the required span between the poles is set, set the spirit level on the string. 	The position where the spirit level is fixed should be the center of the string, e.g. 2.5m point with 5m of string, 5.0m point with 10m of string.
7		**<u>Starting the Canal Alignment with Sprit Line Level:</u>** Line-level can be used to know a sloping point for the design longitudinal slope of the canal. To survey that, at least three persons are needed: two for pole holders and one to read the level.	A slope of 1/500 on a sloped (inclined) land is recommended while 1/1,000 slope may be applied on a flat land. One may think 1/1,000 slope is too gentle for water to flow. However, this slope is quite enough to let the water flow by gravity. As most topography in Zambia is very gentle, steep canal slope with more than 1/500 is not recommend.

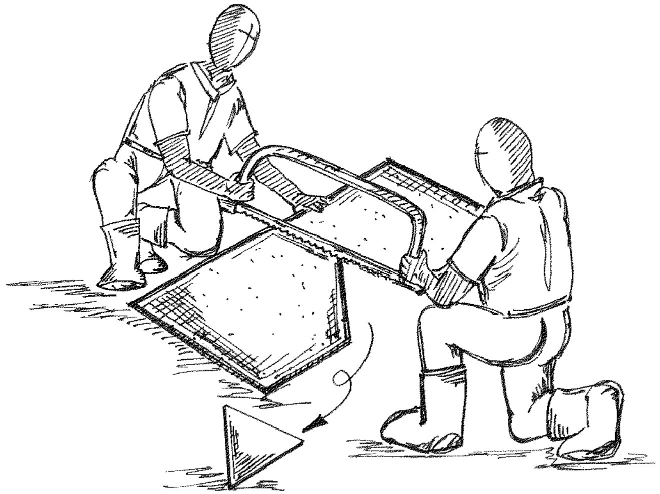
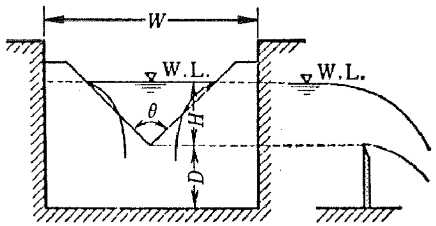
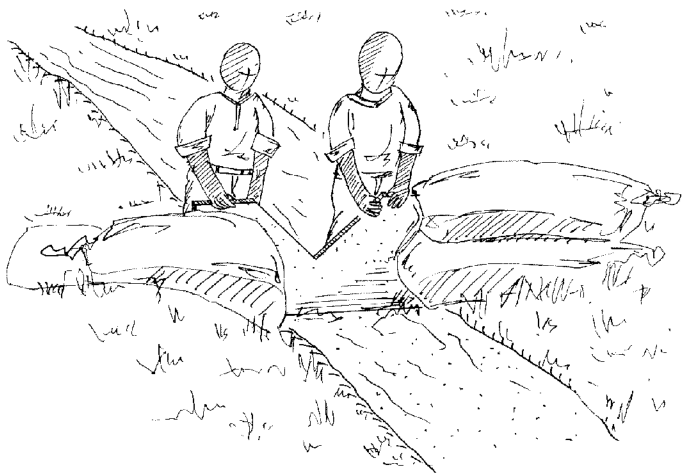
Step	Process	Description	Remarks
8		**<u>Surveying Sloping Point on the Field;</u>** The pole holders should stand at an interval of 5 meters or 10 meters according to the length of the string put over the poles. At this time, the pole holder whose string is tied at a lower position than that of the other pole should stand at a higher position e.g. at the starting point of the canal (He/she stands on the left side in the illustration). The other pole holder (the person on the right) will move to the point where the bubble in the spirit level comes to the center. The level reader checks whether the bubble in the spirit level is at the center or not.	The tied point on the right pole is, as an example, higher by 5 mm than the tied point on the left pole in the illustration. With this situation, when the bubble in the sprit level comes to the center, it automatically means that the ground at the right pole is 5 mm lower than that of left pole. If the distance of the 2 poles is 5m, it gives 1/1,000 gradient (5mm/ 5,000 mm) to the ground over the 2 points).
9		**<u>Do progressing Placing of the Poles:</u>** After a sloping point is set, the pole holder who stand at higher point (left person in the illustration) should move the point to where the other one was (right person in the illustration). The points where the pole holders stand act as bench marks where the pegs are now driven. After this, repeat the same procedure until the required distance of canal is achieved. Upon completion of the line-leveling over the designed distance of the canal, re-align some pegs to get a smoother canal alignment (avoid zigzag alignment).	This method is completely different from conventional pole placing. Conventional placing requires us to place the 2 poles alternately in order to identify a counter level, while this canal alignment necessitates us to place the 2 poles progressively. By placing the 2 poles progressively, designed elevation difference, corresponding to the canal longitudinal slope, over the 2 points is secured since the tying points of the string on the 2 poles are different in elevation.

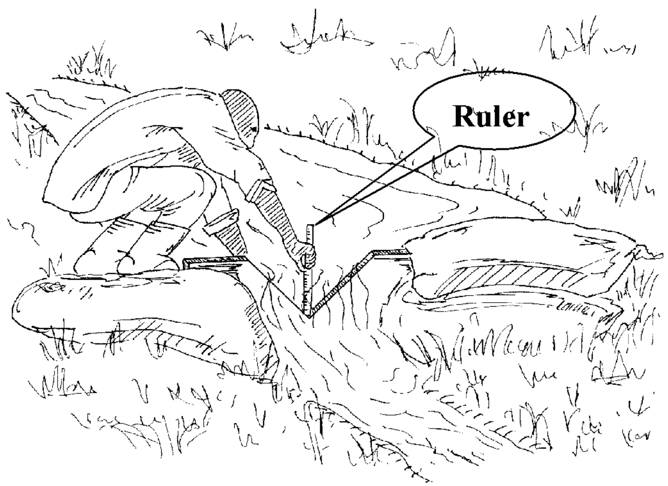
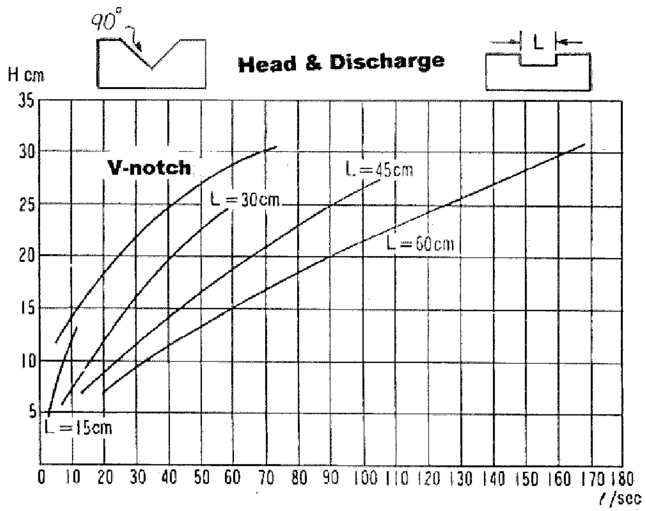
8.6 Discharge measurement (Section 1; Float Method)

<table>
<tr><th>Step</th><th>Process</th><th>Description</th><th>Remarks</th></tr>
<tr><td>1</td><td>
</td><td><u>Measurement of the Water Area;</u>
The float method is available to know a rough estimate of the stream flow. The amount of flow (Q) can be estimated by measuring the size of the stream (A=water area) and the speed (V=velocity) of the water (Q=A*V).</td><td>The water area of the stream (width multiplied by depth) has to be measured. It is better to select a clean and straight section on the stream, at least 5 – 10m long. Measure the depth at one cross-section for at least 3 points (e.g. at 1/4, 1/2, and 3/4 of total width as in the bottom illustration) and calculate the average depth. Then, multiply the average depth into average width of the section, which is the width at the mid point of the average depth from the water level. After the water area for each cross-section is calculated, the representative water area (A) is estimated by averaging all the cross-sectional areas.</td></tr>
<tr><td>2</td><td>How to estimate a cross sectional area:


<table>
<tr><th colspan="2">Depth (m)</th><th>Width, m</th><th>Area, m^3</th></tr>
<tr><td>Depth 1 (1/4)</td><td>0.30</td><td rowspan="4">0.72</td><td rowspan="4">0.252 m^3
(0.35x0.72)</td></tr>
<tr><td>Depth 2 (1/2)</td><td>0.50</td></tr>
<tr><td>Depth 3 (3.4)</td><td>0.25</td></tr>
<tr><td>Average</td><td>0.35</td></tr>
</table></td><td><u>Measurement of the velocity;</u>
A float (e.g. a piece of dry wood) is thrown into the water to measure the velocity. Measure the time (in second) taken by the float to move between the upstream cross-section point (section-a) to the downstream one (section-c). Repeat this measurement at least three times, and calculate the average velocity. Velocity is calculated as follows:
Velocity=Length (m) of the 2 points (e.g. section-a to section-c in the illustration) / time (in second)</td><td>The measured velocity at the surface is larger than the velocity along the bottom and sides. Therefore, the measured velocity at the surface needs to be corrected as follows:
-When the water depth<30cm,
Velocity=average velocity times 0.70
-When the water depth>30cm,
Velocity=average velocity times 0.85
Finally, multiply the average water area by the corrected average velocity. This is the amount of flow (Q=A*V) in cum per second. When multiplied by 1,000, it is now the flow in litter per second.</td></tr>
</table>

8.6. Discharge Measurement (Section 2; V-notch Method)

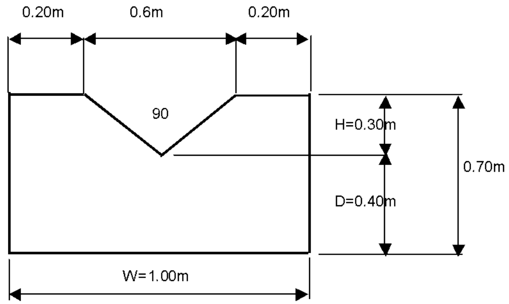
Step	Process	Description	Remarks
1		**<u>Making a V-notch;</u>** Generally, the v-notch is made of wooden board at an angle of 90 degrees. 	If the amount of stream flow is small such as up to 100 lit/sec, v-notch is available to measure the discharge. The application of v-notch is as following (refer to the figure show in the left): ・ 0.5m<=W<=1.2m ・ 0.1m<=D<=0.75m ・ 0.07m<=H<=0.26m ・ H<=W/3
2		**<u>Set the V-notch in the Stream;</u>** The v-notch is set up at suitable site near the place where it is planned to construct the diversion weir.	The v-notch must stand perpendicularly to the stream flow. To stabilize the v-notch, sand bags can be used.

Step	Process	Description	Remarks
3		**Measure the Depth of Nappe;** After setting of the v-notch, the stream flow starts overflowing through the v-notch. The v-notch will be left as it is. When the nappe has become stable, the depth of the nappe has to be measured. The depth here means the distance between the deepest point of the V-notch and the water level right above the deepest point.	To measure the depth of the nappe, a ruler should be prepared. The ruler should be placed perpendicular to the flow exactly, or error in the measurement will take place.
4		**Read the Graph or use Tables;** The amount of stream flow can be known by the graph shown on the left column, or refer to the tables on the following table.	After measurement of the depth of nappe, the depth is checked against the graph to know the volume of flow. The graph shows the relationship between the depth of nappe and discharge. Or otherwise refer to the table on the following page. <u>An exercise in case of V-notch;</u> The depth of nappe: 25cm The amount of flow: 40 lit/sec

Step	Table of Discharge against Ovewflow Depth

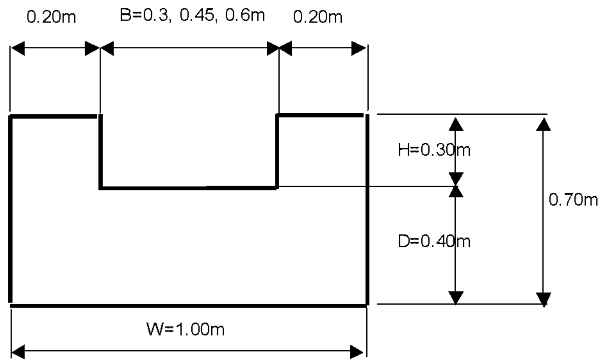
4 **In case of V-notch:**

Over flow depth on V-notch	Discharge	
h (m)	Q (m^3/min)	Q (lit/sec)
0.07	0.11	1.83
0.10	0.26	4.41
0.12	0.42	6.92
0.14	0.61	10.14
0.16	0.85	14.14
0.18	1.14	18.96
0.20	1.48	24.67
0.22	1.88	31.31
0.24	2.34	38.95
0.26	2.86	47.63



4 **In case of rectangular notch:**

Over flow depth on R-notch h (m)	Discharge		
	B=30cm	B=45cm	B=60cm
	Q (lit/sec)	Q (lit/sec)	Q (lit/sec)
0.10	16.59	25.17	34.00
0.12	21.88	32.93	44.54
0.14	27.72	41.36	56.02
0.16	34.08	50.43	68.37
0.18	40.96	60.09	81.56
0.20	48.35	70.32	95.54
0.22	56.23	81.11	110.29
0.24	64.62	92.43	125.80
0.26	73.51	104.27	142.03
0.28	82.90	116.62	158.98



Technical Cooperation Project for Community-Based Smallholder Irrigation (T-COBSI)

Technical Guideline for Implementation of a Permanent Weir Project

JUNE 2015

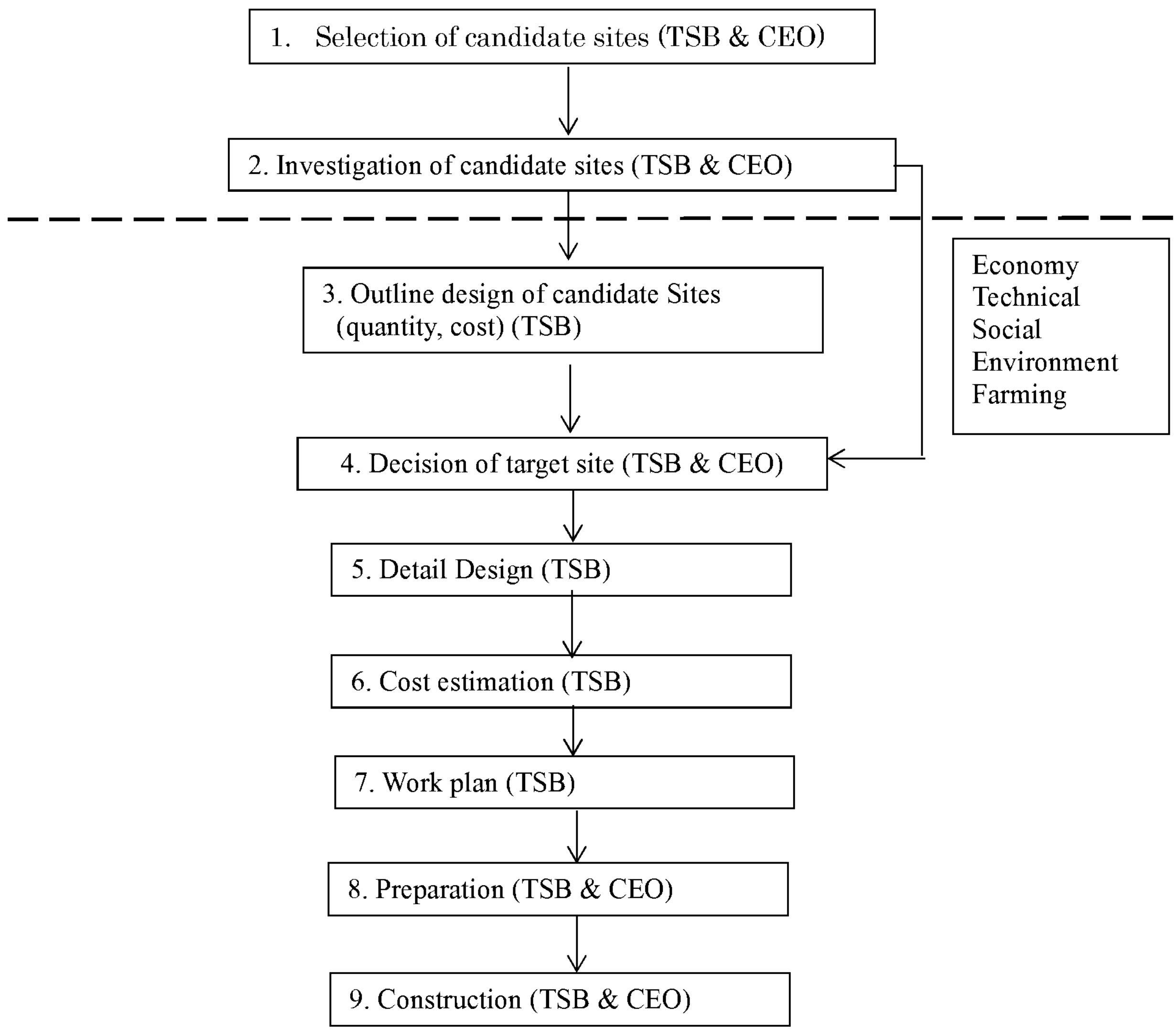
Japan International Cooperation Agency (JICA)

Ministry of Agriculture and Livestock (MAL)

Technical Guideline for Implementation of a Permanent Weir Project

CONTENTS

1. Implementation Procedure



2. Selection of Candidate Sites

Candidate sites are selected considering existing information; natural conditions, social conditions, environmental conditions and O&M such as, (1) slope of riverbank, (2) streamline, (3) terrain, (4) riverbed material, (5) potential area, (6) number of household, (7) farmers organization, (8) available water source, (9) water use of upstream and downstream etc.

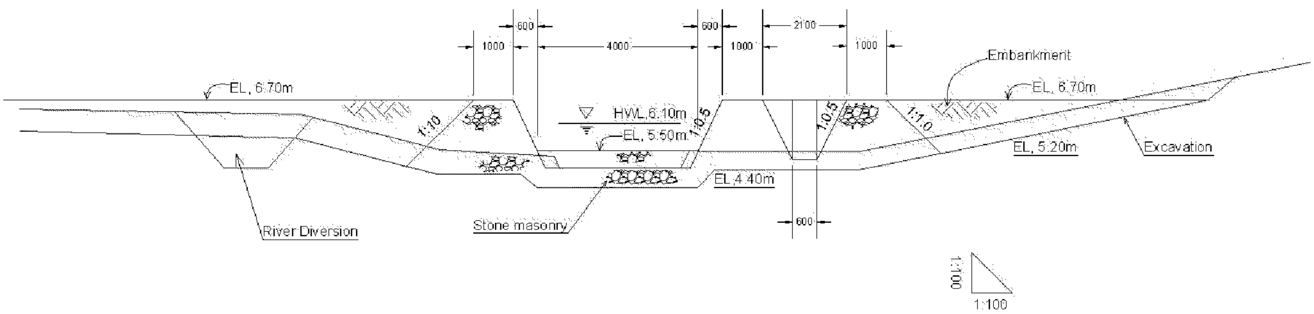
(1) Preparation of a topographical map

If any topographical maps with sufficient precision for the plan are already available from the basic national land survey, the cadastral survey, and the relevant land improvement projects, they can be used. If they have not been prepared yet, it is desirable to prepare them at the initial stage of the investigation. Generally, the topographical map shall be prepared to cover the following area: the beneficial area, its peripheral areas, and areas necessary for planning for irrigation system. GPS and

Google Erath can be utilized to get topographical information.

(2) Slope of riverbank
Slope of riverbank should not be very gentle. If it is gentle, the length of weir will be very long. In many case, the height of weir is about 1.5 ~ 2.0m from river water level. If the slope is 10%, the length of weir should be more than 30 ~ 40m. Water table also should be checked observing the surface of slope.

Gentle slope



Steep slope

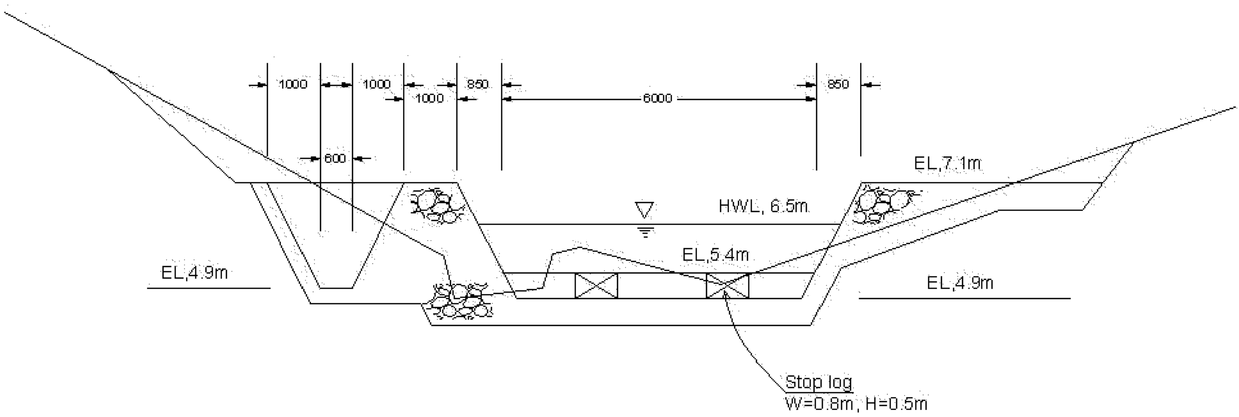


Figure 2-1 Slope of Riverbank and Weir
Source: T-COBSI Project Team

(3) Streamline
Streamline should be stable. It is also desirable to be straight. Streamline in a flat low land tends to be unstable and winding.

(4) Terrain
Dumbo area is excluded in the candidate sites. Generally, temporary weir in dambo area is located in wide flat low land.

(5) River bed material
Rocky foundation does not need apron. Sandy foundation requires long length of apron. Sandy foundation has a difficulty of de-watering during construction.

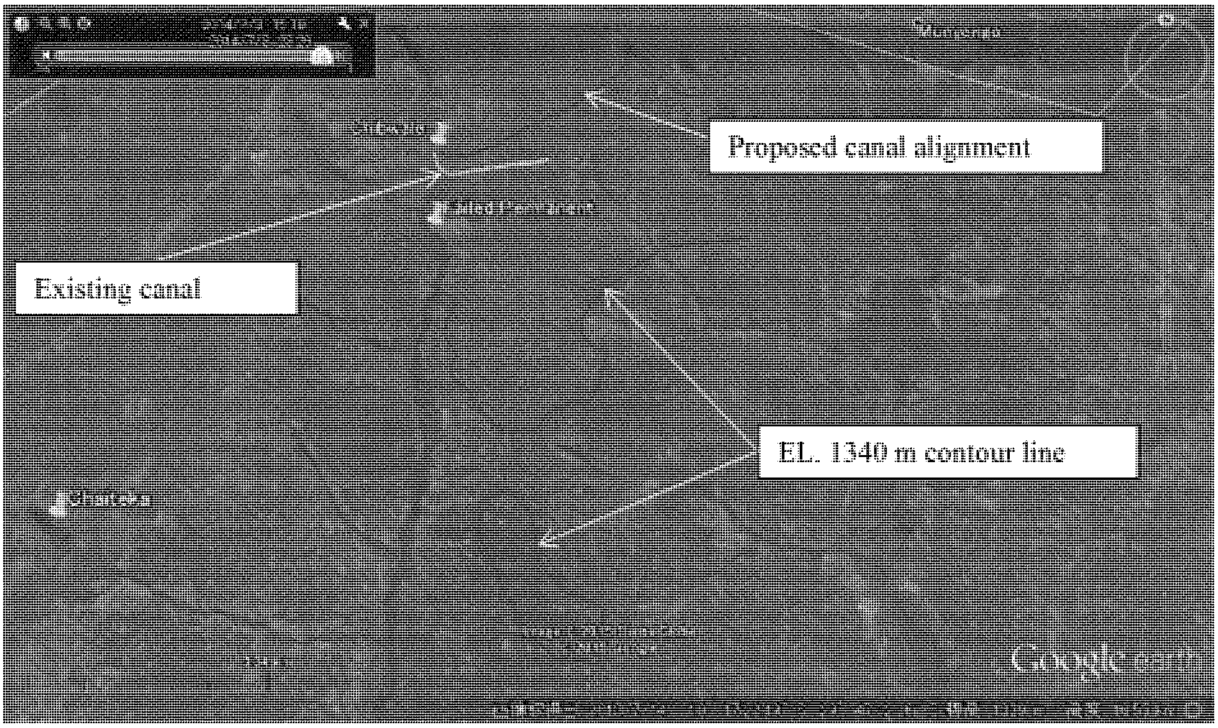


Figure 2-2 Investigation of terrain, beneficiary area, potential area, water use at upstream and downstream, residential area, etc. with Google Earth
Source: T-COBSI Project Team

(6) Potential area
Considering economy, potential area is desirable to be more than 5 has.

(7) Number of household
Considering required labor force, number of household should be more than 30. It is desirable to be more than 50.

(8) Farmers organization
If there is a farmers' organization, it is advantageous to mobilize farmers for construction and O&M.

(9) Available water source
The river/stream should be perennial and water flow quantity should be enough and stable.

(10) Water use of upstream and downstream.
There is no water user for irrigation within 1km downstream from the weir. Water right of downstream should be checked. Upstream water user should be checked if it affects intake water or not.

(10) Others
Consider if any problem of farming, marketing or gender issue.

3. Site Investigation

Site investigation will be conducted at each candidate site.

3.1 Items to be clarified by the investigation

1) Natural condition (water, weather, land-form, geology, soil, etc.)
2) Condition of water usage (irrigation, domestic water, fish pond, cattle, etc.)

3) Social, economic, and farming conditions of project areas
4) Intention of farmers in the project area
5) Construction condition

3.2 Investigation items

3.2.1 Natural Condition

(1) Meteorological Data

As the weather is one of the basic factors of an irrigation plan, the data collected over long period (10 years or more in principle, and 20 years or more with regard to data on temperature, consecutive no-rainy days and pan evaporation, which are closely related with the irrigation plan) at the representative meteorological stations in the area shall be investigated. When the necessary data are not available in the project area, those derived from similar meteorological conditions can be used.

Investigation items are classified in accordance with the type of plan as shown in **Table 3-1**. They shall be selected depending on the type of plan and need.

Table 3-1 Investigation items for each plan

Item		Classification of Plan		
		Farming plan	Irrigation water plan	Other facilities plan
Temperature	Mean temperature	○		
	Minimum temperature	○	○	
Precipitation	Daily precipitation	○	○	
	Monthly precipitation	○	○	
	Annual precipitation	○	○	
	Maximum hourly precipitation			○
Rainy days		○	○	
Sunshine duration		○	○	
Continuous droughty days		○	○	
Most frequent wind direction		○		○
Maximum wind velocity		○		○
Pan evaporation		○	○	

Source: Engineering manual for Irrigation and Drainage "Upland Irrigation". The Japanese Institute of Irrigation and Drainage, 1990

(2) Investigation of river conditions

Investigation of river condition should be executed on (i) water level and discharge, (ii) sedimentation, (iii) stream centerline, (iv) riverbed slope, (v) riverbed materials.

(i) Water level and discharge

Highest water level and representative water level in each month are required to be obtained. Highest water level is obtained by observing past flood mark and by interviewing the villagers. Representative discharge in each month is estimated from water level, flow velocity and cross-section.

(ii) Sedimentation

River sediment is measured in order to arrange for sand removal plan. Sediment at a river structure of vicinity area can be referred.

(iii) Stream centerline

The location of the weir should be selected at a site where the stream centerline is stable and located near the riverbank where the intake is required.

(iv) Riverbed slope

Riverbed slope is an essential hydrological parameter and necessary to estimate discharge. Riverbed slope is obtained by surveying the elevation at 20m interval from 100m upstream to 100m downstream of the weir.

(v) Riverbed materials

Riverbed materials should be observed to estimate roughness coefficient. Value of roughness coefficient is shown in the **Table 3-2**.

Table 3-2 Roughness Coefficient of Natural Flow Canals

Materials and conditions of canals	Roughness Coefficient		
	Minimum	Standard	Maximum
Small canals on flat land			
1). Not weedy, straight. Neither cracks nor crevices are seen when water reaches the high water level	0.025	0.030	0.033
2) Weedy and stony. Neither cracks nor crevices are seen when water reaches the high water level	0.030	0.035	0.040
3) Not weedy but meandering. Some crevices and shallows are seen.	0.033	0.040	0.045
4) Some weeds and stones, meandering. Some abysses and shallows are seen.	0.035	0.045	0.050
5) Meandering. Some crevices and shallows are seen. The changes in gradients and cross-sections are few at low water level.	0.040	0.048	0.055
6) The same as 5) but stony.	0.045	0.050	0.060
7) Weeds and deep crevices are seen along moderate flow areas.	0.050	0.070	0.080
8) Area where weeds grow densely, deep crevices are seen, or many trees are present	0.075	0.100	0.115
Canals in mountain areas. No plants in canals. River banks are usually steep. Trees and shrubs along river banks are submerged when water reaches the high water level.			
1) Cobblestones and gravel on river bed	0.030	0.040	0.050
2) Large cobblestones on river bed	0.040	0.050	0.070
Large canals			
1) Constant cross sections without large cobblestones or shrubs	0.025		0.060
2) Rough and irregular cross sections	0.035		0.100

Source: Engineering Manual for Irrigation and Drainage "Canal Works". The Japanese Institute of Irrigation and Drainage 1987.

(3) Investigation on the influence of flood control

The condition of drainage discharges into rivers upstream and downstream during the ordinary flow should be investigated in order to find the influence of rise of water level by weir upon drainability upstream and downstream. Flood water level and flood pond area should be investigated to decide the height of weir.

(4) Investigation on the foundations

Investigation on the foundations are executed for items such as the structure and properties of the ground, bearing capacity of the ground, conditions of riverbed deposits, ground water level and flow condition of ground water.

Investigation on the foundations should be carried out in order to design suitable foundation structures for the ground condition. Test pitting makes possible appraisal of strata and geology by the naked eye and to estimate bearing capacity.

(5) Topographical survey

Topographical survey for weirs should be done on the following items;

(i) Plane survey

Plane survey of the site is necessary not only for construction of the weir and intake but also for the planning and design of cofferdam. Curvature conditions of the river should be surveyed. It is desirable to draw contour lines on the map.

(ii) Longitudinal and cross section

Profile and cross section of the river are used for designing weir and hydraulic calculations.

(iii) Collection of topographic and other related maps

Prior to field investigations and surveys, topographic maps and other related maps around the scheme should be collected in order to prepare the investigation schedule, and to make a preliminary design.

3.2.2 Condition of Water Usage

Present condition of river utilization such as irrigation, hydropower, water rights, fishery and others should also be investigated.

Investigate rights regarding water sources in the project area and its periphery. Principal investigation items are: 1) Agricultural and other water rights, 2) Fishing rights, and 3) Regulation on the environment such as nature protection. Accurately investigate their contents.

3.2.3 Investigation on Socio-economic Conditions

(1) Investigation of socio-economic conditions

Investigate the total population, number of households, the labor force and income structure in industries, the major economic activities in the area, etc. to identify the roles of agriculture in the socio-economy situation of the area.

(2) Investigation of agricultural structure

Examine the constraints on the development of agricultural production in the area with respect to farm management, income, the marketing, water supply and farmers' consciousness of them.

① The investigation of farm production and income reveals those factors of land, labor, capital, crops produced and farming households which constitute agricultural production structure (scale, organization, capital composition, and differentiation of farmers). Also, investigate the farmers' economy and the profitability (production costs) of each crop. When the land and water-supply conditions constitute the constraints on the increasing farm productivity, examine their present conditions and the factors causing such problems.

② The investigation of marketing reveals the marketing and distribution of agricultural products focusing on the quantity and the prices of each crop for each season according to marketing and distribution channels, and offers a prospect for the demand and supply by crops as well as identification of the problems and measures.

③ The investigation of the water supply, reveals the current land and water utilization conditions and the past development process of land improvement, projects, the bodies managing the land improvement facilities, the property of water use facilities, customs of water use, and water charges to identify the constraints on agricultural development in relation to the water supply.

3.2.4 Investigation on Farming and Cultivation Conditions

(1) Major crops and cultivation management systems

As basic data for future farming plans, recent changes in cropping, the cropping season and technology used for the currently cultivated major crops to identify problems of farming and cultivation techniques.

Investigation contents and method;

①Investigation of crops cultivated

a) Investigate the crops cultivated (summer and winter crops).

②Investigation of cropping season

Investigate the cropping calendar (sowing, transplanting, and harvesting seasons respectively) of each major crop by survey at the agricultural extension service offices, at sites, etc.

③ Investigation of cultivation technology

Investigate the present cultivation technology of major crops by survey at the agricultural extension service offices and at sites. Based on the investigation results identify farming and cultivation technological problems, and examine their countermeasures.

(2) Yield and amount of damages

Investigate the yield of present major crops and crop losses according to factors, and the yield of such crops to be introduced by the plan. In addition, examine the causes of damage affecting the present yield, the possibility of improvement, and the necessary countermeasures, and utilize them as the basic data for formulation of the farming plan and the calculation of the project economy.

(3) Conditions of livestock breeding .

Investigate the number of livestock, number of farmers keeping livestock, breeding scale, systems, production conditions, etc. to identify present problems and examine how to improve the situation.

3.2.5 Investigation of Farmers' Intentions

(1) Investigation method

Interview to the farmers.

(2) Investigation items

① Actual farming conditions
② Farming improvement measures
③ Intentions on improvement of agricultural infrastructure
④ Judgment items of the burden of the project cost
⑤ Intentions on operation and management of facilities
⑥ Other necessary items

3.2.6 Investigation of Related Projects

(1) Land improvement projects

In order to establish the design and the construction plan, examine whether there are any other agricultural infrastructure development projects, including those under planning, in such fields as the improvement of main irrigation and drainage facilities for agriculture, farm road improvement, soil dressing and under-drainage managed or financed by national or district governments or groups.

If there are any, investigate the features of their plan and design, the route selection, the structure, the construction year, and the conditions at the time of construction. In addition, investigate how land improvement districts, cities, towns, and villages, agricultural cooperatives and persons related with agriculture evaluate these projects by means of the analysis of the data in the plans and design specifications of these projects as well as by interviews.

(2) Other projects

①River improvement project

When there are improvement plans for rivers near the site or in the peripheral areas, investigate the route, the river width, the section, the gradient, the flood level, the ordinary water level, the riverbed level, the construction time, the unit drainage discharge, the submergence conditions in the district, how to acquire the land, etc. after the completion of the improvement work.

②Road improvement and new construction projects

When there are improvement and new construction projects of roads near the site or its peripheral areas, investigate the route, the width of the site, the structure, the construction time, how to acquire the land, etc.

③Water utilization project

When there are dam projects for power generation and flood control etc. and industrial water projects near the site or in its peripheral areas, investigate the contents of the plan for water utilization.

3.2.7 Construction Condition

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

Construction materials include cement, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should also be checked. Transportation of materials should be arranged if necessary. Minimum use of construction equipment is encouraged for small scale irrigation schemes. Number of skilled labor and unskilled labor should also be checked.

4. Basic of Irrigation Planning

4.1 Introduction

All field crops need soil, water, air and light (sunshine) to grow. The soil gives stability to the plants; it also stores the water and nutrients which the plants can take up through their roots. The sunlight provides the energy which is necessary for plant growth. The air allows the plants to "breathe".

Without water crops cannot grow. Too much water is not good for many crops either. Apart from paddy rice, there are only very few crops which like to grow "with their feet in the water". The most well-known source of water for plant growth is rain water. There are two important questions which come to mind: What to do if there is too much rain water? What to do if there is too little rain water?

If there is too much rain, the soil will be full of water and there will not be enough air. Excess water must be removed. The removal of excess water - either from the ground surface or from the root zone - is called drainage.

If there is too little rain, water must be supplied from other sources; irrigation is needed. The amount of irrigation water which is needed depends not only on the amount of water already available from rainfall, but also on the total amount of water needed by the various crops.

With respect to the need for irrigation water, a distinction can be made among three climatic situations:

1. Humid climates: more than 1200 mm of rain per year. The amount of rainfall is sufficient to cover the water needs of the various crops. Excess water may cause problems for plant growth and thus drainage is required.

2. Sub-humid and semi-arid climates: between 400 and 1200 mm of rain per year. The amount of rainfall is important but often not sufficient to cover the water needs of the crops. Crop production in the dry season is only possible with irrigation, while crop production in the rainy season may be possible but unreliable: yields will be less than optimal.

3. Semi-arid, arid and desert climates: less than 400 mm of rain per year. Reliable crop production based on rainfall is not possible; irrigation is thus essential. The two major factors which determine the amount of irrigation water which is needed are:

i. the total water need of the various crops

ii. the amount of rain water which is available to the crops

In other words: the irrigation water need is the difference between the total water need of the crops and the amount of rainfall which is available to the crops.

In many countries it is already well known what the crop water needs and irrigation water needs are of the most commonly grown crops. Such data can usually be obtained from the Extension Service, the Irrigation Department or Ministry of Agriculture. It is then not necessary to determine the crop and irrigation water need. However, there may be situations where it is not possible to obtain these data and it would thus be necessary to determine them on the spot.

4.2 Preparation of Basic Plan

(1) Basic plan

Based on the detailed investigation, farming plans, irrigation and water-source plans will integratedly, studied and a basic plan shall be formulated in the direction of the basic concept plan.

- The basic plan includes the determination of benefited areas, farming plans and water-source plans.
- The basic plan influences the facility plans and overall evaluation and benefit of the project.

Therefore, the detailed investigation should be undertaken sufficiently to make the plan harmonious.

(2) Determination of the benefited areas

Determine the benefited area properly based on the detailed investigation, It is the fundamental of the plan formulation.

- The benefited areas, which are already delineated in the basic concept plan, are determined based on detailed investigations on the topography, geographical features, acreage, agricultural economical aspect, farmers' intentions, and related projects, with the method and scale of irrigation, and the smoothness of the irrigation facility management taken into consideration.
- Since the benefited area has a close relationship with the farming, irrigation and water-source plans, the balance with these factors shall be fully taken into account.

(3) Determination of farming program

A farming plan inclusive of the cultivation period, farming method and fertilization management which will be the basic factors for making the irrigation plan will be formulated.

- In the farming plan, the land-use plan applicable to the area will be determined. The management basis such as labor force and farmland on which the plan is prepared is subject to changes, and the supply and demand and the prices of crops also fluctuate. Therefore, the farming program has to be flexible enough to cope with changes in environmental and management conditions of the regions.
- The selection of the crops to be introduced shall fully reflect the intentions of the farmers as well as regional development and program, agriculture promotion area development plans and the expected supply and demand of the crops shall be studied for reference. The crops to be introduced will satisfy the following conditions.

- Crops which are in line with the agricultural promotion plan of the region and match the supply and demand situation.
- Crops which are suited to natural conditions and offer economic benefits.
- Crops whose cropping pattern is compatible with arable land and working condition of farmers, as well as being efficient and reasonable.
- Crops whose cultivating method is feasible judging from the local agricultural technical level.

(4) Determination of irrigation method

Because the irrigation method is closely related to the water supply at the on-farm level, and affects the cost for facilities and maintenance, the most suitable irrigation method for the area by examining its location, farming conditions, and the water-supply situation shall be decided.

1) Classification of irrigation methods

- Irrigation methods are mainly classified into following four groups:
- Sprinkler irrigation:
- Fixed pipe irrigation: Perforation piped irrigation and Drip irrigation

- Surface irrigation: Furrow irrigation, Border irrigation, Contour ditch irrigation and Basin irrigation
- Sub-soil water irrigation

2) Sprinkler irrigation method

This method sprays compressed water like rainfall on the soil using a sprinkler. Several types of sprinklers are available differing in the diameter of the spraying circle, the sprinkling type, and pressure. Generally, a surface or an underground fixed pipe is laid on the farming field, on which sprinkler heads are placed at certain intervals so that the sprinkling circles are overlapped, and even sprinkling can be expected. The method lessens the penetration and loss of supplied water into deep ground or penetration loss due to an uneven soil surface which often occurs in the surface irrigation method, but the sprinkling is easily deflected by wind. Compared with surface irrigation, it is suitable for frequent irrigation on a small scale, and requires less management.

3) Fixed pipe irrigation methods

①Perforated pipe irrigation method

This method uses perforated pipes or hoses made of aluminum, vinyl chloride, or polyethylene, placed on the field surface. The irrigation area formed a rectangle. The method employs relatively low pressure with a large irrigation intensity. Compared with the sprinkler irrigation, the spraying distance is short, and the pipes are arranged densely.

②Drip irrigation method

This method is also known as trickle irrigation. The method irrigates from drip nozzles (emitters) or drip holes made at a certain intervals on polyethylene pipes laid on the soil surface along a line of plants. Water is slowly and frequently dripped around the roots, and is decompressed by several pressure-reducing methods. The drip nozzles have a spiral fluid path in them and the partition tube has a porous orifice in it, both of which are decompressed when compressed water in the primary side passes through. In this irrigation method, only the drip points and nearby surface areas are wet, which makes this method suitable for the smallest but frequent type of irrigation.

Features: ①An elevated soil moisture around the drip points increases the yield. ②Limited water supply only to crop roots saves water. ③High moisture around main root zone means low salinity and less damage even with salt-containing water. ④Low fluid rate in the pipe facilitates an even water supply. ⑤It is controlled with less labor force.

Generally the system operates on $1kg/cm^2$ of terminal pressure, using a decompressor and a filter to prevent clogging.

4) Surface irrigation methods

① Furrow irrigation method

The method irrigates plant roots by water permeated from the side of the furrow. Supply channels are arranged at certain intervals between the moderately sloped furrow, and cause a fixed amount of water to flow. Water is retained for the minimum necessary time to secure water depth downstream to supply sufficient water to the roots, while upstream where water is retained for an excessive time, water penetration loss to the deeper layer cannot be avoided. The irrigation efficiency is influenced by geographical features, intake rate, furrow length, and discharge amount. To make a uniform slope of a furrow, construction machinery is required. -

② **Border irrigation method**

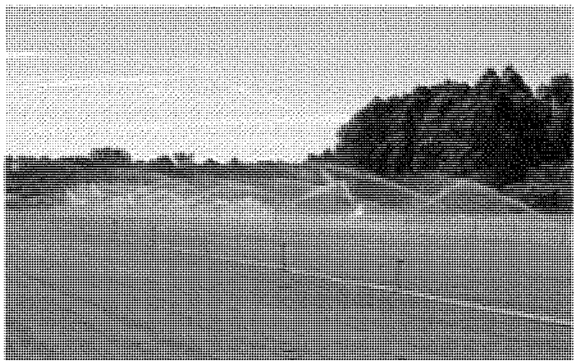
The field is divided into bands by low boundary ridges, and sloped to cause water to flow as a thin laminar flow. The deep layer penetration loss and irrigation efficiency are similar to those of the furrow irrigation method. Compared with the furrow irrigation method, it requires less labor force; whereas it requires greater amount of water and as the limitation factor is the slope, land leveling over a wider area is indispensable. It is often used for irrigating pasture land.

③ **Contour ditch irrigation method**

A ditch to introduce water is prepared with a slope of 1/1,000 along the contour line, and water is supplied from the turnout provided at the ditch. The method is applicable even on relatively irregular land, but the irrigation efficiency is low.

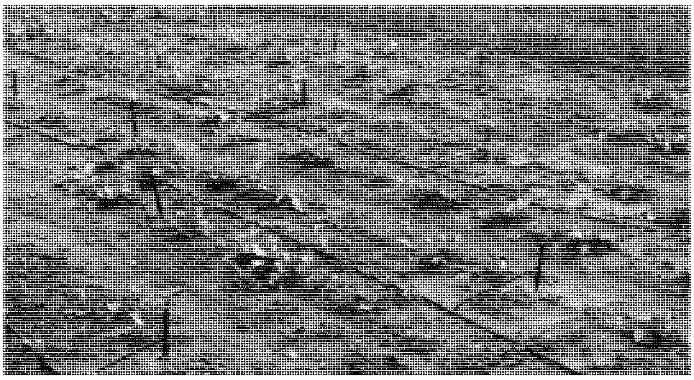
④ **Basin irrigation method**

According to this method, farm land will be flattened and enclosed by ridges. The irrigation water will be conveyed through irrigation canals or pipelines to irrigate the farmland intermittently.

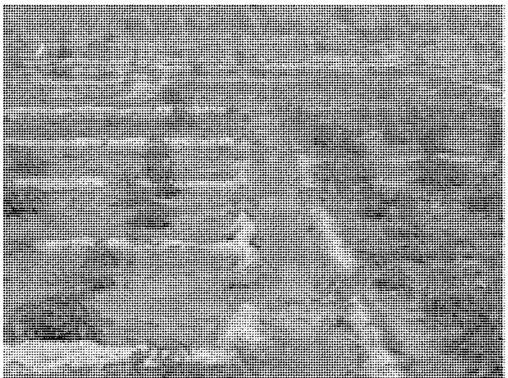


Sprinkler Irrigation

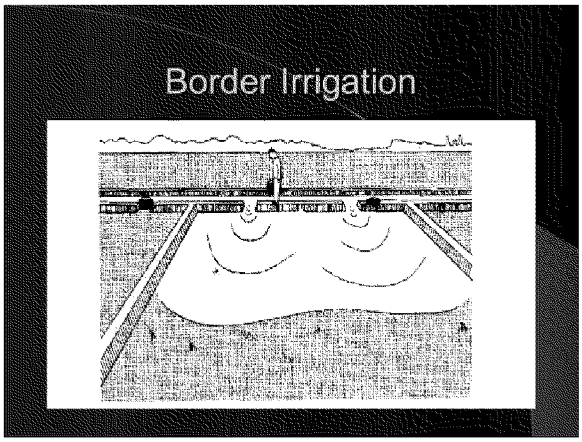
Center Pivot



Drip Irrigation



Basin Irrigation



Contour Ditch

Border Irrigation

5) Determination of the irrigation method

The irrigation method should be the most suitable for the area, and therefore shall be determined by examining following various conditions fully such as a farming program.

- Location

Geographical conditions such as the land slope and contour line, and meteorological conditions such as soil permeability and climate conditions such as wind velocity.

- Farming conditions

Cultivated crops: Restricted factors for determining the irrigation method according to the types of crops

Cultivation method: Plant density, furrowing method, crop rotation system

Level of grouping: Grouping of crops, possibility of cooperative management, level of mechanization

Farming Size: Size of farm management area, farming program, etc.

- Water-supply circumstances

Restriction of available water resources, water requirements and irrigation efficiency, etc.

- Economy, etc.

(5) Determination of irrigation plan

The irrigation plan is a fundamental in determining water resources and the dimension of irrigation facilities. Based on the careful studies of these factors, the basic figures requirement, multipurpose usage, and the amount of water shall be determined.

1) Determination of basic figures for estimating the water requirements

The soil moisture characteristics and moisture permeability of upland fields are investigated to determine the total readily available moisture (TRAM), daily consumptive use of water, irrigation interval days, and net amount of water to be replaced at each irrigation.

2) Determination of water requirement

Irrigation water shall be determined based on the proposed irrigation areas and available water resources, taking into account the fundamental figures of irrigation water requirements, daily rainfall, parameters of multipurpose usage, etc.

3) Study on Water Resources Dependency

An available water resource will be allocated to meet the estimated water requirements, and the required amount of each water-source will be studied.

(6) Determination of Water-source Plan

Based on the irrigation plan and the detailed investigation, the type, location of facility and size of water resources shall be decided.

- Water requirements (water-source dependency) calculated in the irrigation plan shall correspond to the allowable amount of water source in type and location. Then the discharge water balance of the source will be studied from the rainfall and river discharge to decide the design year and the size of the water-source facilities.
- For details of the water-source plan, refer to 4.3.3.6 Water-Source Plan.

4.3 Irrigation Plan

4.3.1 Basis of Water requirement Decision

Water requirements will be decided properly taking the climate of the benefited area, characteristics of soil and crops, and future direction of farming and cropping pattern into consideration.

- To formulate the irrigation plan, the characteristics of rainfall and soil shall be examined carefully, and it is important that the water-holding capacity of the soil should be properly used to increase the ratio of effective rainfall in the water supply, and that the major dimension of the irrigation plan shall be decided.
- To improve the quality as well as the yield of crops, it is important to understand the characteristics of water relation for growing plants, so that the starting time of irrigation and the soil moisture need to be studied for each crop.

4.3.2 Water requirement

1) Procedure for calculation of water requirements*

The water requirement for supplemental irrigation is decided based on the meteorological characteristics, soil moisture and the characteristics of the benefited area and water consumption of upland crops to be irrigated.

**Refer to "FAO Irrigation and Drainage Paper NO.24, Crop Water Management, pg. 2, Calculation Procedures "*

- The procedure of estimating the water requirements for supplemental irrigation is shown in **Fig. 4-1** The calculation of the water requirements shall be proceeded by the determination of the estimated daily consumption of water, irrigation intervals, and net amount of water to be replaced, and these items are important figures in the irrigation plan. These figures will be decided based on the climate, soil moisture and the characteristics in the benefited areas and characteristics consumptive use of water by crops to be irrigated.
- Field irrigation water requirements and gross irrigation water are calculated based on the net amount of water to be replaced and irrigation efficiency.
- The designed daily consumptive use of water is decided from the consumptive use obtained through field investigations on crop consumptive use, and the weather characteristics.

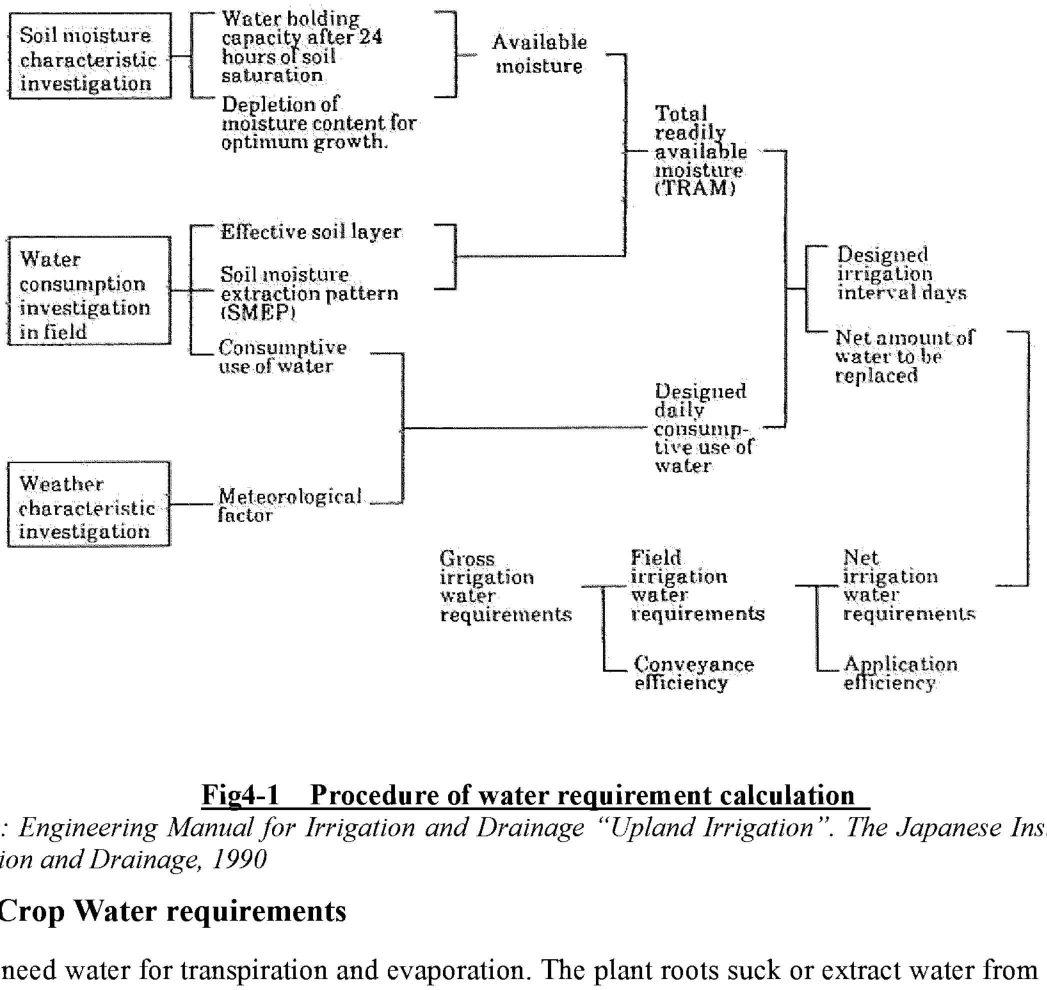


Fig4-1 Procedure of water requirement calculation

Source: Engineering Manual for Irrigation and Drainage "Upland Irrigation". The Japanese Institute of Irrigation and Drainage, 1990

4.3.3 Crop Water requirements

Crops need water for transpiration and evaporation. The plant roots suck or extract water from the soil to live and grow. The main part of this water does not remain in the plant, but escapes to the atmosphere as vapour through the plant's leaves and stem. This process is called **transpiration.** Transpiration happens mainly during the day time.

Water from an open water surface escapes as vapour to the atmosphere during the day. The same happens to water on the soil surface and to water on the leaves and stem of a plant. This process is called **evaporation**.

The water need of a crop thus consists of transpiration plus evaporation. Therefore, the crop water need is also called **"evapotranspiration".**

The water need of a crop is usually expressed in mm/day, mm/month or mm/season.

Suppose the water need of a certain crop in a very hot, dry climate is 10 mm/day. This means that each day the crop needs a water layer of 10 mm over the whole area on which the crop is grown. It does not mean that this 10 mm has to indeed be supplied by rain or irrigation every day.

It is, of course, still possible to supply, for example, 50 mm of irrigation water every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants: every day 10 mm.

The crop water requirement mainly depends on:

· **the climate:** for example, in a sunny and hot climate crops need more water per day than in a cloudy and cool climate.

· **the crop type:** crops like rice or sugarcane need more water than crops like beans and wheat

· **the growth stage:** grown crops need more water than crops that have just been planted.

(1) The Influence of The Climate on Crop Water requirement

A certain crop grown in a sunny and hot climate needs per day more water than the same crop grown in a cloudy and cooler climate. There are, however - apart from sunshine and temperature - other climatic factors which influence the crop water need. These factors are the humidity and the wind speed. When it is dry, the crop water requirement is higher than when it is humid. In windy climates the crops will use more water than in calm climates.
The effect of these four climatic factors on the water need of the crop is shown in **Table 4-1.**

Table 4-1 Effect of Major Climate Factors on Crop Water Requirement

Climatic Factor	Crop Water Requirement	
	High	Low
Sunshine	Sunny	Cloudy
Temperature	Hot	Cool
Humidity	Low (dry)	High (humid)
Wind speed	High (windy)	Low (little wind)

Source: Irrigation Water Management Training Manual No.3 "irrigation Water Need". FAO, 1986

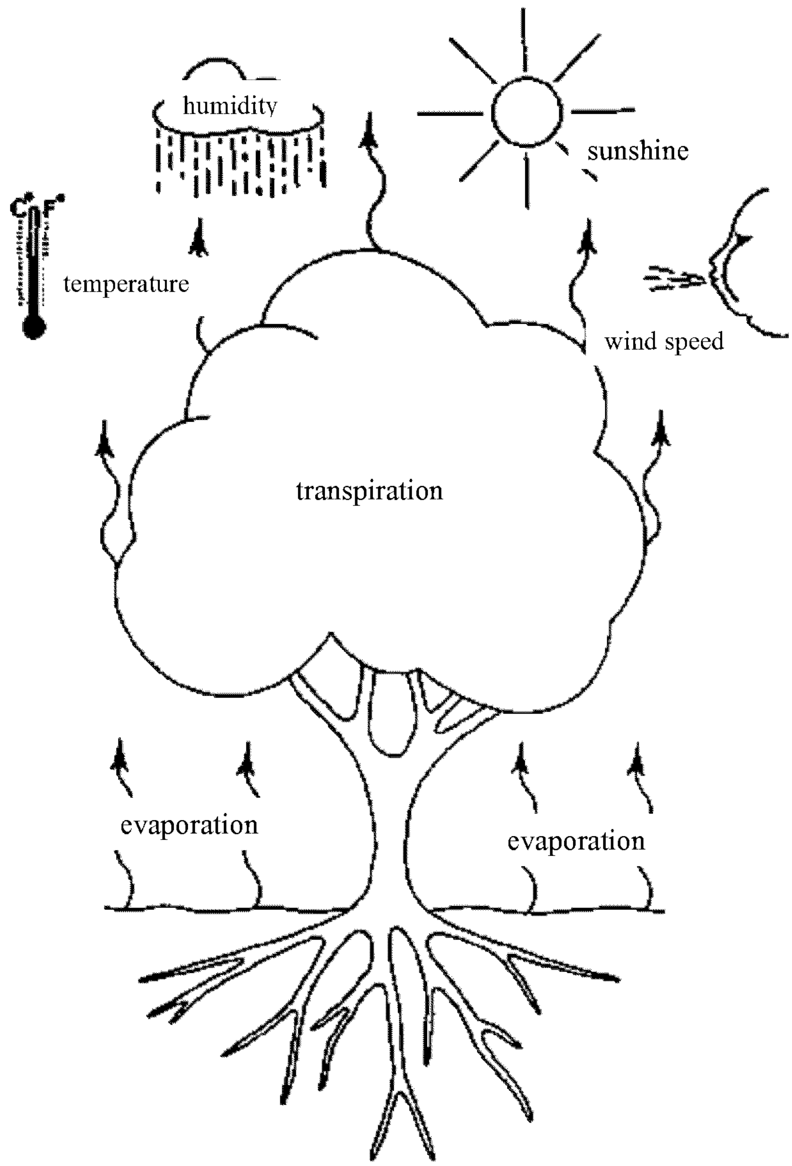


Figure-4-2 Major climatic factors influencing crop water requirement

Source: Irrigation Water Management Training Manual No.3 "irrigation Water Need". FAO, 1986

The highest crop water requirement is thus found in areas which are hot, dry, windy and sunny. The lowest value is found when it is cool, humid and cloudy with little or no wind.

From the above it is clear that one crop grown in different climatic zones will have different water requirement. For example, a certain maize variety grown in a cool climate will need less water per day than the same maize variety grown in a hotter climate.

It is therefore useful to take a certain standard crop or reference crop and determine how much water this crop needs per day in the various climatic regions. As a standard crop or reference crop grass has been chosen.

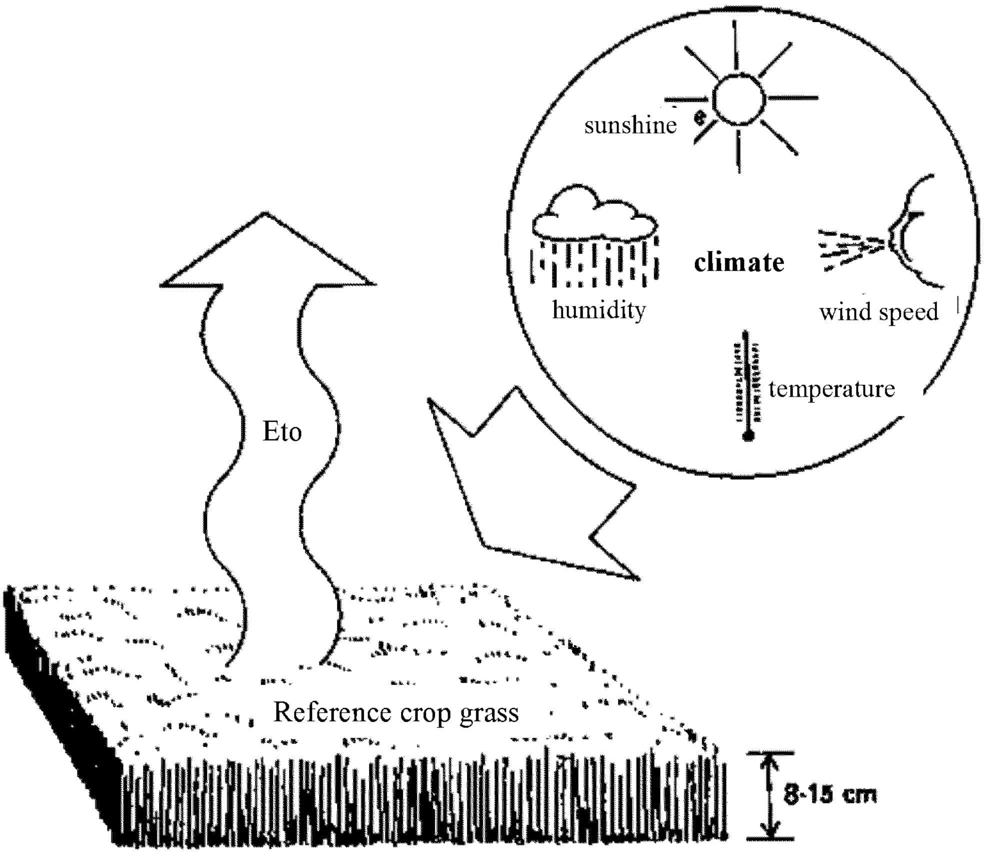


Figure 4-3 Reference crop evapotranspiration

Source: Irrigation Water Management Training Manual No.3 "irrigation Water Need". FAO, 1986

Table 4-2 indicates the average daily water needs of this reference grass crop. The daily water needs of the grass depend on the climatic zone (rainfall regime) and daily temperatures.

Table 4-2 Average Daily Water Requirement of Standard Grass During Irrigation Season

Climatic zone	Mean daily temperature		
	low	medium	high
	Less than 15°C	16 – 25°C	More than 25°C
Desert/arid	4 – 6	7 – 8	9 – 10
Semi arid	4 – 5	6 - 7	8 – 9
Sub-humid	3 – 4	5 – 6	7 – 8
Humid	1 - 2	3 - 4	5 – 6

Source: Irrigation Water Management Training Manual No.3 "irrigation Water Need". FAO, 1986

For example, the standard grass crop grown in a semi-arid climate with a mean temperature of 20°C needs approximately 6.5 mm of water per day. The same grass crop grown in a sub-humid climate with a mean temperature of 30°C needs some 7.5 mm of water per day.

This daily water need of the standard grass crop is also called "reference crop evapotranspiration".

(2) Influence of The Crop Type on The Crop Water Requirement

The influence of the crop type on the crop water need is important in two ways:

1. The crop type has an influence on the daily water needs of a fully grown crop; i.e. the peak daily water requirement: a fully developed maize crop will need more water per day than a fully developed crop of onions.

2. The crop type has an influence on the duration of the total growing season of the crop. There are short duration crops, e.g. peas, with a duration of the total growing season of 90-100 days and longer duration crops, e.g. melons, with a duration of the total growing season of 120-160 days. And then there are, of course, the perennial crops that are in the field for many years, such as fruit trees.

While, for example, the daily water need of melons may be less than the daily water need of peas, the seasonal water need of melons will be higher than that of peas because the duration of the total growing season of melons is much longer.

1) Influence of Crop Type on the Daily Crop Water Requirement

In the previous section it has been indicated how the daily water requirement of standard grass can be estimated. In this section it will be explained how the daily water requirements of other crops can be estimated using as a basis the daily water requirement of the standard grass.

It will be easy to understand that a fully grown maize crop - with its large leaf area - will use more water per day than, for example, a fully grown crop of radishes or onions; that is when the two crops are grown in the same area.

When determining the influence of the crop type on the daily crop water requirement, reference is always made to a fully grown crop; the plants have reached their maximum height; they optimally cover the ground; they possibly have started flowering or started grain setting. When the crops are fully grown their water need is the highest. It is the so-called "peak period" of their water needs.

For the various field crops it is possible to determine how much water they need compared to the standard grass. A number of crops need less water than grass, a number of crops need more water than grass and a number of crops need more or less the same amount of water as grass.

2) Influence of Crop Type on the Seasonal Crop Water Requirement

The crop type not only has an influence on the daily water need of a fully grown crop, i.e. the daily peak water requirement, but the crop type also has an influence on the duration of the total growing season of the crop, and thus on the seasonal water requirement.

Data on the duration of the total growing season of the various crops grown in an area can best be obtained locally. These data may be obtained from, for example, the seed supplier, the Extension Service, TSB or Ministry of Agriculture.

The duration of the total growing season has an enormous influence on the seasonal crop water requirement. There are, for example, many rice varieties, some with a short growing cycle (e.g. 90 days) and others with a long growing cycle (e.g. 150 days). This has a strong influence on the seasonal rice water requirement: a rice crop which is in the field for 150 days will need in total much more water than a rice crop which is only in the field for 90 days. Of course, for the two rice crops the daily peak water need may still be the same, but the 150 day crop will need this daily amount for a longer period. The time of the year during which crops are grown is also very important. A certain crop variety grown during the cooler months will need substantially less water than the same crop variety grown during the hotter months.

(3) Influence of the Growth Stage of the Crop on Crop Water Requirement

A fully grown maize crop will need more water than a maize crop which has just been planted. As has been discussed before, the crop water need or crop evapotranspiration consists of transpiration by the plant and evaporation from the soil and plant surface. When the plants are very small the evaporation will be more important than the transpiration. When the plants are fully grown the transpiration is more important than the evaporation.
Figure 4-4 shows in a schematic way the various development or growth stages of a crop.

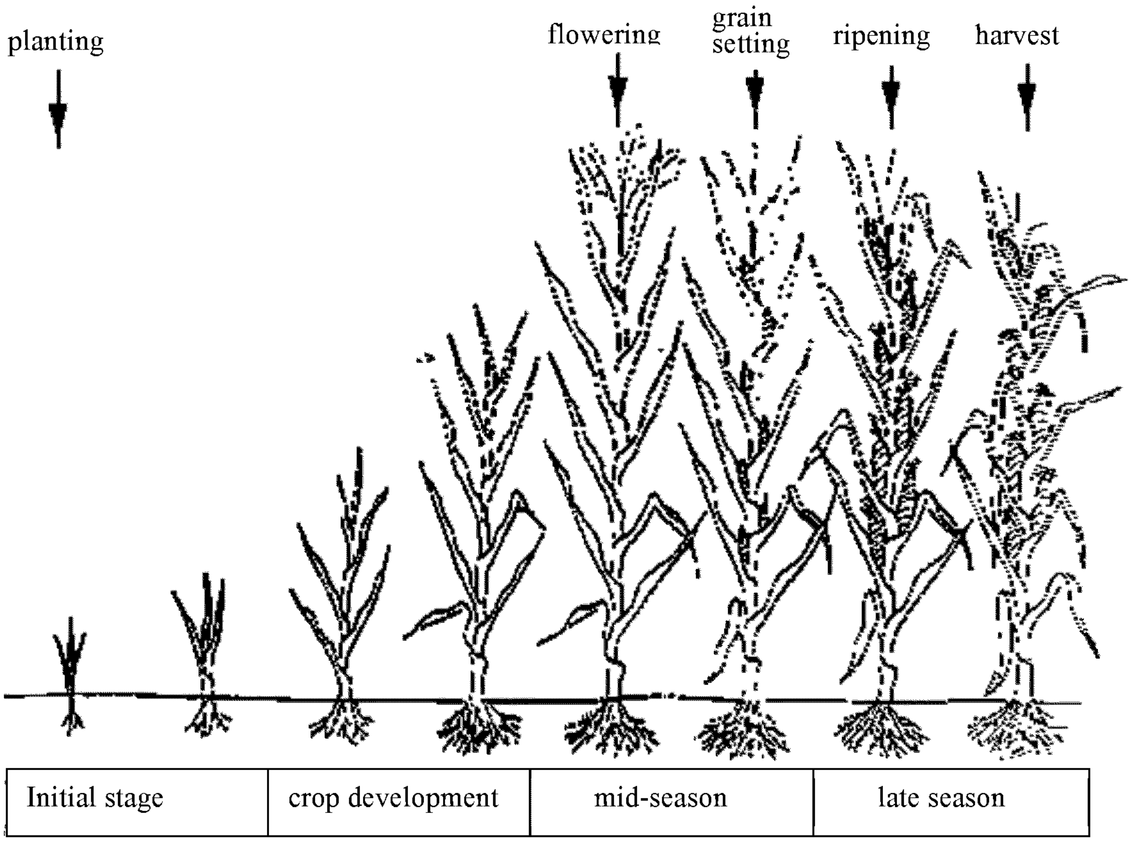


Figure 4-4 Growth stage of a crop

Source: Irrigation Water Management Training Manual No.3 "irrigation Water Need". FAO, 1986

At planting and during the initial stage, the evaporation is more important than the transpiration and the evapotranspiration or crop water requirement during the initial stage is estimated at 50 percent of the crop water requirement during the mid - season stage, when the crop is fully developed.

During the so-called crop development stage the crop water requirement gradually increases from 50 percent of the maximum crop water requirement to the maximum crop water requirement. The maximum crop water requirement is reached at the end of the crop development stage which is the beginning of the mid-season stage.

With respect to the late season stage, which is the period during which the crop ripens and is harvested, a distinction can be made between two groups of crops:

Fresh harvested crops: such as lettuce, cabbage, etc. With these crops the crop requirement need remains the same during the late season stage as it was during the mid-season stage. The crops are harvested fresh and thus need water up to the last moment.

Dry harvested crops: such as cotton, maize (for grain production), sunflower, etc. During the late season stage these crops are allowed to dry out and sometimes even die. Thus their water requirement during the late season stage is minimal. If the crop is indeed allowed to die, the water needs are only some 25 percent of the crop water need during the mid-season or peak period. Of course, no irrigation is given to these crops during the late season stage.

4.3.4 Effective Rainfall

Apart from soil, air and sunlight, crops need water to grow. How much water the various crops need has been explained in previous section.

This water can be supplied to the crops by rainfall (also called precipitation), by irrigation or by a combination of rainfall and irrigation.

If the rainfall is sufficient to cover the water requirements of the crops, irrigation is not required.

If there is no rainfall, all the water that the crops need has to be supplied by irrigation.

If there is some rainfall, but not enough to cover the water requirements of the crops, irrigation water has to supplement the rain water in such a way that the rain water and the irrigation water together cover the water requirements of the crop. This is often called supplemental irrigation: the irrigation water supplements or adds to the rain water.

Not all rain water which falls on the soil surface can indeed by used by the plants. Part of the rain water percolates below the root zone of the plants and part of the rain water flows away over the soil surface as run-off. This deep percolation water and run-off water cannot be used by the plants. In other words, part of the rainfall is not effective. The remaining part is stored in the root zone and can be used by the plants. This remaining part is the so-called effective rainfall. The factors which influence which part is effective and which part is not effective include the climate, the soil texture, the soil structure and the depth of the root zone.

If the rainfall is high, a relatively large part of the water is lost through deep percolation and run-off.

Deep percolation: If the soil is still wet when the next rain occurs, the soil will simply not be able to store more water, and the rain water will thus percolate below the root zone and eventually reach the groundwater. Heavy rainfall may cause the groundwater table to rise temporarily.

Run-off: Especially in sloping areas, heavy rainfall will result in a large percentage of the rainwater being lost by surface run-off.

Another factor which needs to be taken into account when estimating the effective rainfall is the variation of the rainfall over the years. Especially in low rainfall climates, the little rain that falls is often unreliable; one year may be relatively dry and another year may be relatively wet.

In many countries, formulae have been developed locally to determine the effective precipitation. Such formulae take into account factors like rainfall reliability, topography, prevailing soil type etc. If such formulae or other local data are available, they should be used.

4.3.5 Decision of designed water requirements

(1) Calculation of Crop Water Requirement

In the process for estimating the irrigation water requirements, the reference crop evapo- transpiration (ETo) for upland crops could be estimated using the "CROPWAT for Windows Computer Software" [1], being popular in the agricultural development plan in Africa, which is based on the FAO Penman-Monteich Equation. On the other hand, the ETo for paddy rice could be estimated using the modified Penmam Methods. The Penman-Monteith equation is given by the following equation:

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma \dfrac{900}{T + 273} U2(es - ea)}{\Delta + \gamma(1 + 0.34u2)}$$

Where;

ETo	=	Reference evapo-transpitation (mm/day)
Rn	=	Net radiation at the crop surface (MJ/m^{2}per day)
G	=	Soil heat flux density (MJ/m^{2}per day)
T	=	Mean daily air temperature at 2 m height (℃)
U2	=	Wind speed at 2 m height (m/sec)
Es	=	Saturation vapour pressure (kpa)
Ea	=	Actual vapour pressure (kpa)
Es – ea	=	Saturation vapour pressure deficit (pka)
△	=	Slope of saturation vapor pressure curve at temperature T (kpa/℃)
γ	=	Psychometric constant (kpa/℃)

Crop water requirements (ETc/CWR) were estimated by multiplying ETo mentioned in the above by a crop coefficient (Kc), that is:

ETc = ETo x Kc

Where;

ETc/CWR	=	Crop water requirements (mm/day)
ETo	=	Reference crop evapo-transpiration (mm/day)
Kc	=	Crop coefficient

Crop coefficient:

The relationship between the reference grass and the crop actually grown is given by the crop coefficient.

Fully developed maize, with its large leaf area will be able to transpire, and thus use, more water than the reference grass crop: Kc, maize is higher than 1. Cucumber, also fully developed, will use less water than the reference grass crop: Kc, cucumber is less than 1

A certain crop will use more water once it is fully developed, compared to a crop which has just recently been planted.

The climate influences the duration of the total growing period and the various growth stages. In a cool climate a certain crop will grow slower than in a warm climate.

Thus, to determine the crop factor Kc, it is necessary, for each crop, to know the total length of the growing season and the lengths of the various growth stages.

The determination of the Kc values for the various growth stages of the crops involves several steps:

Step 1 - Determination of the total growing period of each crop

Step 2 - Determination of the various growth stages of each crop
Step 3 - Determination of the Kc values for each crop for each of the growth stages

Standard figures of Kc for various crops are sown in the FAO paper 56.

(2) Cropping Patterns

Cropping patterns are planned to calculate crop water requirements and irrigation water requirements, considering topography, water availability, soil conditions, current farming practices, marketing conditions, etc. around each areas

Table 4-3 Sample Cropping Pattern

Crops	area (ha)	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Green Maize	10.00	50												
Tomato	4.00	20												
Egg plant	1.00	5												
Rape	3.00	15												
Cabbage	1.00	5												
Okura	1.00	5												
Total	20.00	100			5	5	5	90	100	100	85	75	5	

Source: T-COBSI Project Team

(3) Estimation of Irrigation Water Requirements

In estimating irrigation water requirements applying the "CROPWAT" equation mentioned above, following procedures and assumptions are taken into considerations;

- Meteorological data

The data collected over long period (10 years or more in principle, and 20 years or more with regard to data on temperature, consecutive no-rainy days and pan evaporation, which are closely related with the irrigation plan) at the representative meteorological stations in the area shall be investigated. When the necessary data are not available in the project area, those derived from similar meteorological conditions can be used. Meteorological data of FAO-CLIMWAT can be used for CROPWAT.

- Crop coefficient

Crop coefficients for maize and upland crop are referred to the authorized values in the computer program, while those for paddy rice are quoted from FAO Technical paper NO. 24

- Effective rainfall

A number of empirically determined formulae can be used. They have been developed under a given set of conditions which may be very different from those under which they are to be applied. Their use elsewhere therefore remains doubtful.

According to FAO-CROPWAT, "In general, the efficiency of rainfall will decrease with increasing rainfall. For most rainfall values below 100 mm/month, the efficiency will be approximately 80%. Unless more detailed information for local conditions, it is suggested to select the Option "Fixed percentage" and give 80% as requested value".

In Northern, Luapula and Muchinga district, monthly precipitation in the dry season is less than 100 mm. Therefore, in this study, 80% is given as rainfall efficiency.

Table 4-4 Result of calculation

MBL 2-7 Kawama	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. MAIZE (Green)	0	0	0	0	0	25.5	114.1	244	231.6	44.4	0	0
2. Tomato MBL2-7	0	0	0	0	0	51.1	141	233.4	218.5	11.8	0	0
3. Egg plant	0	0	0	23.4	153.7	91.5	0	0	0	0	0	0
4. Rape	0	0	0	0	0	80.2	184.8	153.7	0	0	0	0
5. CABBAGE MPR	0	0	0	0	0	0	68.4	169.1	217.7	205	5.2	0
6. Okura MBL	0	0	0	0	0	0	91.4	205.2	191.5	0	0	0
Net scheme irr.req.												
in mm/day	0	0	0	0	0.2	1.3	3.9	6.8	6	1.1	0	0
in mm/month	0	0	0	1.2	7.7	39.6	121	210.4	180	34.8	0.3	0
in l/s/h	0	0	0	0	0.03	0.15	0.45	0.79	0.69	0.13	0	0
Irrigated area	0	0	0	5	5	90	95	95	80	75	5	0
(% of total area)												
Irr.req. for actual area (l/s/h)	0	0	0	0.09	0.57	0.17	0.48	0.83	0.87	0.17	0.02	0

Source: T-COBSI Project Team

(4) Irrigation Efficiency

(1) Water losses

For deciding designed water requirements, water conveyance losses from water source to the field, and various water losses due to spraying in the field is added properly to the designed parameters for irrigation water requirements.

Water losses are obtained from irrigation efficiency which includes application and conveyance efficiencies in the field. It is decided on the reference the values shown in **Table 4-5**

Irrigation efficiency (IE) :

Irrigation efficiency is calculated by following formula:

Ep = Ea x Eb x Ec

Irrigation efficiency: Ep

Conveyance efficiency Ec: ratio of quantity of water at inlet of a block of field / intake water at source

Field canal efficiency Eb: ratio of quantity of water at field inlet / a block of field

Application efficiency Ea: ratio of quantity of water directory available to the crop / field inlet

Distribution efficiency Ed = Ec x Eb

Field efficiency Ef = Eb x Ea

Table 4-5 shows values determined by international institutes.

According to the table below, following coefficients are adopted in this study.

Ed = 0.3, Ea = 0.6

Ep = 0.6 x 0.3 = 0.18

Table4-5 Irrigation efficiency Ec, Eb, Ed, and Ea

Conveyance Efficiency (Ec)			ICID/ILRI
Continuous supply with no substantial change in flow			0.9
Rotational supply in projects of 3,000 – 7,000 ha and rotation areas of 70 – 300 ha, with efficient management			0.8
Rotational supply in large schemes (>10,000ha) and small schemes (<1,000 ha) with respective problematic communication and less effective management: Based on predetermined schedule			0.7
Based on advance request			0.65
Field Canal Efficiency (Eb)			
Blocks larger than 20 ha: unlined			0.8
lined or piped			0.9
Blocks up to 20 ha: unlined			0.7
lined or piped			0.8
Distribution efficiency (Ed = Eb x Ec)			
Average for rotational supply with management and			
Communication adequate			0.65
sufficient			0.55
insufficient			0.40
poor			0.30
Field Application Efficiency (Ea)	USDA	USSCS	
Surface methods			
Light soils	0.55		
Medium soils	0.70		
Heavy soils	0.60		
Graded border		0.60-0.75	0.53
Basin and level border		0.60-0.80	0.58
Contour ditch		0.50-0.55	
furrow		0.55-0.70	0.57
corrugation		0.50-0.70	
Subsurface		Up to 0.80	
Sprinkler, hot dry climate		0.60	
Moderate climate		0.70	
Humid and cool		0.80	0.67
Rice			0.32

ICID: International Committee of Irrigation and Drainage
ILRI: International Institute for Land Reclamation and Improvement
USDA: United States Department of Agriculture
USSCS: United States Soil Conservation Service

(5) Irrigation Water Requirements

Irrigation water requirements are classified into net irrigation water requirements and gross irrigation water requirements including water losses. They are the base for designing the capacity of irrigation facilities and are calculated by following expressions.

Net irrigation water requirements (NWR):

Net irrigation water requirements (NWR) will be calculated by deducting the effective rainfall estimated on the 10-day basis by following equation;

NWR = ETc - Re

Where;

NWR : Net irrigation requirements (mm/day)

ETc : Crop evapo-transpiration (mm/day)
Re : Effective rainfall (mm)

Gross irrigation water requirements (GWR):

Gross irrigation water requirements (GWR) will be calculated by taking into consideration overall irrigation efficiencies (IE). The GWR will be estimated by the following equation.

GWR= NWR/IE

Where;

GWR : Gross irrigation water requirements (mm/day)
NWR : Net irrigation water requirements (mm/day)
IE : Overall irrigation efficiency

Example

Maize, 2nd decade of September : ETc = 8.69 mm/day, IE = 0.18, Re = 0mm

GWR = 8.69 / 0.18 = 48.28 mm/day

for 1 ha,

Q = 48.28 / 1000 x 10000 / 86400 = 0.0056 m3/s = 5.6 l/s

(6) Irrigation Water Requirements for System Capacity

Irrigation water requirements (IWR) to plan the system capacity will be determined by taking into consideration the time of irrigation hours per day and working day per week. The following equation will be used for the determination of the IWR:

IWR = GWR x A x 10,000 /(Hr x 3,600) x 7/v

Where,

IWR : Irrigation water requirements for system capacity (lit./sec)
GWR : Gross irrigation water requirements (mm/day)
A : Irrigation area (ha)
Hr : Water supply hours per day (hrs)
V : Working days per week (days)

Example

GWR = 48.28 mm/day, A = 1 ha, Hr = 8 hrs, V = 5 days

IWR = 48.28 x 1 x 10000 / (8 x 3600) x 7 / 5 = 23.47 lit/s/ha

4.3.6 Water-Source Plan

(1) Designed year for planning

The designed year for planning is basically a drought year which after comes around once in a decade. It should be judged based on the meteorological and rainfall records of a long period.

To prepare an irrigation plan, the designed year for planning should be set, and the possibility of water utilization in the year is studied to prepare a plan which applicable to the water source (including expansion of water source). The designed year for planning is usually a drought year which comes around every ten years.

1) Water from river run - off

The designed year for planning years is a drought year, coming about once in ten years (probability of

1/10 year).

2) Other water sources

The designed year is decided from statistical processing of the consecutive drought days and effective rainfall amount during irrigation period with probability of 1/10. The decision of designed year should be based on meteorological and rainfall data of more than 20 years as a rule.

(2) Water source plan

Water source plan is to examine technical possibility of various water sources as rivers, groundwater, reservoirs, and others and to decide the most economical water source according to the irrigation method and the water requirements.

Amount of available water will be obtained from data of a long period, and its statistical processing is used to secure the water source and the plan itself. As far as technology allows, many water sources should be compared and examined. To optimize water from rivers with low drought discharge, it is necessary to install a farm pond between water source and the irrigation area, and examine water source facilities about the extension of pump operation, and the reduction of the pump capacity. A pump is supposed to operate 24 hours.

To decide a water source plan, a cropping pattern and crop intensity are also examined to use water source efficiently.

In addition, in some structures of irrigation facilities and water management system, operation loss in the irrigation system is expected. Such losses should be recognized and available water source must he sufficient to cover them.

(3) Whole System Plan

Irrigation systems from the field to the water source for the upland irrigation includes on-farm irrigation, the water distribution, and the water conveyance systems.

These three systems relates closely each other, and their harmonious connection with emphasis on economy, function and safety is desired in planning of irrigation systems.

1) Composition of the systems

① On-farm irrigation system

On-farm irrigation system is a general item for valves (including diversion valves) controlling a plurality of sprinkling blocks and other secondary facilities.

②Water distribution system

Water distribution systems is a general term for a series of facilities from a farm pond to the on-farm irrigation systems.

③ Water conveyance system

Water conveyance system is a general term for a series of facilities from the water source to the water distribution system.

4.3.7 On - farm Irrigation System Plan

(1) Decision of furrow length and width

In furrow irrigation, furrow length is restricted by irrigation application efficiency, and soil maintenance. Maximum furrow length should be the length which allows water to reach without soil erosion or great deep zone loss. The larger the furrow discharge, or the smaller the intake rate, the longer the furrow becomes.

To improve labor efficiency of water distribution at one time, a longer furrow is preferable. However, there is a certain limitation in relation with the irrigation application efficiency.

Table 4-6 shows an example of maximum furrow length of different soils. The maximum furrow length of sandy soil, which has small water-holding capacity and large intake rate, is 10m or less. In terms of irrigation labor, furrow irrigation is not appropriate for sandy soil.

Table 4-6 Example of maximum furrow length of different soils

Soil	Root zone depth	One-time irrigation volume	Maximum furrow length
Sandy soil	40cm	16mm	4m
Volcanic ash soil	40cm	44mm	29m
Sandy loam	40cm	34mm	36m
Loam	40cm	38mm	99m
Clay	40cm	44mm	121m

Note: Furrow inclination is 10%. Source: Engineering Manual for Irrigation and Drainage Upland Irrigation, The Japanese Institute of Irrigation and Drainage 1990.

(2) Distribution Method of Irrigation Water

a) General Methods of Water Distribution

Following two types of water distribution methods are generally applied at present;

- Simultaneous distribution, and
- Rotational distribution

1) Simultaneous Distribution

This method involves simultaneous supply of water to all the canals.

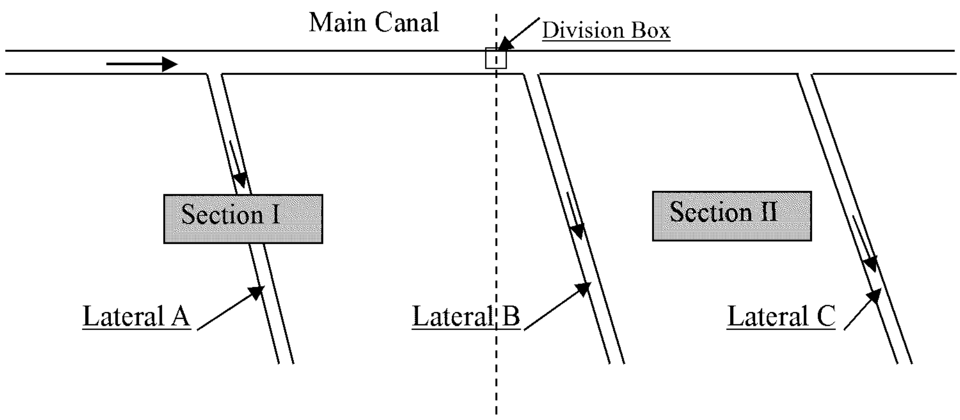
2) Rotational Distribution

Rotational distribution is practiced by rotating the supply of water to different areas. Under this method there are three practices as shown below, namely:

- Rotation by section in main canal
- Rotation by section or turnouts in the lateral/feeder canals
- Rotation by section in the farm ditch

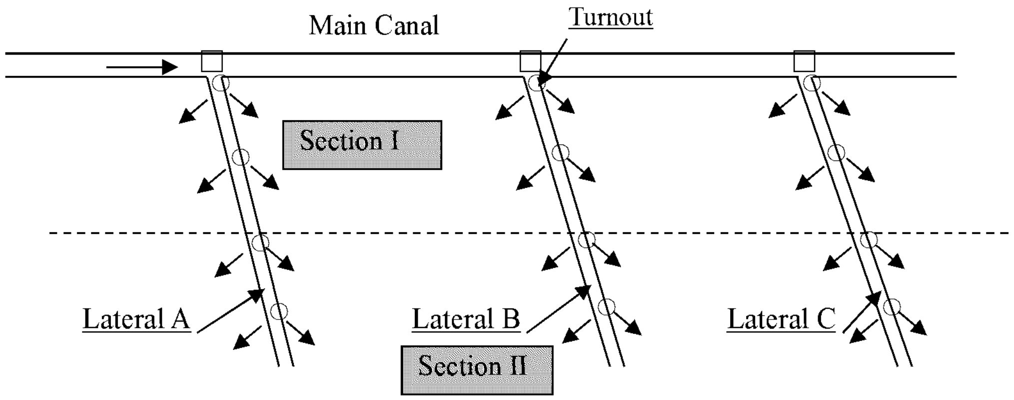
Rotation by Section in Main Canal

Irrigation water is conveyed by rotation to different sections in the main canal (refer to the following figure). This method requires bigger capacities for both conveyance and distribution systems.

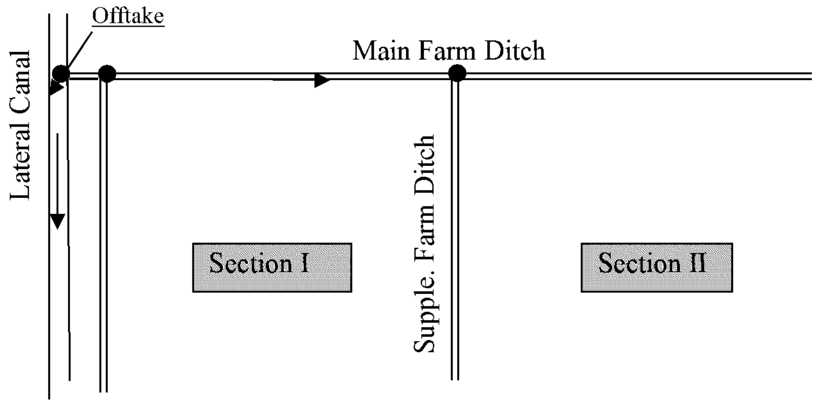


Generally, 3-day to 7-day rotational water supplies are adopted in the small scale irrigation schemes, so that irrigation interval in each scheme should be carefully checked and determined, based on the soil characteristics, estimated crop water requirement, canal and pump capacity, etc.

<u>Rotation by Section or Turnouts in Lateral/Feeder Canals</u>
The main canal conveys a continuous flow while the water is rotated by the section or turnouts of the lateral/feeder canal (refer to the following figure)



<u>Rotation by Section in Farm Ditch</u>
Water is rotated only in rotation area in the farm ditch, and conveyance of water in the main canal and lateral/feeder canals are continuous.



b) Comparison on the Water Distribution Methods

1) Advantages of Rotational Distribution Methods

Advantages of rotational water distribution are as follows;

- Water can be reasonably regulated and evenly distributed over the upper, middle and lower reaches of canal systems to meet the requirements for reducing and/or eliminating the droughts in the spot areas, when the water resources is scarce.
- It may save water which can be used for either extension of new irrigation areas or can be supplied for fish culture uses.
- Furthermore, the farmers will retain confidence in getting timely delivery of a limited amount of irrigation water during dry season and drought year.

2) Advantages of Simultaneous Water Distribution Methods

When the water resource is abundant, this method has the following advantages.

- The investment in the irrigation system is less because of fewer water control structures and measuring devices in the system.
- Less labour is used in simultaneous irrigation as compared with rotational irrigation.

4.3.8 Irrigation Schedule

(1) Introduction

The irrigation schedule indicates **how much** irrigation water has to be given to the crop, and **how often or when** this water is given.

How **much** and how **often** water has to be given depends on the **irrigation water requirement** of the crop. How to determine the irrigation water requirement has been discussed in 4.4.3.5. The irrigation water requirement is defined as the crop water requirement minus the effective rainfall. It is usually expressed in mm/day or mm/month. When, for example, the irrigation water need of a certain crop, grown in a hot, dry climate is 8 mm/day, this means that each day the crop needs a water layer of 8 mm over the whole area on which the crop is grown. This water has to be supplied by means of irrigation.

An irrigation water need of 8 mm/day, however, does **not** mean that this 8 mm has to be supplied by irrigation **every day.** In theory, water could be given daily. But, as this would be very time and labour consuming, it is preferable to have a longer irrigation interval. It is, for example, possible to supply 24 mm every 3 days or 40 mm every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants: every day 8 mm. The irrigation interval has to be chosen in such a way that the crop will not suffer from water shortage.

In **Figure 4-5** it can be seen that, on this soil, the plants start to suffer after approximately one week. Irrigation water should be given before this happens, in order to allow for optimal production. In general this means that irrigation should at the latest take place when approximately half of the available water content of the root zone has been used by the plants. When, for example (**Figure 4-6**), irrigation water is given on day 5, on day 9, on day 13, etc., the plants will not suffer from water shortage.

In principle, the amount of irrigation water given in **one** irrigation application (irrigation depth) is the amount of water used by the plants since the previous irrigation.

The amount of irrigation water which can be given during one irrigation application is however **limited.**

The **maximum amount** which can be given has to be determined and may be influenced by:

- the soil type

- the root depth

- the irrigation method.

The **soil type** influences the maximum amount of water which can be stored in the soil per metre depth. Sand can store only a little water or, in other words, sand has a low available water content. On sandy soils it will thus be necessary to irrigate frequently with a small amount of water. Clay has a high available water content. Thus on clayey soils larger amounts can be given, less frequently.

The **root depth** of a crop also influences the maximum amount of water which can be stored in the root zone. If the root system of a crop is shallow, little water can be stored in the root zone and frequent - but small - irrigation applications are needed. With deep rooting crops more water can be taken up and more water can be applied, less frequently. Young plants have shallow roots compared to fully grown plants. Thus, just after planting or sowing, the crop needs smaller and more frequent water applications than when it is fully developed.

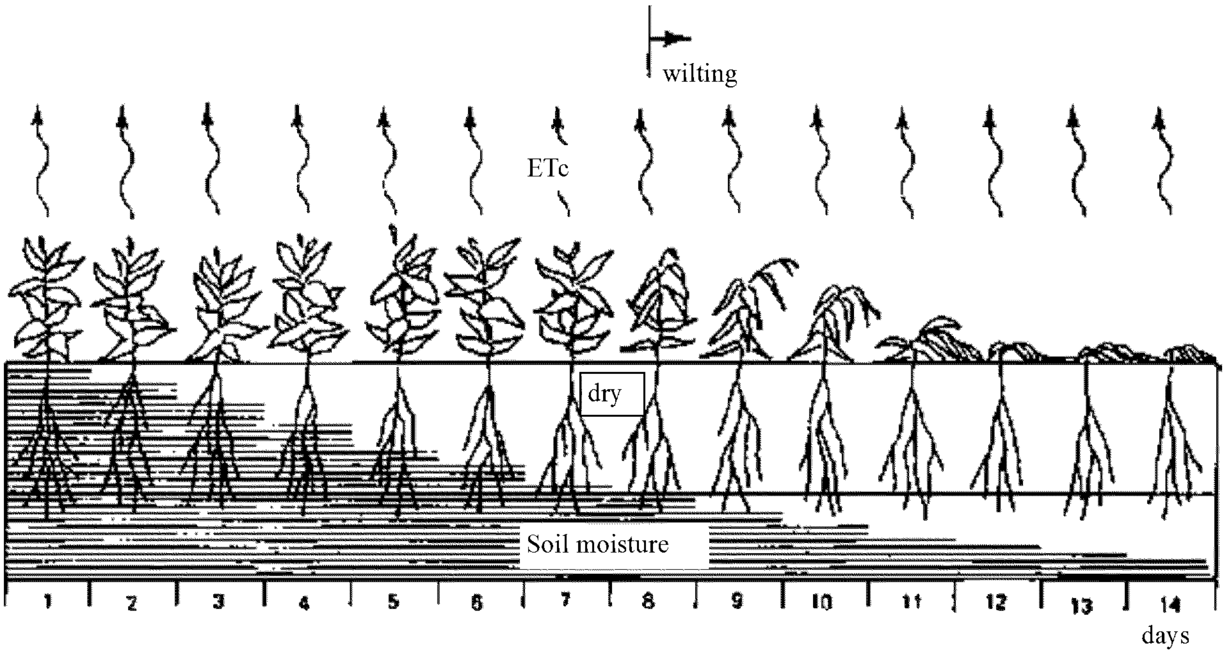


Figure 4-5 with no rainfall and no irrigation
Source: Irrigation Water Management Training Manual No.4 "Irrigation Scheduling". FAO, 1989

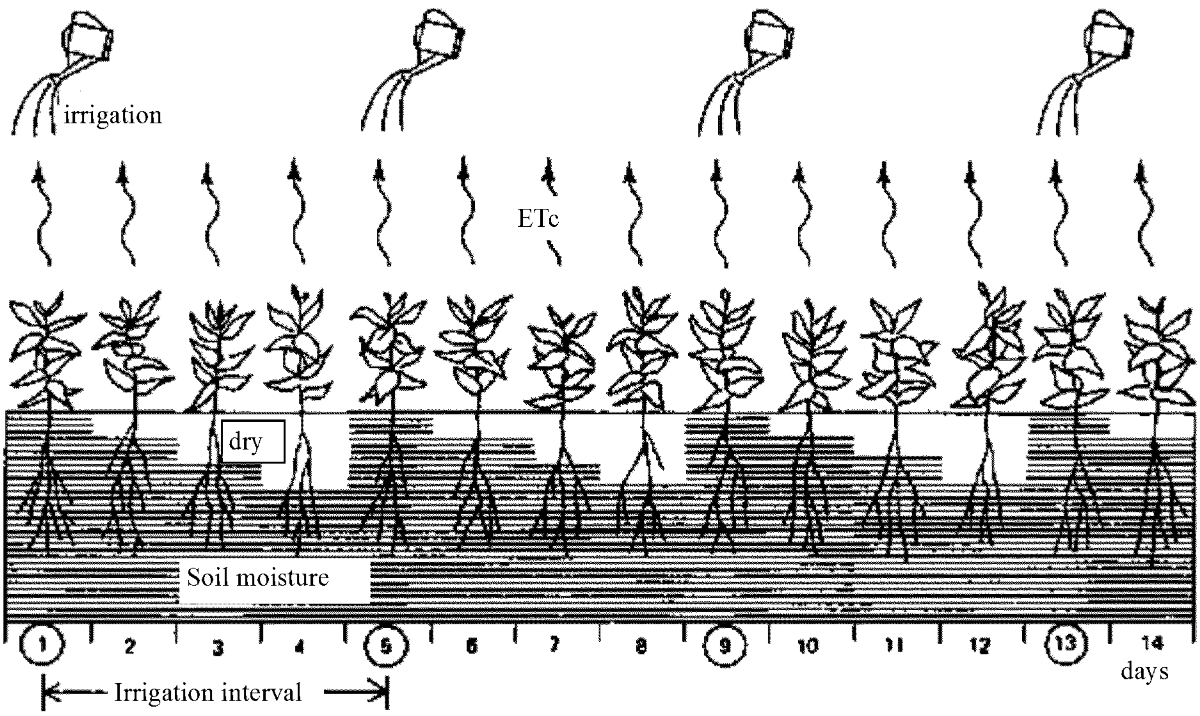


Figure 4-6 with irrigation
Source: Irrigation Water Management Training Manual No.4 "Irrigation Scheduling". FAO, 1989

The accurate determination of an irrigation schedule is a time-consuming and complicated process. The introduction of computer programs, however, has made it easier and it is possible to schedule the irrigation water supply exactly according to the water needs of the crops. Ideally, at the beginning of the growing season, the amount of water given per irrigation application, also called the irrigation depth, is small and given frequently. This is due to the low evapotranspiration of the young plants and their shallow root depth. During the mid season, the irrigation depth should be larger and given less frequently due to high evapotranspiration and maximum root depth. Thus, ideally, the irrigation depth and/or the irrigation interval (or frequency) vary with the crop development.

When sprinkler and drip irrigation methods are used, it may be possible and practical to vary both the irrigation depth and interval during the growing season. With these methods it is just a matter of turning on the tap longer/shorter or less/more frequently.

When surface irrigation methods are used, however, it is not very practical to vary the irrigation depth and frequency too much. With, in particular, surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the schedule all the time.

Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval; in other words, to keep the irrigation depth and the interval constant over the growing season.

(2) Seasonal Variation of Crop Water Requirement and Available Water

Figure 4-7 shows an example of the peak irrigation requirement of each month at the intake. It varies from 0.18 lit/s to 105.92 lit/s. there is a lot of leeway of available water in May, June, July, October and November. If cropping pattern is planned efficiently, available water is utilized more efficiently. The peak irrigation requirement must be less than available water.

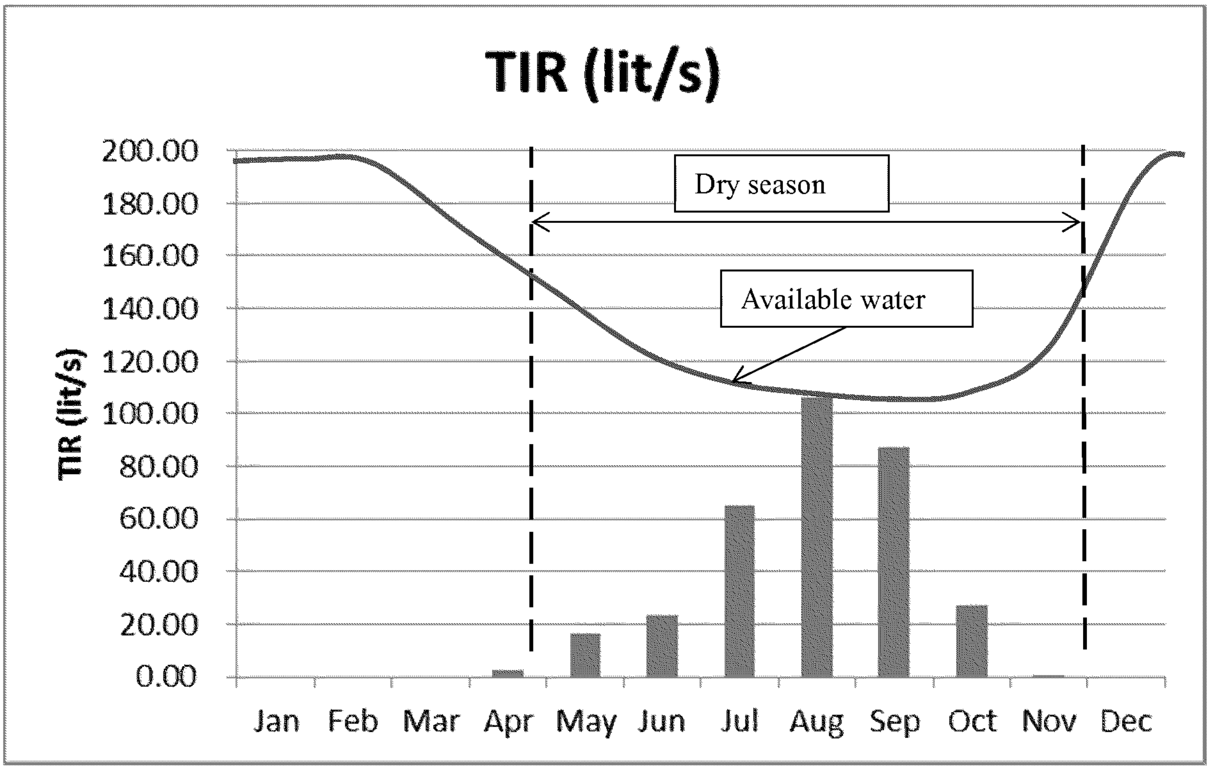


Figure 4-7 Monthly Total Irrigation Requirement (Scheme)
Source: T-COBSI Project Team

Table 4-7 shows example of irrigation requirement of typical crops.

In case of once/week, 8 hours irrigation, approximately 110 lit/s is required for 1ha. And it is enough for 5 has if rotation Monday to Friday each 1 ha or without rotation.

Table 4-7 Example Irrigation Requirement for Each Crop

Crop	Location	CIR	NIR	NIR(week)	Secondary Q.	Main Q	Secondary Q.	Main Q
frequency		daily	daily	1day/week	daily, 8hrs	daily, 8hrs	1day/week, 8hrs	1day/week, 8hrs
		mm/dec	mm/dec	mm/day	lit/s/ha	lit/s/ha	lit/s/ha	lit/s/ha
Maize	Mbala	92.00	153.33	97.58	4.84	16.13	33.88	112.93
Tomato	Mbala	86.10	143.50	91.32	4.53	15.10	31.71	105.69
Egg plant	Mbala	60.30	100.50	63.95	3.17	10.57	22.21	74.02
Rape	Mbala	68.00	113.33	72.12	3.58	11.92	25.04	83.47
Cabbage	Mbala	73.60	122.67	85.87	3.87	12.91	29.81	99.38
Okura	Mbala	72.90	121.50	85.05	3.84	12.78	29.53	98.44
Potato	Mansa	64.80	108.00	75.60	3.75	12.50	26.25	87.50
Onion	Mansa	81.90	136.50	95.55	4.74	15.80	33.18	110.59

Source: T-COBSI Project Team

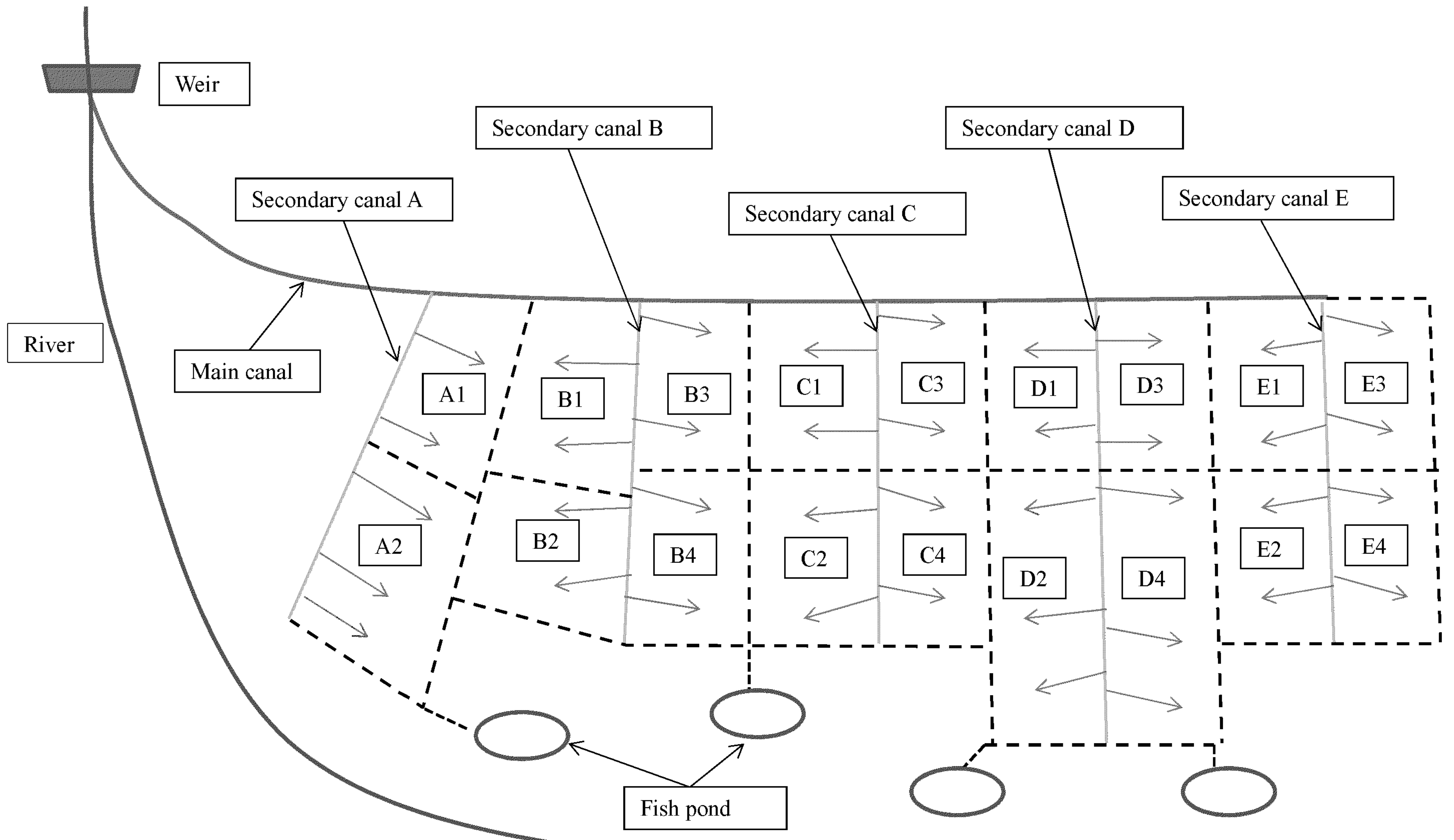
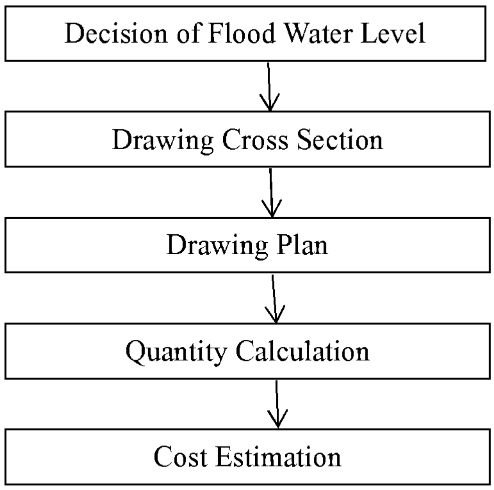


Figure 4-8 Irrigation Canal and Block Allocation

5. Outline Design

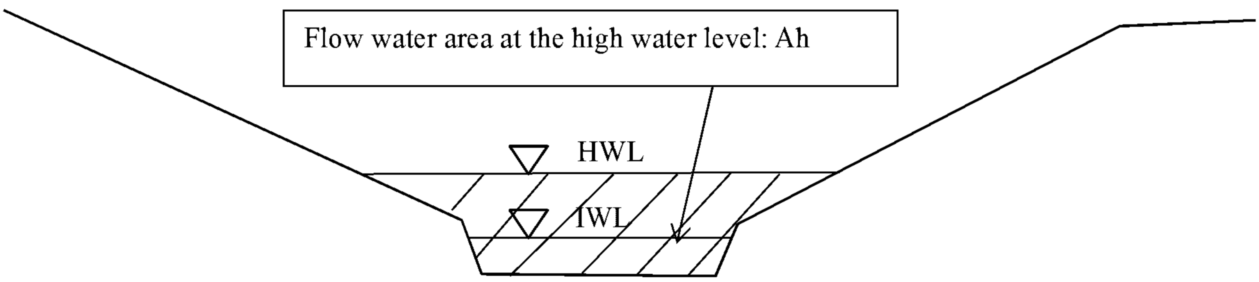
Based on the investigation of candidate sites, outline design should be prepared for each candidate site.

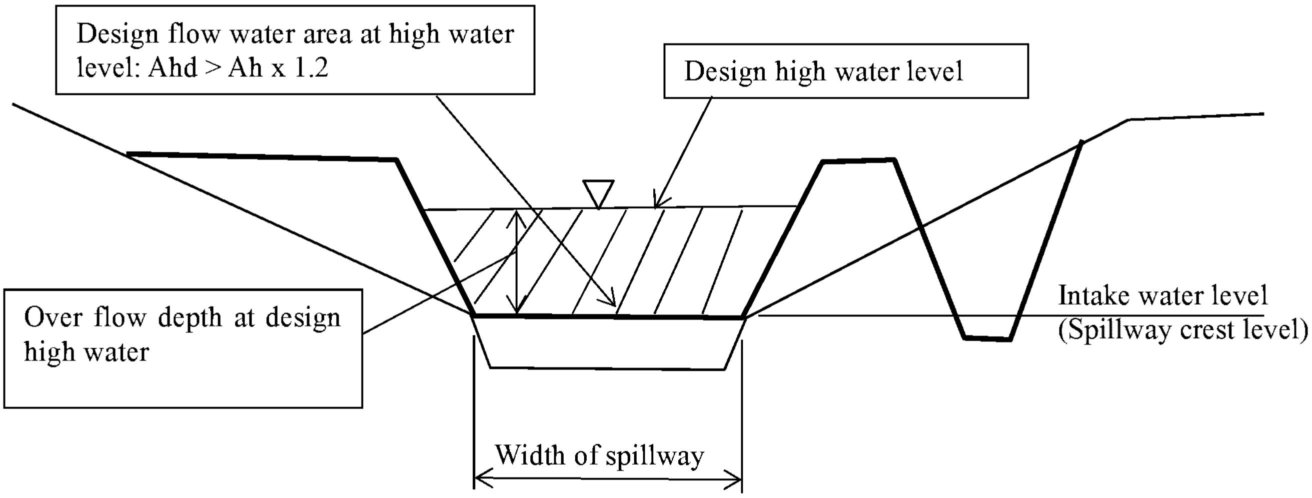
5.1 Procedure of Outline Design

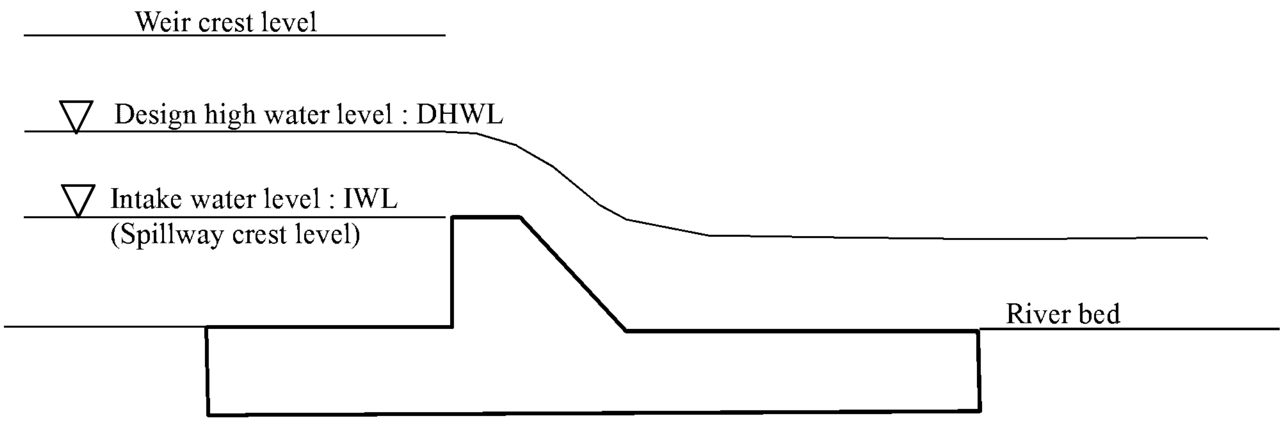


5.2 Decision of Flood Water Level

① Draw cross section of river at the weir center line
② Put high water level in the drawing
③ Calculate the flow water area at the high water level : Ah
④ Decide intake water level (spillway crest level) : IWL
Crest level of spillway = existing intake water level + 0.1 ~ 0.2m
⑤ Decide the width of spillway ≒ Width of existing river
⑥ Decide design flow water area at the high water level: Ahd > Ah x 1.2 (20% margin)
⑦ Decide the design high water level
⑧ Decide the weir crest level = DHWL + 0.6m







Sample calculation of Ahd

W (m)	D (m)	Ahd (m2)
6.00	1.00	7.00
7.00	1.00	8.00
8.00	1.00	9.00
8.00	0.90	8.01
9.00	1.00	10.00
9.00	0.90	8.91
9.00	0.80	7.84
10.00	1.00	11.00
10.00	0.90	9.81
10.00	0.80	8.64
10.00	0.70	7.49

5.3 General Layout

River diversion work is comprised of main weir, intake, spillway, apron, riverbed protection and slope protection.

(1) Elevation
- River bed: actual elevation based on the survey
- High water level (Ah) : interview to the farmers, flood mark
- Intake water level (IWL): existing intake water level + 0.1 ~ 0.2 m.
- Spillway crest elevation : = IWL
- Design high water level (DHWL) : spillway crest elevation + overflow depth
- Main weir crest elevation : DHWL + 0.6m
- Intake bottom elevation : spillway crest elevation – 0.3 ~ 0.4 > riverbed

(2) Dimension

① Stone masonry intake
- Location of intake : just beside the overflow section.
- Bottom width of intake
  Bottom width of intake is decided to meet to required discharge capacity.
  Rough standard bottom width is as follows;
    Beneficiary area is more than 15 ha: 1.0m
    Beneficiary area is less than 15 ha: 0.6m
- Slope of side wall shall be 1 : 0.5
- Slope of intake canal (hydraulic gradient) : 1/500
- Thickness of stone masonry slope protection : minimum 20cm
- Thickness of stone masonry structure : minimum 45cm
- Width of top of intake : minimum 60cm

➢ Intake water flow quantity

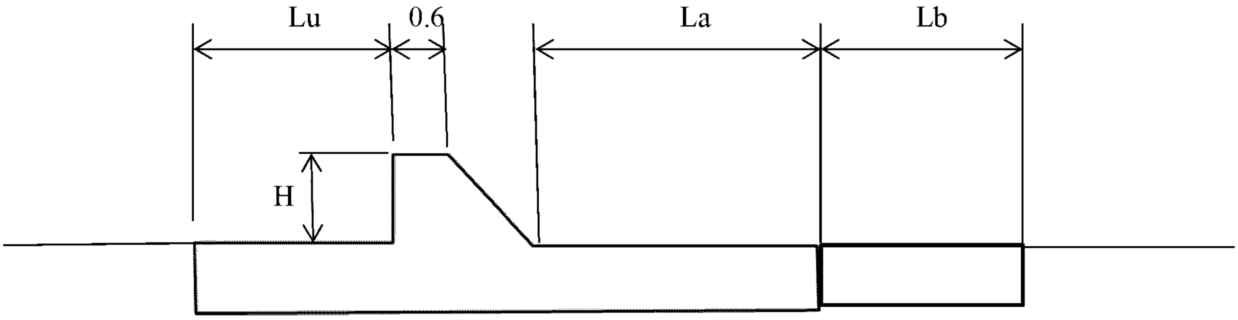
$Q = A \times V$ (m^3/sec)
Where;
Q = Discharge (m^3/sec)
A = Flow area (m^2)
V = Flow velocity (m/sec)
$V = 1/n \times R^{2/3} \times I^{1/2}$ (Manning Formula)
n = Roughness coefficient : 0.025 (rough stone wet masonry)
I = Intake canal slope (hydraulic gradient) : 0.002 (general in this project)
R = Hydraulic mean depth (m)

Table 5-1 Hydraulic calculation (Manning Formula) trapezoid 1:0.5

Bottom width (m)	Depth (m)	R (m)	I	n	V (m/s)	A (m^2)	Q (m^3/s)
0.600	0.200	0.134	0.002	0.025	0.468	0.140	0.065
0.600	0.300	0.177	0.002	0.025	0.564	0.225	0.127
0.600	0.400	0.214	0.002	0.025	0.640	0.320	0.205
1.000	0.200	0.210	0.002	0.025	0.632	0.220	0.139
1.000	0.300	0.271	0.002	0.025	0.750	0.345	0.259
1.000	0.400	0.321	0.002	0.025	0.839	0.480	0.403

② Main weir

- Width of crest of overflow section : minimum 60cm
- Width of crest of non-overflow section : minimum 60cm
- Downstream slope of weir : 1 : 1
- Upstream face of weir : vertical
- Width of stop-log : maximum 80cm
- Thickness of apron : minimum 50cm (soil foundation)
- Setting Depth of main weir : minimum 50cm (soil foundation)
- Length of downstream apron (La): see Table 4-3
- Length of upstream apron (Lu): generally 1.0 ~ 2.0m
- Length of riverbed protection (Lb): see Table 4-4



➢ Length of apron

To prevent scouring downstream of the weir by the overflowing water, a downstream apron is provided. The length of the apron can be obtained from following formula. (Engineering Manual for Irrigation and Drainage Head Works, The Japanese Institute of Irrigation and Drainage 1989).

$La = 0.6 \times C \times \sqrt{H}$

Where, La: length of downstream apron (m)

C: Bligh's C, coefficient which varies depending on the type of the foundation. (Table 5-2)

H: Height of the weir from downstream riverbed (m)

Table 5-2 Coefficients for Blighs' Method and Lanes' Method

Foundation	Bligh's coefficient C	Lane's coefficient C'
Silty sand or silt	18	8.5
Fine sand	15	7.0
Medium sand	-	6.0
Coarse sand	12	5.0
Gravel	-	4.0
Coarse gravel	-	3.5
Sandy gravel	9	-
Cobble stone with gravel	-	3.0
Rocks with cobble stone and gravel	-	2.5
Rocks with gravel and sand	4 – 6	-
Soft clay	-	3.0
Medium clay	-	2.0
Heavy clay	-	1.8
Hard clay	-	1.6

Table 5-3 below contains computed lengths of aprons for different weir heights and soil conditions, with C for medium clay assumed at 5.0.

Table 5.3 Length of La (m)

Height of weir (m)	Silty sand or silt	Fine sand	Coarse sand	Medium clay
0.5	7.6	6.4	5.1	2.1
0.6	8.4	7.0	5.6	2.3
0.7	9.0	7.5	6.0	2.5
0.8	9.7	8.0	6.4	2.7
0.9	10.2	8.5	6.8	2.8
1.0	10.8	9.0	7.2	3.0
1.1	11.3	9.4	7.6	3.1
1.2	11.8	9.9	7.9	3.3

➢ Length of riverbed protection

Riverbed protection work is provided continuously to the apron to prevent scouring. Riverbed protection work prevent scour by reducing the energy of the high velocity flow that passes the weir gradually using the resistance of riverbed protection, making the flow velocity the same as that of downstream river following the riverbed protection.

The material of riverbed protection work should be gabions or stone pitching. Recommended length of riverbed protection work should be obtained from following Bligh's formula. Slope protection of both sides should be the same length as apron and riverbed protection.

La = L – Lb

L = 0.67 x C x $\sqrt{\ }$ (H x q) x f

La: Length of apron

Lb: length of riverbed protection (m)

L: total length of protection including length of apron La (m)

H: height of the weir from downstream riverbed.

q: flow quantity per unit width of design flood discharge (m^3/sec/m)

f: safety factor, 1.0 in case of fixed weir

C: Bligh's coefficient

Generally, q = 2.0 to 8.0 in small scale irrigation scheme. In T-COBSI, q is assumed at 5.0.

Table 5-4 Length of riverbed protection

H	C	q	L	H	C	q	L
0.5	5.0	5.0	5.3	0.8	5.0	5.0	6.7
0.5	12.0	5.0	12.7	0.8	12.0	5.0	16.1
0.6	5.0	5.0	5.8	0.9	5.0	5.0	7.1
0.6	12.0	5.0	13.9	0.9	12.0	5.0	17.1
0.7	5.0	5.0	6.3	1.0	5.0	5.0	7.5
0.7	12.0	5.0	15.0	1.0	12.0	5.0	18.0

Medium clay: C=5.0, Coarse sand: C=12.0

➢ Decision of length of apron

According to Table 4-3 and 4-4, recommended length of apron is as follows;

Table 5-5 Recommended length of apron

Foundation	H (m)	La (m)	Lb (m)	L (m)
Medium clay	0.6	2.3	3.5	5.8
Medium clay	0.8	2.7	4.0	6.7
Medium clay	1.0	3.0	4.0	7.5
Sandy soil	0.6	5.6	8.3	13.9
Sandy soil	0.8	6.4	9.7	16.1
Sandy soil	1.0	7.2	10.8	18.0

③ Embankment

If the length of weir is very long, approximately more than 15m one side, embankment is constructed for non-overflow section to reduce cost and construction period.

- Width of crest of embankment : 2.0m
- Upstream and downstream slope : 1:1.5

④ Main canal

1) Canal Alignment

Recommended way of canal alignment is to use line level. Interval of the two poles should preferably be 5 meter, and one side of the tied points should be 0.5 – 1 cm higher than the other. Pole with higher tied point should always be placed foreside, not like conventional alternate placing. 0.5 cm difference in 5 meter gives 1:1000 gradient suitable for gentle topography, and 1 cm gives 1:500 gradient adaptable for sloped topography. Upstream end of main canal should not be affected by a river flood. If it is located in the area which it is affected by a river flood, it should be constructed with stone masonry.

2) Canal Lining

Canal is categorized into two; either non-lining or lined. Lining is made of brick or stone masonry (concrete lining is sometimes seen but the cost beyond farmers' affordability excludes this option).

Earth canal is the most simple and economical. With simple tools such as hoe, hand shovel, and wheelbarrow, construction is very easy and cheap. However, since this is non-lining, water conveyance loss is high due to seepage/leakage and much maintenance works such as grass cutting, de-silting, reshaping of cross section and so on are needed in every season.

Lining can be done with clay soil, plastic paper, stone, brick, or masonry. These canals reduce the canal conveyance loss and also minimize maintenance works as compared to earth canal. In particular, reducing the canal conveyance loss becomes very important when diversion water is not enough to cover all the prospective service area. Lining can also prevent the canal from being eroded, which in turn minimizes the maintenance work and makes canal life longer.

Investment for lining, on the other hand, is higher than earth canal except for clay, stone and recycled plastic paper linings. Farmers in rural area make bricks by themselves. Therefore, brick lining is cheaper than stone masonry, and damaged parts or bricks can easily be replaced by the farmers. Stone masonry lining is more durable than brick, but requires much cement, which may go beyond the farmers' affordability.

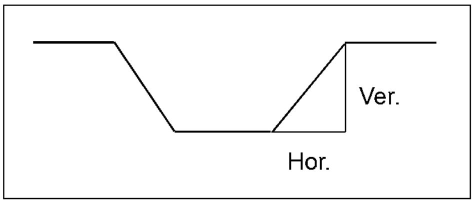
3) Canal Design

i) Cross-section and side-slopes

For earth canals, standard trapezoidal shape is commonly used. Required slope depends on the stability of the soil. Recommendable side slopes for different soils are given in **Table 4-6** below:

Table 5-6 Recommended Side Slopes for Different Types of Soils

Type of Soils	Recommendable Side Slope (Ver.) : (Hor.)
Clay	2 : 1
All other soils	2 : 1
Sand	1 : 1



Generally, rectangular cross section requires less excavation and less quantity of stone masonry or bricks. Considering safety of structure, it is recommendable to adopt trapezoid cross section. However, rectangular cross section may be adopted in case that the depth is less than 0.6 m, due to small soil pressure.

ii) Freeboard

Freeboard acts as a reserve depth in a canal to allow some variations in water flow. The freeboard is decided according to the planned discharge; more discharge, higher free board and less discharge, smaller free board. Irrigation schemes undertaken in this Guideline are small-scale, therefore a minimum 10 cm to maximum of about 20 cm freeboard is recommended.

iii) Allowable flow velocity

The design velocity of canals must be determined within the limits of two factors; namely, 1) the minimum allowable velocity that causes neither accumulation of sediment of soils nor growth of waterweeds, and 2) the maximum allowable velocity that does not produce erosion of canal materials by the flow. Refer **Table 4-7** for Maximum allowable velocities of different types of canals.

The minimum allowable velocity: 0.45 – 0.90 m/sec

Within this range of mean velocity, soil sediments are not accumulated in a canal where the particle size of suspended sediment is not larger than silt. Waterweeds hindering the flow capacity of the canal do not grow when the mean velocity is more than 0.7 m/sec.

Table 5-7 Maximum Allowable Velocity

Type of Canal Material	Maximum Allowable Velocity, (m/s)	Type of Canal Material	Maximum Allowable Velocity, (m/s)
Sandy soil	0.4 - 0.6	Thin concrete (approx.10cm)	1.5 - 2.5
Sand-loam	0.5 - 0.7		
Clay-loam	0.6 - 0.9	Brick masonry with mortar filled	2.50
Clay	0.9 - 1.5		
Rock	1.0 - 2.0		

Table 5-8 Value of Roughness Coefficient

Materials and conditions of canals	Roughness Coefficient		
	Minimum value	Standard value	Maximum value
Concrete (cast-in-place flume, culvert, etc.)	0.012	0.015	0.016
Concrete (shotcrete)	0.016	0.019	0.023
Concrete (with precast flume, pipe, etc.)	0.012	0.014	0.016
Concrete (reinforced concrete pipe)	0.011	0.013	0.014
Concrete block masonry	0.014	0.016	0.017
Cement (mortar)	0.011	0.013	0.015
Asbestos cement pipe	0.011	0.013	0.014

Steel (locked bar or welded)	0.010	0.012	0.014
Steel (revet)	0.013	0.016	0.017
Smooth steel surface (not painted)	0.011	0.012	0.014
Smooth steel surface and pipe (painted)	0.012	0.013	0.017
Corrugated surface (steel sheet)	0.021	0.025	0.030
Cast iron (not painted)	0.011	0.014	0.016
Cast iron sheet and pipe (painted)	0.010	0.013	0.014
Chloride vinyl pipe		0.012	
Reinforced plastic		0.012	
Ceramic pipe	0.011	0.014	0.017
Earth lining		0.025	
Asphalt (smooth surface)		0.014	
Asphalt (rough stone)		0.017	
Masonry (rough stone wet masonry)	0.017	0.025	0.030
Masonry (rough stone dry masonry)	0.023	0.032	0.035
Wood (wooden gutter)	0.010	0.012	0.014
Wood (lined in thin layer, treated with creosote)	0.015	0.017	0.020
Rock tunnel with no lining on overall cross-sectional area	0.030	0.035	0.040
Rock tunnel with no lining except concrete placed on the bottom	0.020	0.025	0.030
Vegetation coverage (turfing)	0.030	0.04	0.050

Source: Engineering Manual for Irrigation and Drainage Canal Works, The Japanese Institute of Irrigation and Drainage 1987.

4) Canal slope (earth)

Steep canal slope creates erosion due to its high flow velocity through it. On the other hand, too gentle slope cause heavy silting in the canal and also enlarges canal section to accommodate the required flow. Canal slope depends on the difference between the elevation at intake and farmland. If the slope is too steep and the water velocity is too high, the slope should be made gentler by setting a drop. If the slope can not be made steeper, frequent maintenance of de-silting should be required.

5) Canal dimension

The minimum canal bed width should be 0.30m considering maintenance work.

The recommended canal dimension; bottom width, water depth and total depth (= water depth + freeboard) for different design discharges and canal slopes and are presented in **Table 5-9, 10, 11** below:

$Q = A \times V$ (m^3/sec)
Where;
Q = Discharge (m^3/sec)
A = Flow area (m^2)
V = Flow velocity (m/sec)
$V = 1/n \times R^{2/3} \times I^{1/2}$
n = Roughness coefficient : Table 4-8
I = Intake canal slope (hydraulic gradient) : 0.002 (general in this project)
R = Hydraulic mean depth (m)

Table 5-9 Main Canal Hydraulic Analysis (1)

Bottom Width = 0.6m, I = 0.002, n = 0.025							
Q (m^3/s)	V (m/s)	A (m^2)	P (m)	R (m)	Water Depth (m)	Freeboard (m)	Canal Height (m)
0.025	0.346	0.072	0.846	0.085	0.110	0.190	0.300
0.050	0.431	0.116	0.979	0.118	0.169	0.131	0.300
0.075	0.487	0.154	1.086	0.142	0.218	0.183	0.400
0.100	0.528	0.189	1.180	0.160	0.259	0.141	0.400
0.125	0.562	0.223	1.265	0.176	0.297	0.103	0.400
0.150	0.590	0.254	1.342	0.189	0.332	0.168	0.500
0.175	0.614	0.285	1.414	0.201	0.364	0.136	0.500
0.200	0.636	0.314	1.482	0.212	0.394	0.106	0.500
0.225	0.656	0.343	1.545	0.222	0.423	0.177	0.600
0.250	0.674	0.371	1.606	0.231	0.450	0.150	0.600

Table 5-10 Main Canal Hydraulic Analysis (2)

Bottom Width = 1.0m, I = 0.002, n = 0.025							
Q (m^3/s)	V (m/s)	A (m^2)	P (m)	R (m)	Water Depth (m)	Freeboard (m)	Canal Height (m)
0.200	0.6109	0.327	1.640	0.200	0.2864	0.114	0.400
0.225	0.6330	0.355	1.689	0.210	0.3080	0.192	0.500
0.250	0.6532	0.383	1.735	0.221	0.3288	0.171	0.500
0.275	0.6717	0.409	1.780	0.230	0.3487	0.151	0.500
0.300	0.6889	0.436	1.823	0.239	0.3679	0.132	0.500
0.325	0.7049	0.461	1.864	0.247	0.3864	0.114	0.500
0.350	0.7199	0.486	1.904	0.255	0.4044	0.196	0.600
0.375	0.7341	0.511	1.943	0.263	0.4219	0.178	0.600
0.400	0.7475	0.535	1.981	0.270	0.4389	0.161	0.600
0.450	0.7723	0.583	2.055	0.284	0.4716	0.128	0.600
0.500	0.7948	0.629	2.124	0.296	0.5027	0.197	0.700

Table 5-11 Branch Canal Hydraulic Analysis

Bottom Width = 0.3m, I = 0.03, n = 0.025							
Q (m^3/s)	V (m/s)	A (m^2)	P (m)	R (m)	Water Depth (m)	Freeboard (m)	Canal Height (m)
0.005	0.578	0.009	0.362	0.024	0.028	0.172	0.200
0.010	0.735	0.014	0.395	0.035	0.043	0.158	0.200
0.015	0.841	0.018	0.422	0.042	0.055	0.146	0.200
0.020	0.923	0.022	0.446	0.049	0.065	0.135	0.200
0.025	0.991	0.025	0.467	0.054	0.075	0.125	0.200
0.030	1.047	0.029	0.487	0.059	0.084	0.116	0.200

6. Preparation of Drawing

(1) Longitudinal cross section

① Based on the site survey along the dam axis, longitudinal cross section of existing ground level is drawn.
② According to the decided width of spillway, intake bottom and elevations of spillway crest, crest level of non-overflow section, intake bottom, etc. longitudinal section of weir is drawn.
③ Scale of the drawings shall be 1:100.
④ Elevations and dimensions are indicated in the drawing.
⑤ The drawing covers end of weir + 5m both sides.

(2) Plan

① Spillway and non-overflow section is drawn according to the dimensions.
② End line of stonemasonry weir is drawn according to the slope and height.
③ Upstream apron and downstream apron is drawn.
④ Intake is drawn according to intake wall slope and bottom width.
⑤ Intake canal is drawn according to top width, slope and height of wall
⑥ Upstream of intake part is drawn.
⑦ Slope protection is drawn.
⑧ Other part is drawn.

(3) Coross Sections.

① Standard cross sections for spillway, non-overflow section and intake canal are drawn
② Following cross sections are drawn
- River center line
- Left side abutment (beginning, middle, end)
- Right side abutment (beginning, middle, end)
- Intake canal (beginning, middle, end)
- Upstream of intake
- Other part as necessary

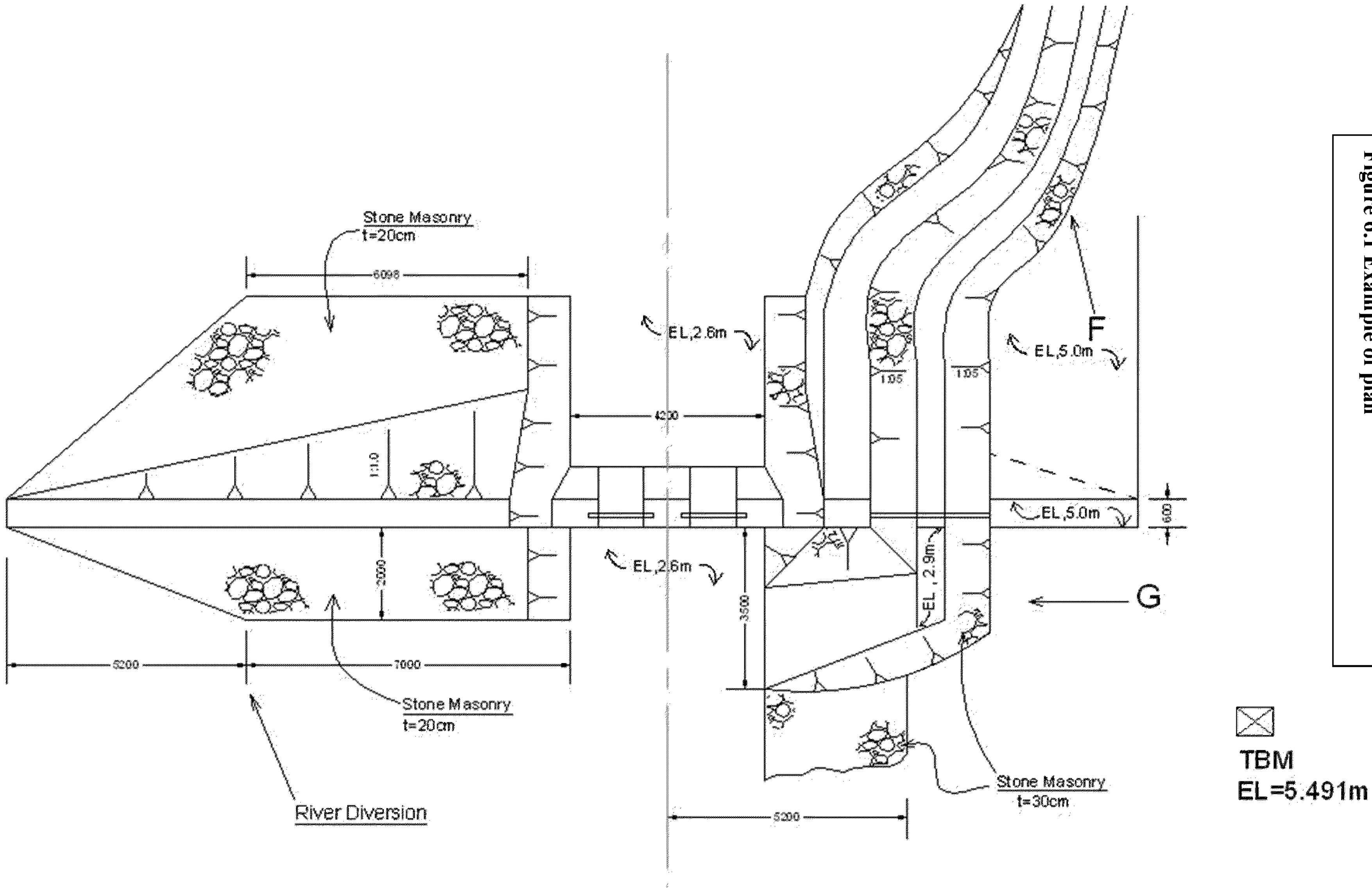


Figure 6.1 Example of plan

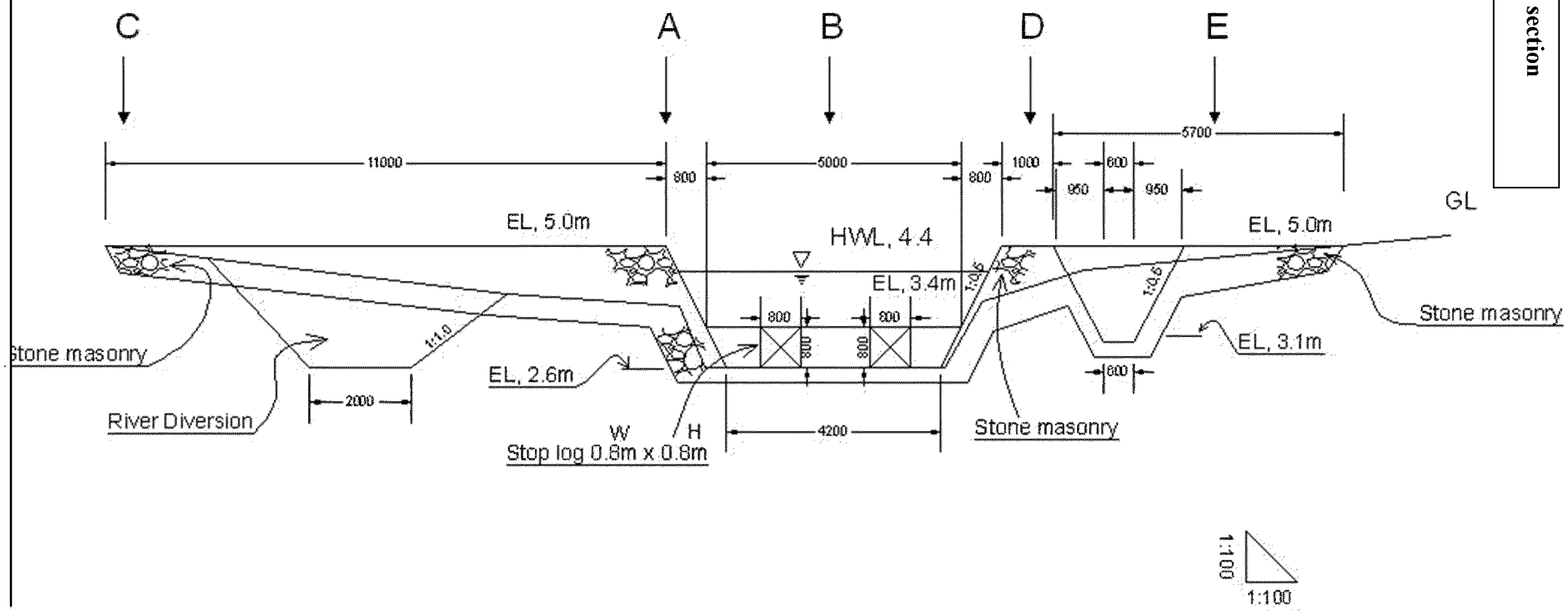


Figure 6.2 Example of longitudinal section

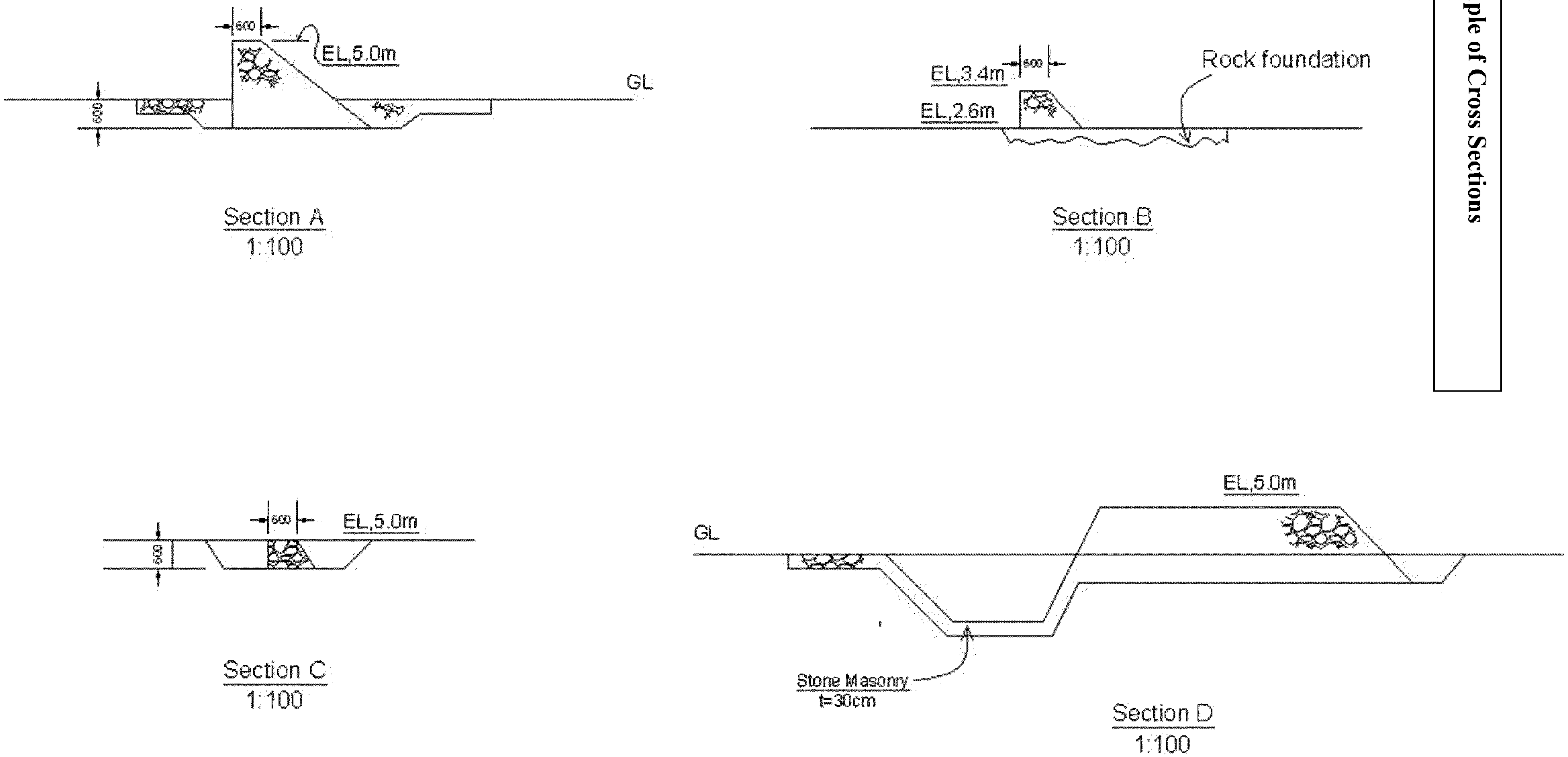


Figure 6.3 Example of Cross Sections

7. Work Plan

(1) General

Construction plan is to establish that the way how the project is implemented safely and within the specified time and cost, and construction method and procedure. Construction work has different types, sizes, and locations and construction conditions are different from one to another. To execute these works in systematic and organized ways, the construction plan appropriate for each work needs to be prepared.

i) Based on design, work method is established.
ii) Based on design, quantity of required materials is calculated.
iii) Based on quantity and work method, required manpower is calculated.
iv) Based on quantity and manpower, construction cost is calculated.
v) Based on manpower, work schedule is drawn up.

(2) Bill of Quantity

Quantity of required materials should be calculated in accordance with drawing. Following items are calculated.

- Excavation
- Embankment
- Stone masonry
- Rubble stones
- Mortar
- Sand
- Cement
- Pipes
- Others

i) Excavation

Quantity of excavation is calculated in accordance with cross section.

$V_{ex} = (A1 + A2)/2 \times L1 + (A2 + A3)/2 \times L2 + \ldots\ldots + (An\text{-}1 + An)/2 \times Ln$

Vex: Excavation volume (m^3)
An: Cross sectional area of excavation at An (m)
Ln: Distance between An-1 and An (m)

or

$V_{ex} = A \times D$ (m^3)
A: Excavation area (m^2)
D: Excavation depth (m)

ii) Embankment

Quantity of embankment shall be calculated in accordance with cross section.

$V_{em} = (A1 + A2)/2 \times L1 + (A2 + A3)/2 \times L2 + \ldots\ldots + (An\text{-}1 + An)/2 \times Ln$

Vem: Embankment volume (m^3)
An: Cross sectional area of embankment at An (m)
Ln: Distance between An-1 and An (m)

iii) Stone masonry

Quantity of stone masonry is calculated in accordance with cross section.

iv) Rubble stone (stone masonry)

Quantity of rubble stone for stone masonry is calculated as follows

$V_{rs} = V_{sm} \times 1.08$ (m^3)

1.08: coefficient of loss
Vrs: Volume of rubble stone (m^3)
Vsm: Volume of stone masonry (m^3)

v) Mortar for stone masonry
Quantity of mortar for stone masonry is calculated as follows
Vmo = Vsm x 0.5 x 1.1 (m^3)
Vmo: Volume of mortar for stone masonry (m^3)
Vsm: Volume of stone masonry (m^3)
0.5: coefficient of ratio
1.1: coefficient of loss

vi) Sand for mortar
Quantity of sand for mortar is calculated as follows
Vsa = Vmo x 0.8 (m^3)
Vsa: Volume of sand (m^3)
Vmo: Volume of mortar (m^3)

vii) Cement
Quantity of cement for mortar is calculated as follows
Vc = Vmo x 9.0 (bags)
Vc: Volume of cement (bags)
Vmo: Volume of mortar (m^3)
viii)

Example of quantity calculation sheet is shown in **Table 7-1.**

(3) Cost estimation

Construction cost is calculated based on bill of quantity and man power. Example of cost calculation sheet is shown in **Table 8.2**.

(4) Man Power and Tools Planning

Standard of required manpower, material and tools for each work is estimated as **Table 8.1**. These were established.

Example of tools planning is shown in Table 8.3.

Table 7-1 Example of Quantity Calculation Sheet

Site Name MBL 2-7 KAWAMA

No.	Item	Specifoication ／Quality	calculation	Amount	Unit	Remarks
1	Excavation					
	Left side		((7.7 x 7.0) + (7.7 + 1.8)/2 x 5.2 x 0.6 = 68.72 m3			
	Right side		7.5 x 0.6 x 15 = 67.5 m3			
			68.72 + 67.5 = 136.22 m3			
	River diversion		(2+6.0)/2 x 2.1 = 8.4 m2			
			8.4 x 30 = 252 m3			
	Toral		136.22 + 252 = 388.22	388.00	m^3	
2	Stone masonry				m^3	
	Left side abutment	section A	(0.6 + 2.3)/2 x 1.7 = 2.465 m2	18.01		
		section C	(0.6 + 1.2)/2 x 0.6 = 0.54 m2			
			(2.465 + 0.54)/2 x 11.0 = 16.53 m3			
			2.465/2 x 1.2 = 1.48 m3			
	Left side slope		2.0 x 7.0 x 0.2 = 2.80 m3	3.84	m^3	
			(2.0 x 5.2)/2 x 0.2 = 1.04 m3			
	Weir		(0.6 + 1.4)/2 x 0.8 x 4.6 = 3.68 m3	3.68	m^3	
	Right side bank		(1.0 + 2.2)/2 x 1.2 = 1.92 m2	25.71	m^3	
			(2.0 + 0.6)/2 x 0.5 = 0.65 m2			
			0.6 x 0.7 = 0.42 m2			
			1.92 + 0.65 + 0.42 = 2.99 m2			
			2.99 x (3 + 10/2) = 23.92 m3			
			2.99 x 1.2 / 2 = 1.79 m3			
	Right side abutment		(0.6 + 1.5)/2 x 0.9 = 0.945 m2	3.26	m^3	
			(0.945 + 0.54)/2 x 3.1 = 2.31 m3			

No.	Item	Specifoication ／Quality	calculation	Amount	Unit	Remarks
	Rigjht side upstream protection		(2.1 + 0.6) x 2.0 = 5.4 m2	2.66	m^3	
			3.0 x 1.2 = 3.6 m2			
			(2.1 + 0.6 + 3.0) x 1.5 / 2 = 4.275 m2			
			(5.4 + 3.6 + 4.275) x 0.2 = 3.98 m3			
	Canal lining		(1.1 + 0.6 + 1.7) x 0.2 x 15 = 10.2 m3	10.20	m^3	
	Intake		(0.6 + 0.6 + 1.9) / 2 x 1.9 = 1.945 m2	1.85	m^3	
			1.945 x 0.95 = 1.85 m3			
	River diversion		8.4 x 2.5 = 21.0 m3	21.00	m^3	
	Total					
				90.20	m^3	
3	Embankmet					
	Right side		2.5 x 4 x 0.9 / 2 = 4.5 m3			
			4 x 4 x 0.5 x 0.9 / 2 = 3.6 m3			
	River diversion	backfilling	8.4 x 10 + 8.4 x 30 / 2 = 210 m3			
			4.5 + 3.6 + 210 = 218.1	218.10	m^3	

No.	Item	Specifoication /Quality	calculation	Amount	Unit	Remarks
4	Materials					
	Rubble Stone	20–30cm	90.2 x 1.08 =	97.42	m^3	
	Mortar		90.2 x 0.5 x 1.1 =	49.61	m^3	
	Sand		49.61 x 0.8 =	39.69	m^3	
	Cement	ordinally portland	49.61 x 9 =	446.49	bags	
	Stop log	plywood	1.2m x 0.8m x 2 + 0.8 x 1.9 = 3.44 m2	2.00	pc	
		timber 50x50	0.8 x 2 + 0.4 x 5 = 3.6 m	1.00	pc	
5	Tool					
	rammer			4.00	pc	

8 Work Schedule

Based on quantity and required manpower for each item, construction period for each item is estimated. If the available labor per day is enough, putting large manpower into the work, shorten the construction period is shortened. Example of manpower planning is shown in the **Table 8.4.** Based on this man power planning, work progress schedule is drawn up. If man power is enough, work items can be executed simultaneously. Example of work progress schedule is shown in the **Figure 8-1**.

(1) Standard Manpower and Quantity Per Unit

Standard manpower and quantity per unit is shown below.

a. Embankment

Embankment (by hand)	per 10m^3	quantity	unit
unskilled labor		7.60	Man*day

Ex. For 100m^3: 76 man*day = 10 days / 7.6 man/day = 20 days / 3.8 man/day

b. Excavation

Excavation (by hand)	per 10m^3	quantity	unit
unskilled labor		7.80	Man*day

Ex. For 100m^3: 78 man*day = 10 days / 7.8 man/day = 20 days / 3.9 man/day

c. Mortar Mixing

1:4 Mortar	per 0.89m^3/day	quantity	unit
unskilled labor (mixing)		2.0	Man/day
unskilled labor (helper)		4.0	Man/day

Ex. For 8.9 m^3 mortar: 10 days / 6.0 unskilled labors = 5 days / 12.0 unskilled labors (2 sets)

d. Stone Masonry (not including mortar mixing)

Stone Masonry	per 1.0 m^3	quantity	Unit
skilled labor		0.6	Man*day
unskilled labor		3.6	Man*day

Ex. For 10 m^3 stone masonry: skilled labor 6 man*day + unskilled labor 36 man*day
=6 days by (1 skilled labor and 6 unskilled labors)/day
=3 days by (2 skilled labor and 12 unskilled labors)/day = 2 sets/day

(Mortar mixing: 0.89 m^3/day/1set. Stone masonry 1.0 m^3 requires 0.5 m^3 mortar.
Stone Masonry 10m^3 requires 5 m^3 mortar
If 6days, mortar mixing 1set/day, If 3days, mortar mixing 2 sets)

(2) Work Group

Work group shall be organized according to work item. Available number of work groups shall be considered in work schedule. Number of work group depends on number of skilled labor or leader. If number of skilled labor is not enough, OJT by skilled labor, leader for another group can be cultivated.

Generally, one group (1 set) has one skilled labor and 10 to 15 unskilled labors.

Standard organization of work item is shown in the Table-1.

Ex. Construction of brick canal 1 set
Brick laying: skilled labor 1, unskilled labor 3
Mortar mixing: unskilled labor 2
Excavation (Shaping): unskilled labor 2
Helper (carry sand, water, mortar, bricks): unskilled labor 4

Generally, following work groups are organized;

- Excavation
- Embankment
- Stone Masonry
- Sand Carrying
- Stone Carrying
- Water Carrying
- Pipe Installation

(3) Critical work

Critical work is the work item which directly affects work period. The work that, if the work delayed, total work period will be longer than scheduled. To complete construction work within the period, number of work group for critical work shall be increased and some work items shall be executed simultaneously.

4) Work Schedule

Work schedule shall be developed considering manpower planning (available number of skilled and unskilled labors, work groups) and critical work. Work schedule shall be most efficient. Work schedule is shown in bar chart.

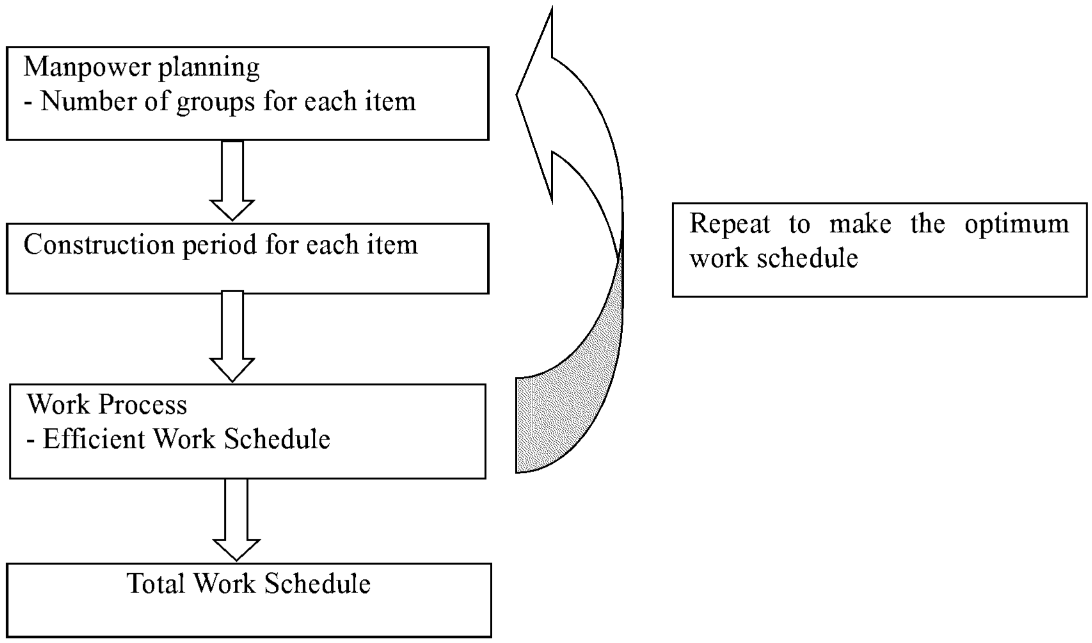

Manpower planning
- Number of groups for each item
Construction period for each item
Work Process
- Efficient Work Schedule
Total Work Schedule
Repeat to make the optimum work schedule

Table 8.1 Standards of Required Manpower, Materials and Tools

Item	name	specification, quality, shape	quantity	unit	remarks
1-1	Mortar per 1m^3	1:3	0.89m^3/day/1set		
	Material				
	Cement	Ordinary Portland	9.00	bags	450kg
	Sand	River sand	0.80	m^3	1.0 x 0.8
	Material Total				
	Labor				
	Mortar mixing	unskilled labor	2.25	man	2 x 9 / 8
	Helper	unskilled labor	4.50	man	4 x 9 / 8
	Labor Total		6.75	man	
	Tools (Daily)				
	Shovel		2.00	pcs	
	Bucket	20 lit	2.00	pcs	
	Wheel barrow		1.00	pc	
	Mortar box		1.00	pc	
1-2	1:3 Mortar per 0.89m^3 / day/ 1 set				
	Material				
	Cement	Ordinary Portland	8.00	bags	400kg
	Sand	River sand	0.71	m^3	0.89 x 0.8
	Material Total				
	Labor				
	Mortar mixing	unskilled labor	2.00	man	
	Helper	unskilled labor	4.00	man	
	Labor Total		6.00	man	
	Tools (Daily)				
	Shovel		2.00	pcs	
	Bucket	20 lit	2.00	pcs	
	Wheel barrow		1.00	pc	
	Mortar box		1.00	pc	
2-1	Excavation (by hand)	per 10m^3			
	Labor				
	unskilled labor		7.80	man	
	Tools				
	Shovel		3.00	pcs	
	Pickaxe		2.00	pcs	
	Hoe		2.80	pcs	
	String		1.00	roll	
	Peg				

Item	name	specification, quality, shape	quantity	unit	remarks
2-2	Hauling excavated material per 1.0 m^3 by wheel barrow				
	Labor				
	unskilled labor	～20m	0.02	man	
	Wheel barrow	20～40m	0.06	man	
		40～60m	0.14	man	
		60～80m	0.24	man	
		80～100m	0.34	man	
		100～120m	0.44	man	
		120～140m	0.56	man	
		140～160m	0.66	man	
		160～180m	0.78	man	
		180～200m	0.90	man	
		one way distance			
3	Embankment (by hand)	per 10m^3			
	unskilled labor		7.60	man	
	Tools				
	Shovel		2.00	pcs	
	Hoe		3.60	pcs	
	Rammer		2.00	pcs	
	String		1.00	roll	
	Peg				
4-1	Finishing slope (cut earth) per 100m^2				
	Labor				
	Foreman		1.40	man	
	Unskilled labor		11.80	man	
	Total labor		13.20	man	
	Tools				
	Shovel		4.00	pcs	
	Hoe		7.80	pcs	
	String		1.00	roll	
4-2	Finishing slope (embankment) per 100m^2				
	Labor				
	Foreman		1.60	man	
	Unskilled labor		25.80	man	
	Total labor		27.40	man	
	Tools				
	Shovel		4.00	pcs	
	Hoe		21.80	pcs	
	String		1.00	roll	

Item	name	specification, quality, shape	quantity	unit	remarks
5	Stone masonry	per 1m^3			
	Material				
	Rubble stone		1.08	m^3	
	Mortar		0.55	m^3	
	Total material				
	Labor (not include mortar mixing)				
	Foreman		0.30	man	
	Skilled labor		0.60	man	
	Unskilled labor		3.60	man	
	Total labor		4.50	man	
	Tools (Daily, not include mortar mixing)				
	Bucket	20 lit	4.00	pcs	
	Wheel barrow		4.00	pc	
	Trowel		4.00	pcs	
	Builder's level		1.00	pc	
	Measuring tape		1.00	pc	
	Peg				
6	Gathering stones	per 10m^3 distance 50m			
	Unskilled labor		15.00	man	
	Tools (daily)				
	Wheel barrow		7.00	pcs	
	14 lbs hammer		4.00	pcs	
	4 lbs hammer		2.00	pcs	
	Chisel		2.00	pcs	

Table 8.2 Example of Cost Calculation Sheet

No.	Item	Specification/Quality	Quantity	Unit	Unit Price ZMK	Price ZMK	Remarks
1	Preparation Work						
	Site clearing	unskilled labor	50.0	man	0.0	0.0	
	Gathering stones	unskilled labor	146.1	man	0.0	0.0	
	Gathering sand	unskilled labor	19.8	man	0.0	0.0	
	labor total	unskilled labor	216.0				
2	Stone Masonry Weir	V=	90.2	m^3			
	rubble stone		97.4	m^3	0.0	0.0	
	sand		39.7	m^3		0.0	
	cement	ordinary portland	446.5	bag	75.0	33,486.8	
	Plywood	1200x2400x12	2.0	pc			
	Timber	50x50x5,500	1.0	pc			
	material total					33,486.8	
	excavation	unskilled labor	302.6	man	0.0	0.0	
	mortar mixing	unskilled labor	297.7	man	0.0	0.0	
	stone masonry	foreman	27.1	man	0.0	0.0	
		skilled labor	54.1	man	0.0	0.0	
		unskilled labor	324.7	man	0.0	0.0	
	labor total					0.0	
3	Transportation						
		Truck	5.0	day		0.0	
	Total Material Cost					33,486.8	
	rubble stone		97.4	m^3	0.0	0.0	
	sand		39.7	m^3		0.0	
	cement	ordinary portland	446.5	bag	75.0	33,486.8	
	Plywood	1200x2400x12	0.0	pc		0.0	
	Timber	50x50x5,500	0.0	pc		0.0	
	Total Labor Cost					0.0	
	foreman	27.1	27.1	man	0.0	0.0	
	skilled labor	54.1	54.1	man	0.0	0.0	
	unskilled labor	1,141.0	540.7	man	0.0	0.0	
	Total Construction Cost					33,486.8	

Table 8.3 Example of Tools Planning

No.	Item	Specification/Quality	Quantity	Unit			Remarks
1	Mortar mixing 1set				1set		
	Tools (Daily)						
	Shovel		2.00	pcs	2.00	pcs	
	Bucket	20 lit	2.00	pcs	2.00	pcs	
	Wheel barrow		1.00	pc	1.00	pc	
	Mortar box		1.00	pc	0.00	pc	
2	Stonemasonry work	1set			1set		
	Tools (Daily, not include mortar mixing)						
	Bucket	20 lit	2.00	pcs	2.0	pcs	
	Wheel barrow		2.00	pc	2.0	pc	
	Trowel		3.00	pcs	3.0	pcs	
	Builder's level		1.00	pc	1.0	pc	
	Measuring tape	5m	1.00	pc	1.0	pc	
	Peg						
3	Excavation (by hand)	per 10m^3 1set			2.5 set		
	Tools						
	Shovel		2.00	pcs	8.0	pcs	
	Pickaxe		2.00	pcs	5.0	pcs	
	Hoe		3.80	pcs	9.0	pcs	
	String		1.00	roll	1.0	roll	
	Peg						
4	Embankment (by hand)	per 10m^3 1set			2.5 set		
	Tools						
	Shovel		2.00	pcs	8.0	pcs	
	Hoe		3.60	pcs	9.0	pcs	
	Rammer		2.00	pcs	8.0	pcs	
	String		1.00	roll	1.0	roll	
	Wheelbarrow		4.00	pcs	10.0	pcs	
	TOTAL REQUIRED TOOLS						
	Shovel				8.0		
	Pickaxe				5.0		
	Bucket				6.0		+dewatering
	Whellbarrow				10.0		
	String				1.0		
	Trowel				3.0		
	Builders level				1.0		
	Measuring tape	5m			1.0		
	Watering can				3.0		

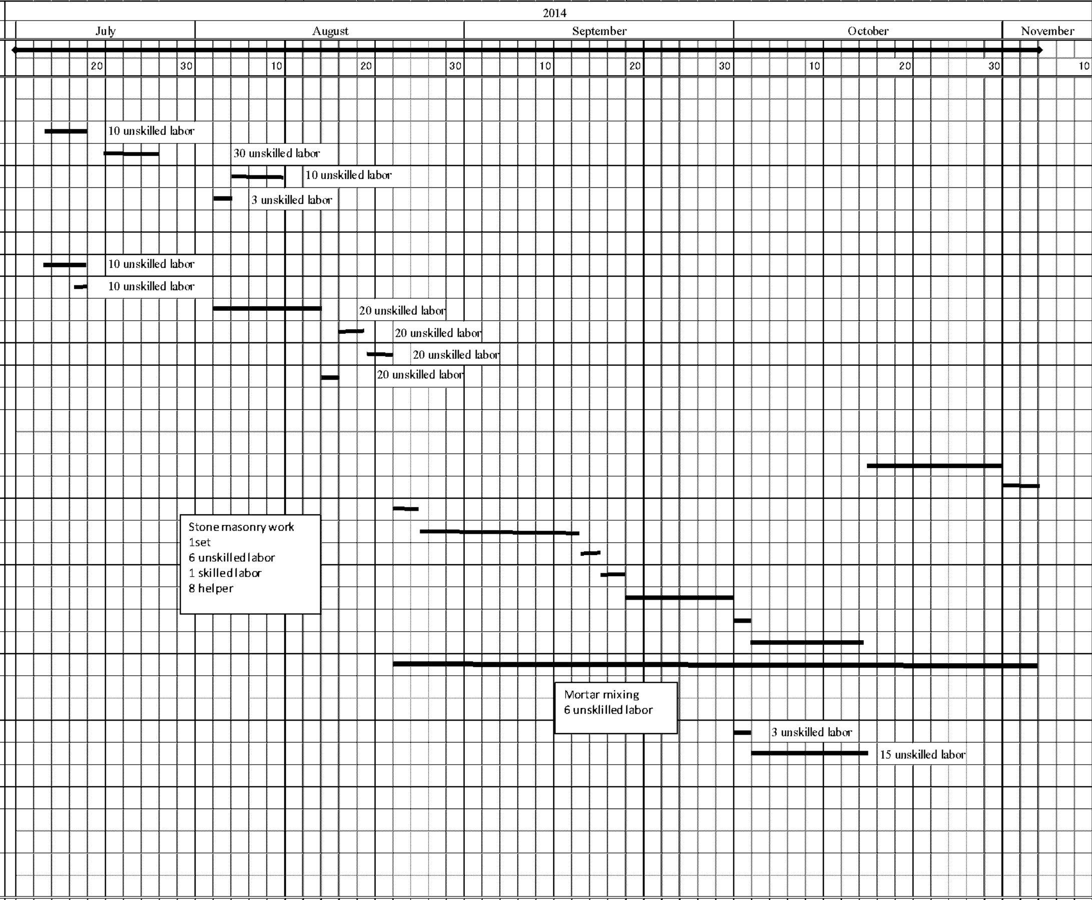
Table 8.4 Example of Manpower Planning

No.	Item	Specification/ Quality	Quantity	Unit			Remarks
	Work Period						
	Site clearing	unskilled labor			50.0	man・day	
	Gathering stones	unskilled labor	97.4	m^3	146.1	man・day	15man/10m^3
	Gathering sand	unskilled labor	39.7	m^3	19.8	man・day	5.0man/10m^3
1	Excavation		Amount	m^3			7.8man/10m^3
1-1	Left side		68.7	m^3	53.6	man・day	
1-2	Rigjht side		67.5	m^3	52.7	man・day	
1-3	River diversion		252.0	m^3	196.6	man・day	
2	Stone masonry		90.2	m^3			
2-1	Left side abutment		18.0	m^3			
		unskilled labor			64.8	man・day	3.6man/m^3
		skilled labor			10.8	man・day	0.6man/m^3
		foreman			5.4	man・day	0.3man/m^3
2-2	Left side slope		5.8	m^3			
		unskilled labor			20.9	man・day	3.6man/m^3
		skilled labor			3.5	man・day	0.6man/m^3
		foreman			1.7	man・day	0.3man/m^3
2-3	Weir		3.7	m^3			
		unskilled labor			13.3	man・day	3.6man/m^3
		skilled labor			2.2	man・day	0.6man/m^3
		foreman			1.1	man・day	0.3man/m^3
2-4	Right side bank		25.7	m^3			
		unskilled labor			92.5	man・day	3.6man/m^3
		skilled labor			15.4	man・day	0.6man/m^3
		foreman			7.7	man・day	0.3man/m^3
2-5	Right side abutment		2.3	m^3			
		unskilled labor			8.3	man・day	3.6man/m^3
		skilled labor			1.4	man・day	0.6man/m^3
		foreman			0.7	man・day	0.3man/m^3
2-6	Right side upstream protectioon		4.0	m^3			
		unskilled labor			14.4	man・day	3.6man/m^3
		skilled labor			2.4	man・day	0.6man/m^3
		foreman			1.2	man・day	0.3man/m^3
2-7	Canal lining		15.3	m^3			
		unskilled labor			55.1	man・day	3.6man/m^3
		skilled labor			9.2	man・day	0.6man/m^3
		foreman			4.6	man・day	0.3man/m^3
2-8	Intake		1.9	m^3			
		unskilled labor			6.8	man・day	3.6man/m^3
		skilled labor			1.1	man・day	0.6man/m^3
		foreman			0.6	man・day	0.3man/m^3
2-9	River diversion		21.0	m^3			
		unskilled labor			75.6	man・day	3.6man/m^3
		skilled labor			12.6	man・day	0.6man/m^3
		foreman			6.3	man・day	0.3man/m^3
3	Embankment		218.1	m^3			
3-1	Right side		8.1	m^3	6.2	man・day	7.6man/10m^3
	River diversion	backfilling	210.0	m^3	159.6	man・day	7.6man/10m^3
	Total						
	excavation	unskilled labor	388.0	m^3	302.6	man・day	7.8man/10m^3
	Stone masonry	unskilled labor	90.2	m^3	324.7	man・day	3.6man/m^3
		skilled labor	90.2	m^3	54.1	man・day	0.6man/m^3
		foreman	90.2	m^3	27.1	man・day	0.3man/m^3
	mortar work	unskilled labor	49.6	m^3	297.7	man・day	6man/m^3
	Embankment/backfilling	unskilled labor	218.1	m^3	165.8	man・day	7.6man/10m^3

Figure 8-1 Example of Work Progress Schedule.

PROGRESS SCHEDULE MBL 2-7 Kawama

Item No.	Work Description	Quantity	
1	Preparation Work		
1-1	Site clearing	5.0	day
1-2	Gathering stones	5.6	day
1-3	Gathering sand	5.8	day
1-4	Prteparation of tools	1.0	day
2	Temporary Work		
2-1	Preparation of access road	5.0	day
2-2	Preparation of temporary stock yard	1.0	day
2-3	Excavation of river diversion	11.3	day
2-4	Excavation of left side	3.1	day
2-5	Excavation of right side	3.0	day
2-6	Construction of coffer dam	2.0	day
3	Stone masonry		
3-1	Left side abutment	12.4	day
3-2	Left side slope	4.0	day
3-3	Weir	2.6	day
3-4	Right side bank	17.7	day
3-5	Right side abutment	1.6	day
3-6	Right side upstream protection	2.8	day
3-7	Canal lining	10.6	day
3-8	Intake	1.3	day
3-9	River diversion filling stone masonry	14.5	day
3-10	Mortan mixing	57.1	day
4	Embankment/back filling		
4-1	Right side	2.4	day
4-2	River diversion	12.2	day
5	Weekly Meeting	124.8	day
	supervision by CEO, TSB		
	Supervision by JICA Expert		



Foreman																																																									
Skilled Labor																						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	36
Unskilled Labor		20	20	30		30	30	30				23	30	30	30	20	20	20	20	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	24	36	36	36	36	36	36	36	21	21	21	21	21	21	21	21	21	1257
Total	0	20	20	30	0	30	30	30	0	0	0	23	30	30	30	20	20	20	20	20	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	25	37	37	37	37	37	37	37	22	22	22	22	22	22	22	22	22	1293

9. Comparison of proposed upgrade sites

In accordance with the result of the site investigations, outline design of each site is prepared and bill of quantities, construction cost, and work period are estimated. Then, based on such technical and economic point of view, coupled with the consideration in environmental and social impact, farming system, and institutional arrangement, proposed upgrade site is selected.

Table 9-1 Comparison of Candidate Sites

District	Mporokoso		
Site	MPR 14-1 Mpela	MPR 4-1 Kasanda	MPR 6-1 Kapumo
Outline	22 households irrigate 8 ha.	16 households irrigate 3 ha.	25 households irrigate 1.5 ha. FTC also uses the furrow
Technical View	Permanent weir is adoptable L=40m, H=2.1m, both side combind type weir. Width of spillway = 4m, Stonemasonry: 185m3, Embankment: 95m3	Permanent weir is adoptable L=35m, H=2.8m, both side combind type weir. Width of spillway = 8m, Stonemasonry: 255m3, Embankment: 130m3 River flow: 130 lit/s (June,2014)	Permanent weir is adoptable. L=40m, H=2.8m, left side combind type weir. Width of spillway = 10m, Stonemasonry: 125m3, Embankment: 105m3 River flow: 200 lit/s (June, 2014)
	○	○	○
Farming O&M	Vegetable, beans: 4.0 ha Cabbage, Tomato, Onion: 4.0 ha Maintenance of furrow is carried out every three months. The furrow is well maintained.	Maize: 1.5ha, Tomato: 0.75ha, Vegetable: 0.5ha, Sugar cane: 0.25ha, Fish Pond: 14 Maintenance of furrow is carried out by themembers twice a year.	Vegetable: 2.0lima, Maize: 2.0lima, Tomato: 1.5 lima, Sugar cane: 0.5 lima Maintenance of furrow is carried out by themembers once a year.
	◎	○	○
Social and Environmental View	No significant environmental impacts. Need to cut trees around the site. Young people are actively working for irrigation group	No significant environmental impacts. No need to cut trees around the site.	No significant environmental impacts. Need to cut trees around the site.
	◎	○	○
Socio-economic View	Cost: 70,000ZMK, 22 HH, Potential are 25 ha.	Cost: 95,000ZMK, 16 HH, Potential area 16 ha.	Cost: 50,000ZMK, 25 HH, Potential area 20 ha.
	○	○	○
Oveall	Current irrigated area is enough large. Young people are working actively and sustainability and expansion of area is expected	Most costly and less beneficiaries.	Most economical but current irrigated area is small.
Priolity	1	3	2

10. Construction

(1) Surface Preparation

Ground surfaces in areas to be excavated or where facilities are to be located should be cleared of all trees, bush, debris and surface vegetation. Stumps and roots larger than 50 mm in diameter should completely uproot and removed. Matted roots, surface vegetation should be removed regardless of size; they should completely remove with roots to a depth of not less than 10 cm below ground surface. All trees or groups of trees designated should be protected from damage from any construction operations.

(2) Temporary Works

- Access road

Access roads should be constructed as required before or during the progress of work and maintained thereafter. Access roads are used to carry sand, stones, cement, tools etc. to the site.

- Temporary storage yard

Temporary storage yard should be prepared to store sand and stones. This yard should have enough space and suitably allocated so as not to interfere with cultivation. This yard should be located beside the site.

- Temporary cofferdam

The objective of a temporary cofferdam is to divert the course of the river artificially during the construction period. In principle, the scale of the temporary cofferdam must be sufficient to prevent overflow by floods and the infiltration of river water during normal flow thereby ensuring the safe performance of work.
Since temporary cofferdam is often used as an access to the other side of river, it should be enough strong for load of wheelbarrow.
If excavation of river diversion is difficult because of rock, multiple-stage diversion can be adopted.

- Dewatering

Before commencement of the permanent works, the temporary cofferdam must first be dewatered. Since dewatering greatly affects the quality of work and the construction schedule, careful arrangement is required. The dewatering volume is hard to estimate because it depends on soil, the structure of the temporary cofferdam, the difference between outside and inside water levels and the area inside the temporary cofferdam. Basically, dewatering is done by manpower, however, if large amount of dewatering, a pump should be prepared.

(3) Excavation

Excavation should be planned and carried out to minimize adverse effects on the existing facilities and structures, as well as the vehicular and pedestrian traffic of and around the construction site.

Over excavation, below the depths indicated, should, unless otherwise be specified, refilled and compacted. If soft or unsuitable soil is found at the excavated depth, additional excavation should be carried out to depth and filled and compacted. Soil disturbed or weakened and soils deteriorated by exposure to weather should be excavated and excavated areas refilled and compacted.

Generally, all excavations should be kept free from water during construction. If soft or unsuitable soil is encountered after excavation to the designated bottom of the trench or structure, the ground should be excavated to a firm foundation level and filled over the excavated area with backfilling material.

(3) Replacement and Embankment

Material for the replacement and embankment should be placed in horizontal layers of uniform thickness over a width determined and in conformity with the lines, grades, sections, and dimensions. The layer of loose material other than rock should be not more than 30 cm thick. After adjustment of the moisture content, the loose material should be compacted.

(4) Stone Masonry

1) Material

i) Stone

Stone for Stone Masonry should consist of field stone or rough un-hewn quarry stone as nearly rectangular in section as is practical, including such stone or material observed being in use on the existing work. The stone should be sound, tough, durable, dense, resistant to the action of air and water, and suitable in all respects for the purpose intended. The size of the stone should be 10 cm minimum and 30 cm maximum.

ii) Sand

Sand for mortar should be river sand, free from silt, salt and other organic foreign matter.

iii) Water

Water for mortar should be clean and free from harmful matter, such as oil, salts, organic matter, or any material which may have a harmful effect on the mortar. Potable water (except for bacteriological limits and conditions) is suitable for the mixing of mortar under all conditions.

iv) Mortar mix

Standard mixing proportion of cement and mortar is as follows,

Ordinary Portland Cement   cement 1 : sand 3in dry weight.

Mortar should be mixed uniformly with water to the proper consistency for spreading by trowel. Mortar which has been mixed with water for more than 45 minutes should not be used.

2) Construction

Excavation should be made to the required shape and depth, and should be compacted to a firm, even surface. All surpluses, soft and unsuitable material should be removed and replaced with suitable material which should be thoroughly compacted.

Stone should be washed with water before placing. Mortar should be pushed into the interstices of the stone within a short time after placing. The spaces between the stones are then filled with mortar. Sufficient mortar should be used to completely fill all voids, except that the face surface of the stone is left for exposition. The surface of stone masonry should be finished neatly and smoothly. After completion of Stone Masonry, it should be cured with water for more than 10 hours.

(5) Safety and Environment

1) Safety

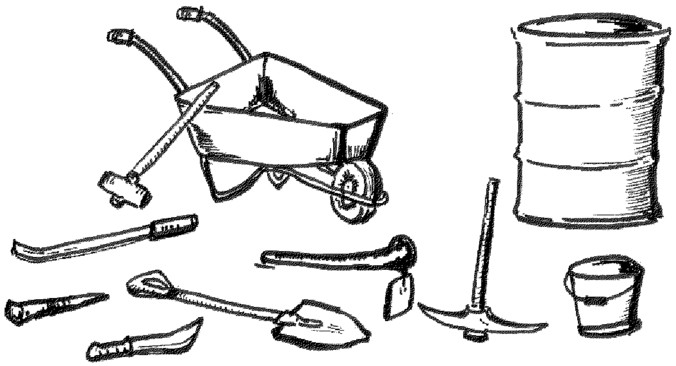
Reasonable precaution to protect persons or property from injury should be exercised and maximum care should also be put in place for people around them.

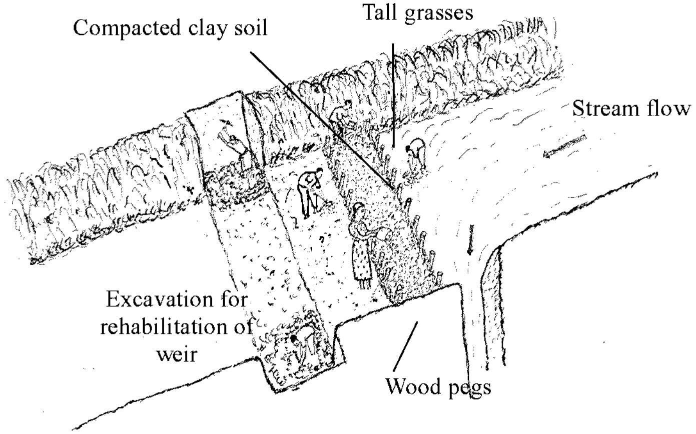
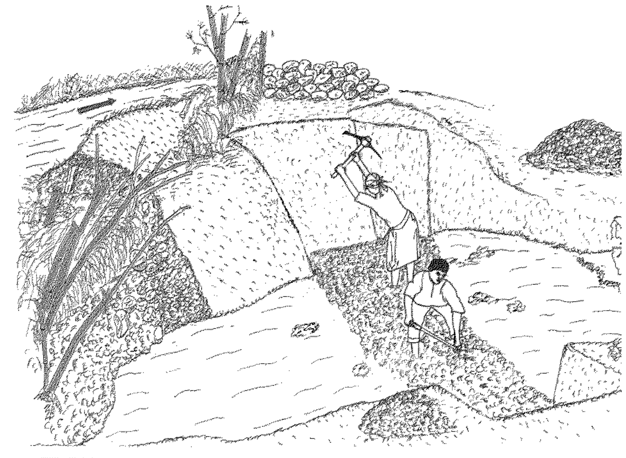
2) Environment

All necessary precautions should be taken to secure the efficient protection of all waterways against pollution, including spillage of oil which may be likely to cause injury to fish or plant life. Waste water from washing tools for mortar work such as mortar box, shovels, buckets and trowels should not be poured into a river directly.

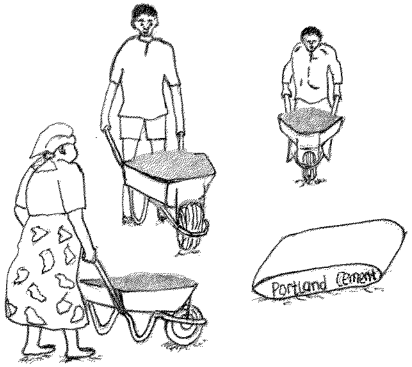
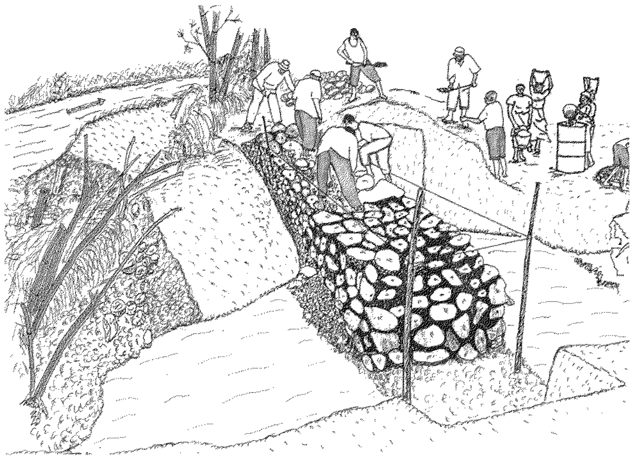
10. Construction

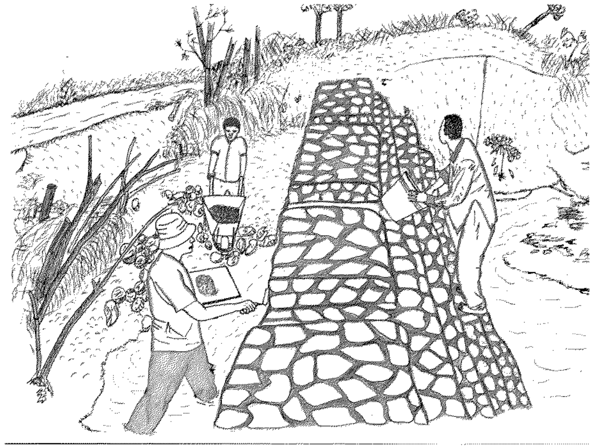
(1) Stone Masonry Weir

Step	Process	Description	Remarks
1		**<u>Tools Required:</u>** For the construction of permanent weir, the major tools required are: - Wheelbarrows - Hoes - Panga knives - Pickaxes - Chisels - Hammers - Buckets - Drum - Slashers - Shovels - Trowel	
2		**<u>Tools Required;</u>** For the construction of permanent weir, the major material required are: - Cement - Rubble stones - River sand	

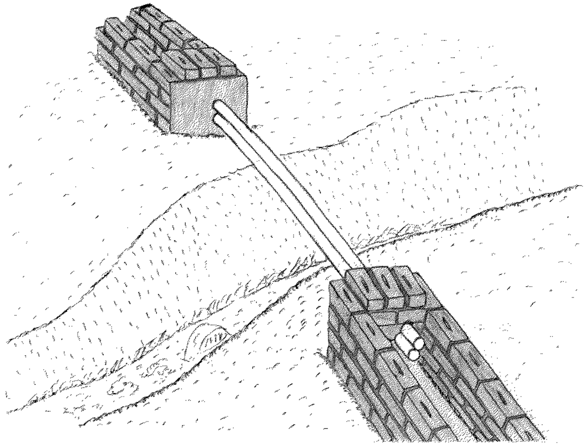
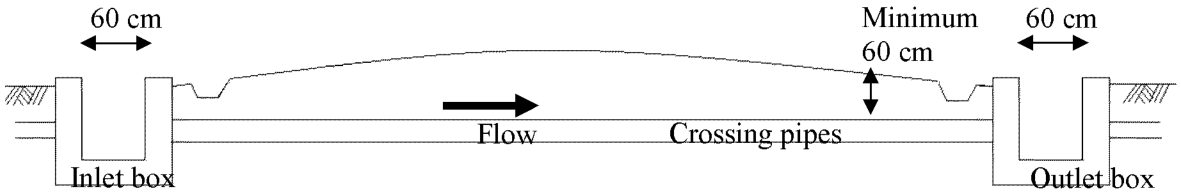
	Process	Description	Remark
3		<u>Cofferdam Construction</u> (a) Cofferdam with soils - Position wooden poles at the diversion point - Weave grass fence to tap the stream flow - Put clay soil on the grass fence - Compact the soil using logs (b) Cofferdam with sand bags - To fill sand bags with soils - To place sand bags tight each other at diversion point.	- Cofferdam is constructed to close the river (upstream of the construction site) so that the weir point is dry throughout the construction. - Rammers may be used for the compaction when available.
4		<u>Excavation for Weir</u> 1. The foundation is excavated to bedrock at least 50 cm depth from riverbed. 2. Abutment is excavated 1m horizontal direction into river bank. 3. The line of upstream end, downstream end and abutment shall be indicated with pegs and strings.	- If soft or unsuitable soil is found at the excavated depth, additional excavation shall be carried out. Precaution(>1.5m excavation) - Maximum safety against land sliding shall be ensured when excavating an abutment. - Elevation of cutting shall be checked.

5		**De-watering** 1. During the construction of the base, ensure that foundations are dry by dewatering using buckets.	- If there is a lot of ground water, dewatering shall be carried out continuously with buckets. Drain ditch and drain pit are required to be arranged. - Drainage pumps or treadle pumps may be used when buckets are not sufficient. -
6		**Mortar Mixing Place Preparation** 1. Excavate a curved surface on a flat place (1.7m diameter). 2. Compact the surface with rammers or stones. 3. Lay bricks around the curved surface. 4. Place mortar in spaces between the bricks.	- The mixing place shall be as close to the construction place. - Compaction seals off all voids. - The Place can also be used for future rehabilitation.
		Water for Mortar 1. Prepare drum(s) of water for mortar at the site on the day of construction. 2. Water shall be clean water.	- Number of drums depends on the number of mortar mixing place.

7		<u>Stages of Mortar Mixing</u> 1. Standard mixing proportion of cement: sand is; ***1:3 in weight (dry)*** 2. Measure one 50kg bag of Cement and six buckets (20liter) of sand. If the sand is dry, 20 liter of water is poured and mixed first. Then additional water is sprayed and mixed to the proper consistency. 3. 1 bag of cement will be used with sand at the standard mortar mixing place at the same time.	
8		<u>Weir Construction</u> 1. Make sure that the closed river is dry, if not keep on dewatering. 2. Wash stones before used for construction. 3. Line the stones with the flat surface facing outside the structure (use a builders' level when constructing). 4. Mortar is pushed into the interstices and spaces between the stones. 5. Stones are placed layer by layer.	- Washing removes all debris thereby increasing the bond strength. - Voids shall be filled with mortar completely so that leakage may not happen and strength is secured. - Crest elevation and dimension shall be checked.

9		**<u>Finishing and Curing</u>** 1. The surface of stone masonry needs to be finished neatly and smoothly. 2. After completion of stone masonry, it needs to be covered with grasses or straw mats for curing mortar. 3. Water shall be sprayed from time to time.	

(2) Gully Crossing and Road Crossing

<table>
<tr><th></th><th>Process</th><th>Description</th><th>Remark</th></tr>
<tr><td>1</td><td></td><td><u>Gully Crossing</u>
1. A gully crossing is constructed to convey water across a gully.
2. The length of pipe is normally less than 6m.
3. The pipe is required to be installed at the height of 10cm from canal bed.</td><td>- Considering the strength of pipe and necessity of support, the length is less than 6m.
- Since the length of pipe is limited, the location of gully crossing is decided considering the length.</td></tr>
<tr><td>2</td><td colspan="2"><u>Road Crossing</u>


1. Pipes are installed under ground and soil covering depth shall be more than 60cm.
2. The pipes are installed at the height of 10cm from canal bed.</td><td>- Road crossing is constructed to convey water across the road.</td></tr>
</table>

11. O&M of Irrigation Facilities

11.1 Maintenance of Irrigation Facilities

(1) River Diversion Weir

As per fixed type weir of stone masonry or gabion, no routine maintenance work is usually required. Inspection around the weir should be carried out periodically and after every flood and every year before starting dry season irrigation. Following items should be inspected,

- Damaged part of stone masonry.
- Damaged part of slope protection.
- Scouring at downstream of the weir.
- Sediment at upstream.
- Scouring at both side abutments.

Damaged part of stone masonry should be repaired with mortar and damaged part of gabion should also be considered for rehabilitation. Scoured part at downstream of the weir should be protected by gabion or stone pitching. Scoured side abutment should be replaced with stone masonry or gabion, or reinforced with gabion or sand bags. In the case that sediment accumulated to inflow to canal, it should be removed. Maintenance check list is shown in the **Table 11-1.**

(2) Canals

1) Main and Secondary Canals

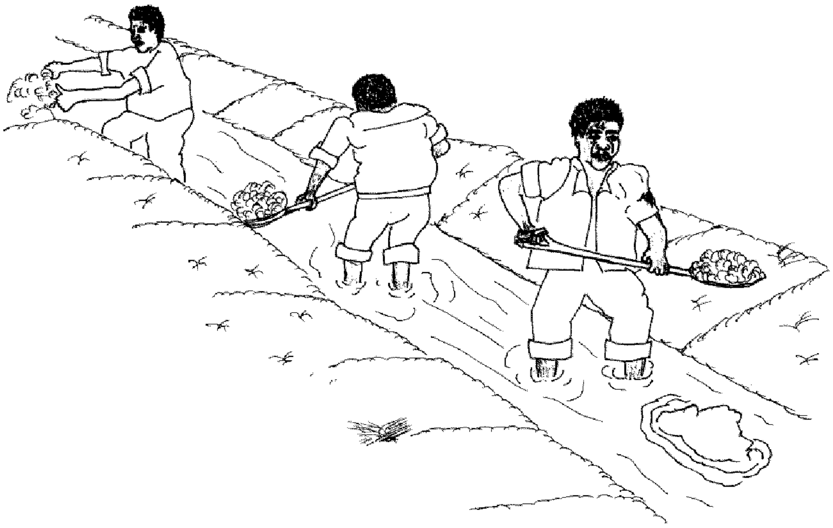
Stream water usually contains certain amount of suspended particulars, causing sedimentation in the canal. Eroded soil loss from field also gets into canal, resulting in the sedimentation in the canal. Maintenance work for canal should be done at least once before the irrigation season starts. Maintenance works required for the canal are; cleaning, weeding, de-silting, re-shaping, and also minor repairs as described below;

1) Earth canal

- Bushes and trees on the canal embankments should be removed. They may obstruct the water flow and their roots open the banks and develop leakages.
- Grasses, sediments and debris in the canal should be removed. While cleaning the canal, care must be so taken that the original shape of the cross-sections is kept. For this, a wooden frame with exact dimensions of the designed cross-section can be of great help.
- Crossing sections by people and animals (livestock) along the canal should be strengthened by hard compaction or lined with stones, bricks or masonry.
- Holes/cracks in the canal should be filled with sticky clay soil, and eroded sections should be rebuilt to the original shape.

2) Brick lined canal

- Grasses, sediments and debris in the canal should be removed.
- Cracks and water leaking point should be repaired with mortar.



2) Division Box, Discharge Box and Turnout

Division box, discharge box and turnout are made of brick masonry and the same maintenance work as brick masonry canal is required. In addition, maintenance on stop-log grooves is required. Damaged stop-log grooves should be repaired and reshaped with mortar to meet to stop-log. In case the connection part to earth canal is scoured, the part should be reinforced with gravel laying. Maintenance check list is shown in the **Table 11-1.**

(3) Maintenance Cost

Maintenance cost for each item is estimated as shown in **Table 11-2**.

Table 11-1 Maintenance Check Lists

Maintenance Check List for River Diversion Weir

Item	Frequency	Point to be checked	Findings
1. River	Daily	Water level	Elevation, Enough or not.
conditions	Daily	Water flow conditions	Stable or not. Flood, Rich or Drought.
	Daily	Sediment	If it is a lot to affect intake, it shall be removed.
		Others	Water quality, flotage etc.
2. Weir	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	At after	Erosion at abutment	Need repair or protection or not
	Annually	Water leakage	Small scale or large scale. Need repair or not
	Annually	Riverbed scouring at downstream	Need protection or not
	Daily	Sediment	If it is a lot to affect intake, it shall be removed.
	Annually	Damage of gabion	Small scale or large scale. Need repair or not
	Annually	Subsidence and deformation of gabion	Stable or not. Need repair or not.
		Others	
3. Intake	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	Daily	Sediment	If it is a lot to affect intake pipes, it shall be removed.
	Daily	Trash	If it is a lot to block intake pipes, it shall be removed
	Daily	Water level	Enough or not
	Monthly	Damage of pipes	Need repair or not.
	Daily	Function	Functioning or not.
		Others	
4. Others	Monthly	Conditions of stop log	Need repair or not.
	Monthly	Conditions of gate	Need painting, reapir or not.
		Protection bund	Collapse or erosion. Need repair or not.

Maintenance Check List for Canal System

Item	Frequency	Point to be checked	Findings
1. Brick or	Daily	Water flow conditions	Smooth or not
concrete	Monthly	Crack or damage	Small scale or large scale. Need repair or not
lined canal	Annually	Conditions of drain ditch (along the main canal)	Functioning or not. Need excavation or not.
	Monthly	Sediment	Small scale or large scale. Need removal or not
	Monthly	Weeds	A lot or a few. Need clearing or not.
		Others	
2. Earth canal	Daily	Water flow condition	Smooth or not
	Monthly	Cross section area	Enough cross section or not
	Monthly	Erosion	Need repair or not
	Monthly	Weeds	Need clearing or not
		Others	
3. Road	Daily	Water flow conditions	Smooth or not
crossing and	Monthly	Sediment	Small scale or large scale. Need removal or not
gully crossing	Monthly	Crack or damage	Small scale or large scale. Need repair or not
	Daily	Trash	If it is a lot to block pipe, it shall be removed
		Others	
4. Structures	Daily	Water flow conditions	Smooth or not
(division box,	Monthly	Sediment	Small scale or large scale. Need removal or not
drop box	Monthly	Crack or damage	Small scale or large scale. Need repair or not
turnout)	Monthly	Conditions of stop log	Need repair or not
		Others	
5. Others			

Source: T-COBSI Project Team

Table 11-2 Maintenance Cost for Each System

		Maintenance Cost Estimation						
	No.	Item	Specification/Quality	Quantity	Unit	Unit Price	Price	Remarks
						ZMK	ZMK	
	1	**River Diversion Weir**						
	1-1	Annual maintenance						
	(1)	Removal of sediment	unskilled labor	10.0	man		0.0	2man x 5 days
		Total		10.0	man		0.0	
	1-2	Every 5 years						
	(1)	Repair of stone masonry	weir, intake	1.00	m^3			
		rubble stone		0.54	m^3		0.0	
		sand		0.40	m^3		0.0	
		cement	ordinary portland	4.50	bags		0.0	
		material total					0.0	
		mortar mixing	unskilled labor	6.0	man		0.0	1day
		stone masonry	foreman	1.0	man		0.0	1day
			skilled labor	1.0	man		0.0	1day
			unskilled labor	5.0	man		0.0	1day
		labor total					0.0	
	2	**Open Canal System**						
	2-1	Annual maintenance						
	(1)	Cleaning canal	300m					
		unskilled labor		20.0	man		0.0	
	(2)	Repair of earth canal						
		Re-shaping	unskilled labor				0.0	each plot owner
	2-2	Every 3 years						
	(1)	Repair of brick lining						
		equivalent to 10m construction		10.0	m			
		Bricks		608.5	pcs		0.0	730.2x10/12
		Sand		0.2	m^3		0.0	0.34x10/12x0.5
		Cement	ordinary portland	2.6	bag		0.0	0.34x10/12x9
		material total					0.0	
		mortar mixing	unskilled labor	4.0	man		0.0	

		brick laying	skilled labor	1.0	man		0.0	
			unskilled labor	7.5	man		0.0	
		labor total					0.0	
	(2)	Repair of structures						
		equivalent to 1 box construction		1.0	box			
		bricks		223.0	pcs		0.0	223.0x1
		sand		0.1	m^3		0.0	0.15x0.8x1
		cement		1.4	bag		0.0	0.15x1x9
		material total					0.0	
		mortar mixing	unskilled labor	4.0	man		0.0	
		brick laying	foreman	0.3	man		0.0	0.33x1
			skilled labor	0.3	man		0.0	0.33x1
			unskilled labor	0.7	man		0.0	0.67x1
		labor total					0.0	
		Every 3 years Total	material				0.0	
			labor				0.0	

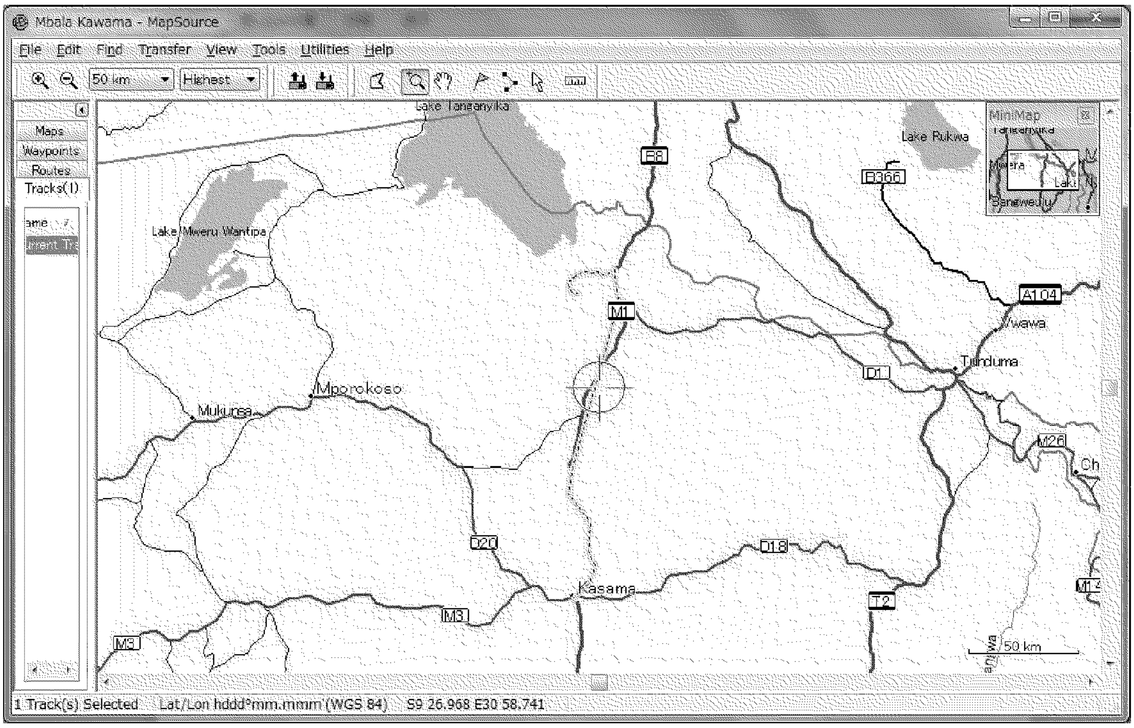
Source: T-COBSI Project Team

Annex-1 GPS (Garmin) and Google Earth

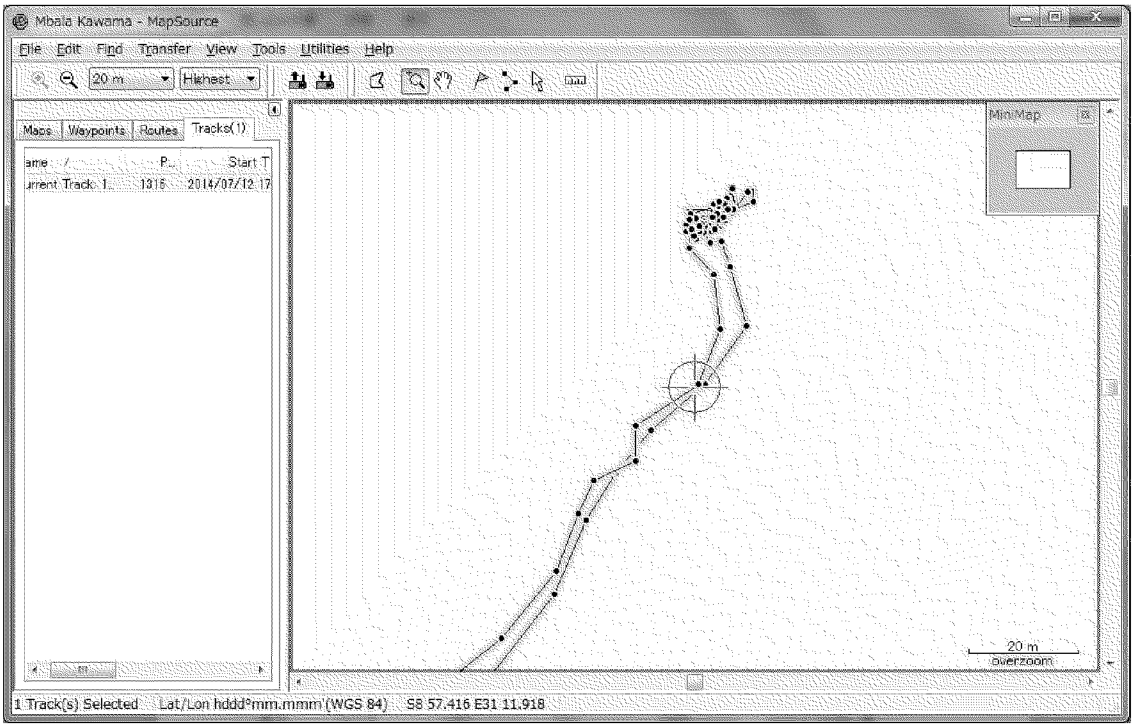
1. GPS

① Installation of Mapsource
② Start up Mapsource
③ Transfer data to the computer

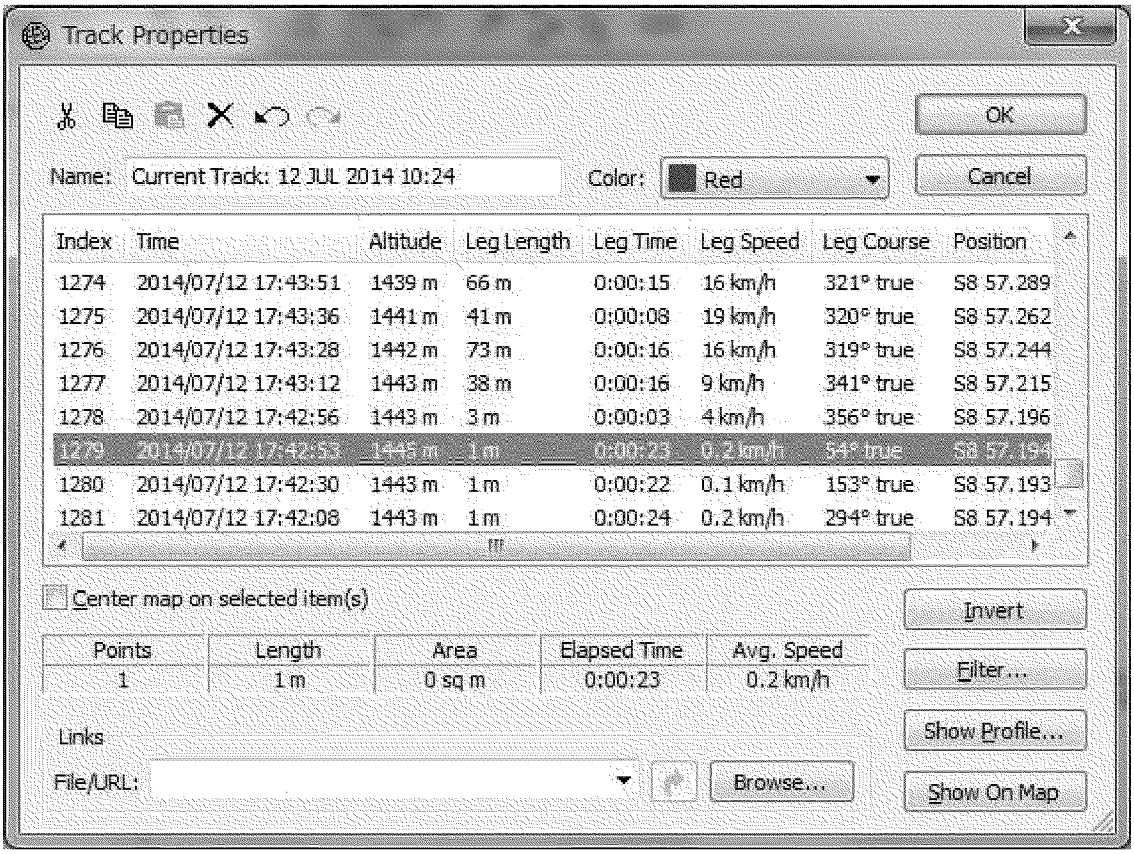
Large area map



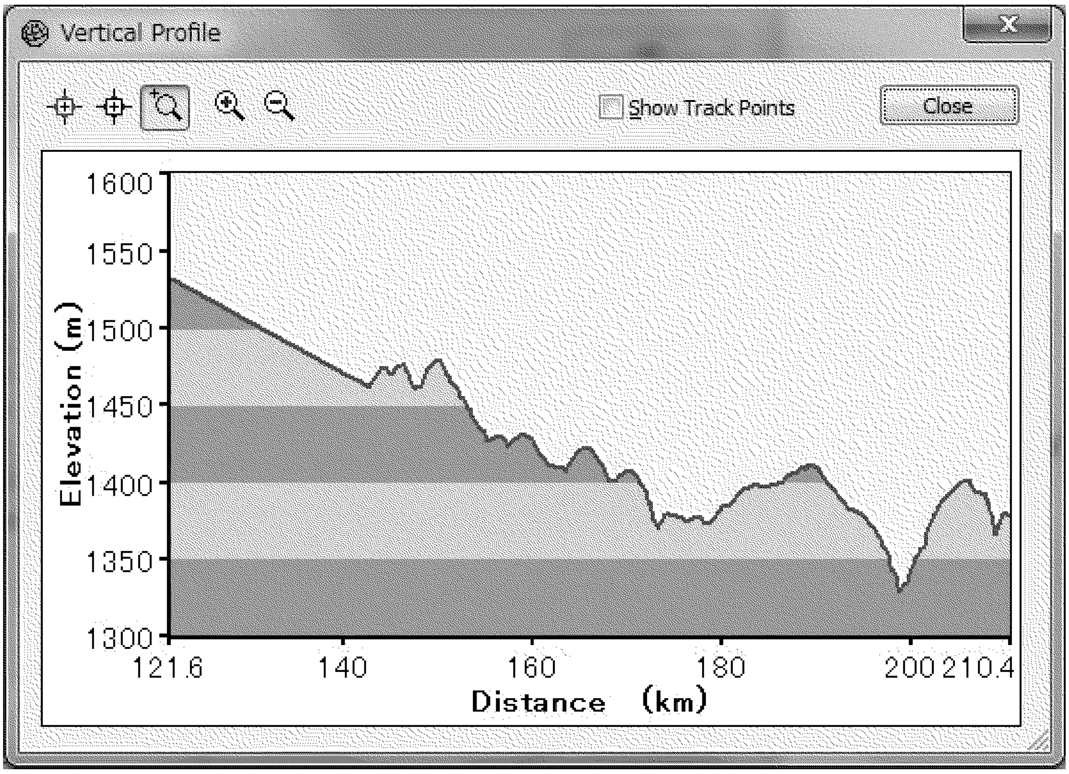
Small area map



Data log



Profile

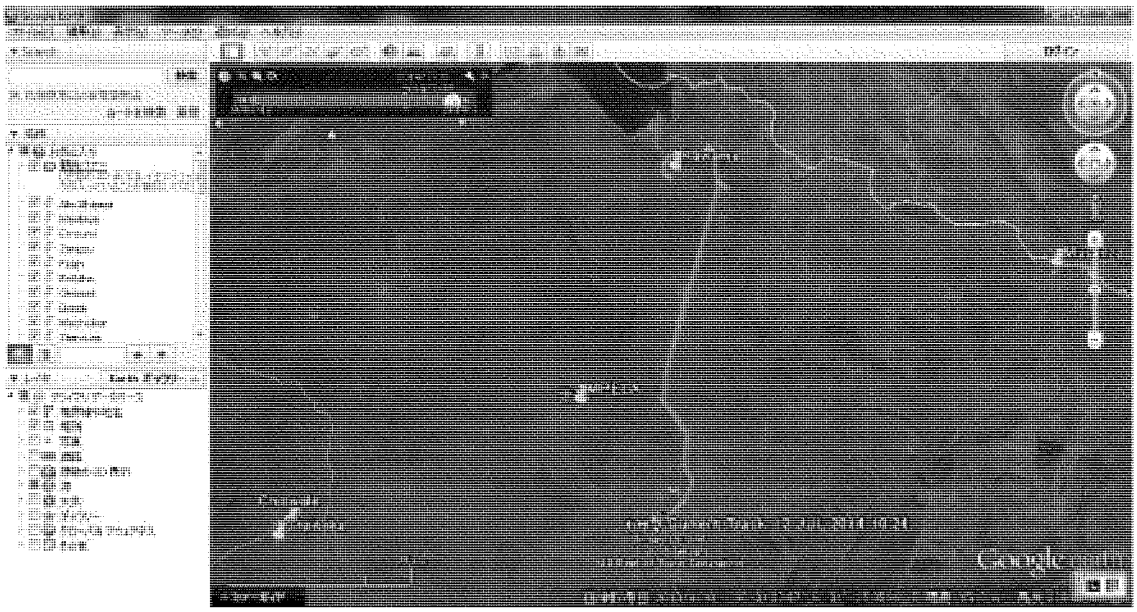


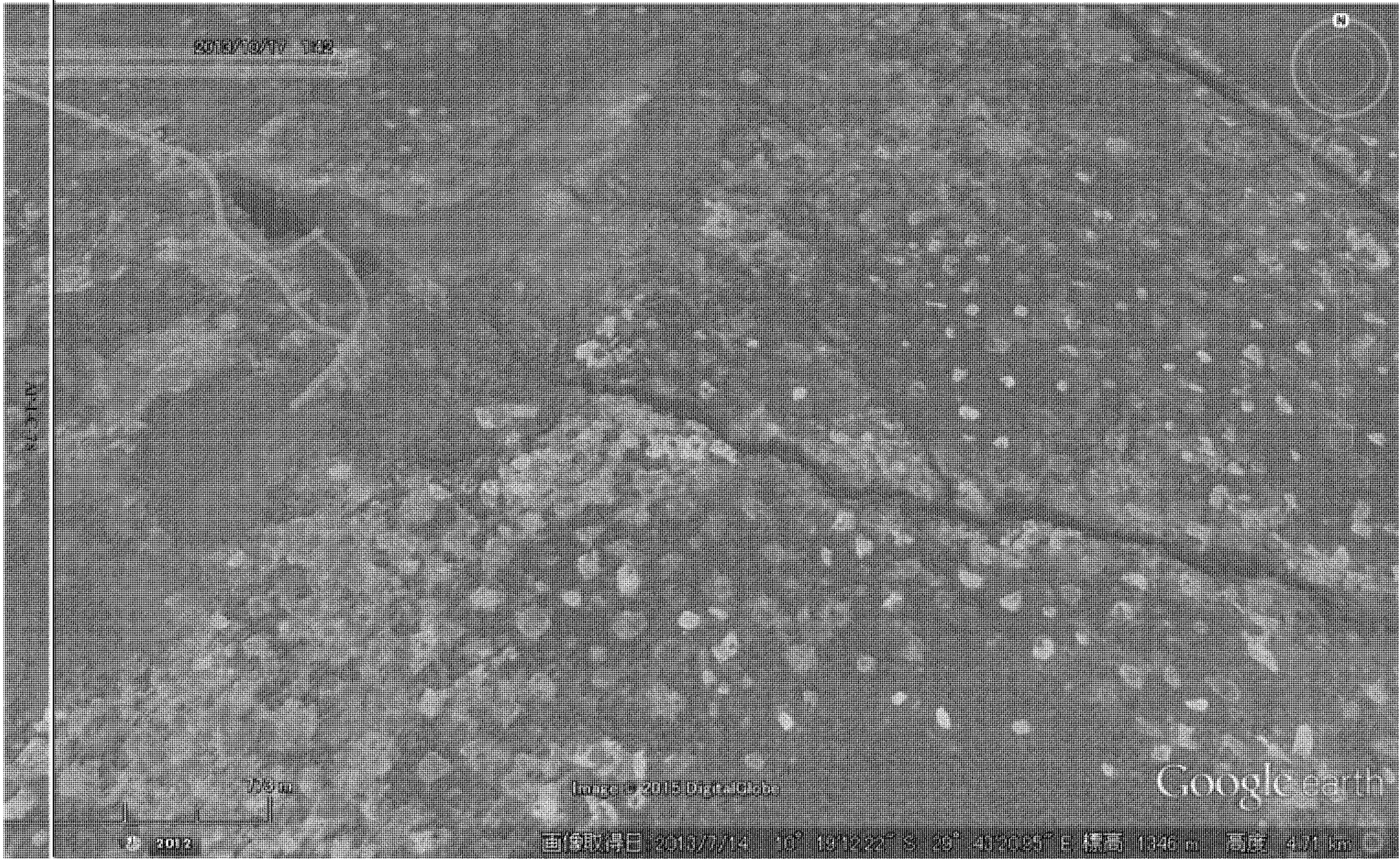
2. Google Erath

Transfer data to Google Earth

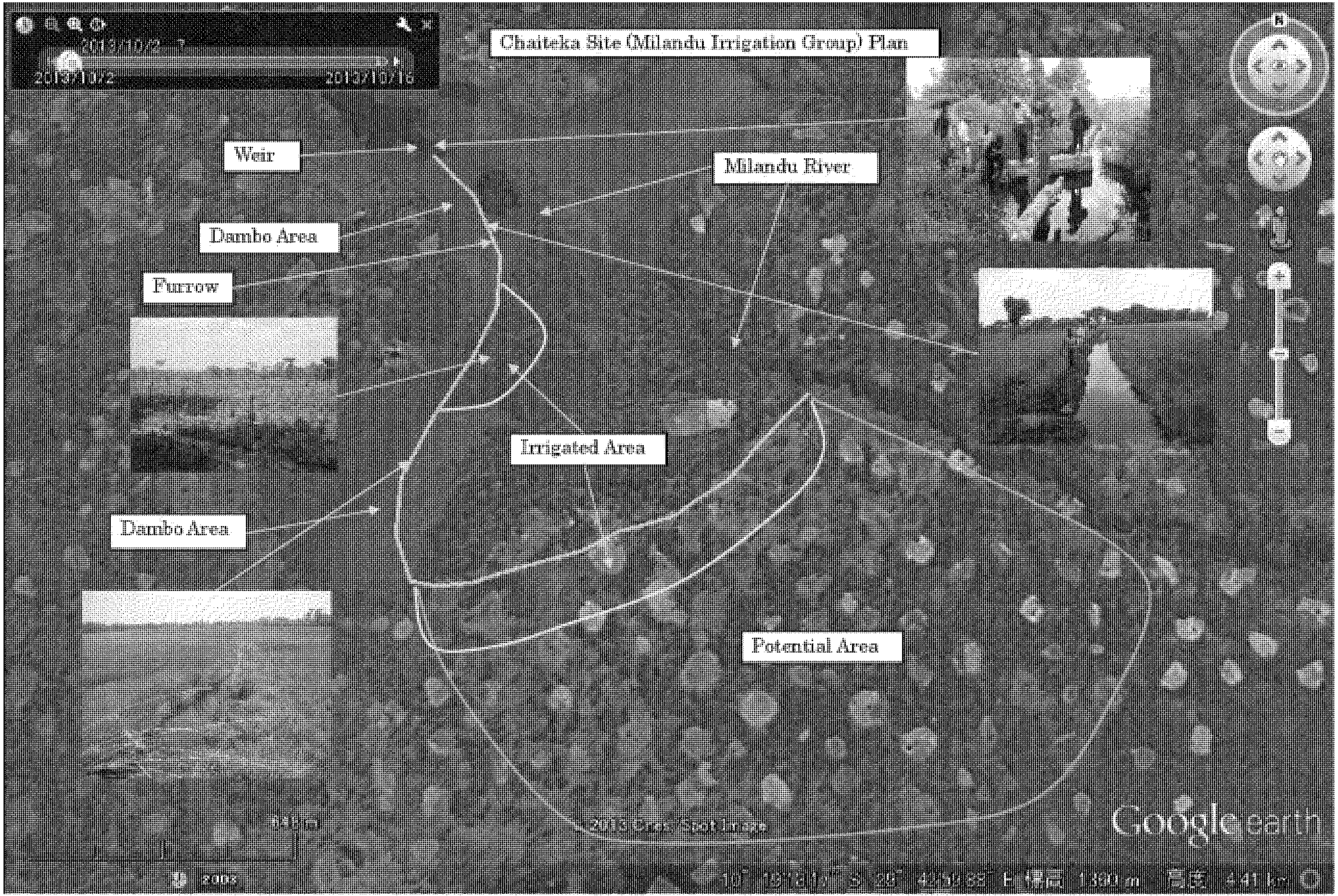
Tool → GPS → check Garmin, import from file → import

Save image




Google earth


Google earth


Chaiteka Site (Milandu Irrigation Group) Plan
Weir
Milandu River
Dambo Area
Furrow
Irrigated Area
Dambo Area
Potential Area
Google earth

Annex-2 CROPWAT

1. Irrigation Water Requirement

(1) Crop Water Requirement

In the process for estimating the irrigation water requirements, the reference crop evapo- transpiration (ETo) for upland crops could be estimated using the "CROPWAT for Windows Computer Software" [1], being popular in the agricultural development plan in Africa, which is based on the FAO Penman-Monteich Equation. On the other hand, the ETo for paddy rice could be estimated using the modified Penmam Methods. The Penman-Monteith equation is given by the following equation:

$$ETo = \frac{0.408\,D(Rn - G) + \gamma \frac{900}{T+273} U2(es - ea)}{D + \gamma(1 + 0.34u2)}$$

Where;

ETo	=	Reference evapo-transpitation (mm/day)
Rn	=	Net radiation at the crop surface (MJ/m^2per day)
G	=	Soil heat flux density (MJ/m^2per day)
T	=	Mean daily air temperature at 2 m height (℃)
U2	=	Wind speed at 2 m height (m/sec)
Es	=	Saturation vapour pressure (kpa)
Ea	=	Actual vapour pressure (kpa)
Es – ea	=	Saturation vapour pressure deficit (pka)
△	=	Slope of saturation vapor pressure curve at temperature T (kpa/℃)
γ	=	Psychometric constant (kpa/℃)

Crop water requirements (ETc/CWR) were estimated by multiplying ETo mentioned in the above by a crop coefficient (Kc), that is:

ETc = ETo x Kc

Where;

ETc/CWR	=	Crop water requirements (mm/day)
ETo	=	Reference crop evapo-transpiration (mm/day)
Kc	=	Crop coefficient

(2) Cropping Patterns

Cropping patterns are planned to calculate crop water requirements and irrigation water requirements, considering topography, water availability, soil conditions, current farming practices, marketing conditions, etc. around each areas

Sample Cropping Pattern

Crops	area (ha)	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Green Maize	10.00	50												
Tomato	4.00	20												
Egg plant	1.00	5												
Rape	3.00	15												
Cabbage	1.00	5												
Okura	1.00	5												
Total	20.00	100			5	5	5	90	100	100	85	75	5	

(3) Estimation of Irrigation Water Requirements

In estimating irrigation water requirements applying the "CROPWAT" equation mentioned above, following procedures and assumptions are taken into considerations;

- Meteorological data

  The data collected over long period (10 years or more in principle, and 20 years or more with regard to data on temperature, consecutive no-rainy days and pan evaporation, which are closely related with the irrigation plan) at the representative meteorological stations in the area shall be investigated. When the necessary data are not available in the project area, those derived from similar meteorological conditions can be used. Meteorological data of FAO-CLIMWAT can be used for CROPWAT.

- Crop coefficient

  Crop coefficients for maize and upland crop are referred to the authorized values in the computer program, while those for paddy rice are quoted from FAO Technical paper NO. 24

- Effective rainfall

  A number of empirically determined formulae can be used. They have been developed under a given set of conditions which may be very different from those under which they are to be applied. Their use elsewhere therefore remains doubtful.

  According to FAO-CROPWAT, "In general, the efficiency of rainfall will decrease with increasing rainfall. For most rainfall values below 100 mm/month, the efficiency will be approximately 80%. Unless more detailed information for local conditions, it is suggested to select the Option "Fixed percentage" and give 80% as requested value".

  In Northern, Luapula and Muchinga district, monthly precipitation in the dry season is less than 100 mm. Therefore, in this study, 80% is given as rainfall efficiency.

2. Irrigation Water Requirement

(1) Irrigation efficiency

Irrigation efficiency is calculated by following formula:

$Ep = Ea \times Eb \times Ec$

Irrigation efficiency Ep

Conveyance efficiency Ec: ratio of quantity of water at inlet of a block of field / intake water at source

Field canal efficiency Eb: ratio of quantity of water at field inlet / a block of field

Application efficiency Ea: ratio of quantity of water directory available to the crop / field inlet

Distribution efficiency $Ed = Ec \times Eb$

Field efficiency Ef = Eb x Ea

Table 1 shows values determined by international institutes.
According to the table below, following coefficients are adopted in this study.
Ed = 0.3, Ea = 0.6
Ep = 0.3 x 0.6 = 0.18

Table 1 Ec, Eb, Ed, and Ea

Conveyance Efficiency (Ec)			ICID/ILRI
Continuous supply with no substantial change in flow			0.9
Rotational supply in projects of 3,000 – 7,000 ha and rotation areas of 70 – 300 ha, with efficient management			0.8
Rotational supply in large schemes (>10,000ha) and small schemes (<1,000 ha) with respective problematic communication and less effective management:			
Based on predetermined schedule			0.7
Based on advance request			0.65
Field Canal Efficiency (Eb)			
Blocks larger than 20 ha: unlined			0.8
lined or piped			0.9
Blocks up to 20 ha: unlined			0.7
lined or piped			0.8
Distribution efficiency (Ed = Eb x Ec)			
Average for rotational supply with management and			
Communication adequate			0.65
sufficient			0.55
insufficient			0.40
poor			0.30
Field Application Efficiency (Ea)	USDA	USSCS	
Surface methods			
Light soils	0.55		
Medium soils	0.70		
Heavy soils	0.60		
Graded border		0.60-0.75	0.53
Basin and level border		0.60-0.80	0.58
Contour ditch		0.50-0.55	
furrow		0.55-0.70	0.57
corrugation		0.50-0.70	
Subsurface		Up to 0.80	
Sprinkler, hot dry climate		0.60	
Moderate climate		0.70	
Humid and cool		0.80	0.67
Rice			0.32

ICID: International Committee of Irrigation and Drainage
ILRI: International Institute for Land Reclamation and Improvement
USDA: United States Department of Agriculture
USSCS: United States Soil Conservation Service

(2) Irrigation Water Requirement

Irrigation water requirements are classified into net irrigation water requirements and gross irrigation water requirements including water losses. They are the base for designing the capacity of irrigation facilities and are calculated by following expressions.

Net irrigation water requirements (NWR):

Net irrigation water requirements (NWR) will be calculated by deducting the effective rainfall estimated on the 10-day basis by following equation;

$$NWR = ETc - Re$$

Where;

NWR : Net irrigation requirements (mm/day)
ETc : Crop evapo-transpiration (mm/day)
Re : Effective rainfall (mm)

Gross irrigation water requirements (GWR):

Gross irrigation water requirements (GWR) will be calculated by taking into consideration overall irrigation efficiencies (IE). The GWR will be estimated by the following equation.

$$GWR = NIR/IE$$

Where;

GWR : Gross irrigation water requirements (mm/day)
NWR : Net irrigation water requirements (mm/day)
IE : Overall irrigation efficiency

Irrigation Water Requirements for System Capacity

Irrigation water requirements (IWR) to plan the system capacity will be determined by taking into consideration the time of irrigation hours per day and working day per week. The following equation will be used for the determination of the IWR:

$$IWR = GWR \times A \times 10{,}000 / (Hr \times 3{,}600) \times 7/v$$

Where,

IWR : Irrigation water requirements for system capacity (lit./sec)
GWR : Gross irrigation water requirements (mm/day)
A : Irrigation area (ha)
Hr : Water supply hours per day (hrs)
V : Working days per week (days)

3 CROPWAT

Example of calculation of irrigation water requirement by CROPWAT is shown in Table A2-1 - Table A2-8.

(1) Scheme Water Requirements

Table 2 Result of calculation

MBL 2-7 Kawama												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. MAIZE (Green)	0	0	0	0	0	25.5	114.1	244	231.6	44.4	0	0
2. Tomato MBL2-7	0	0	0	0	0	51.1	141	233.4	218.5	11.8	0	0
3. Egg plant	0	0	0	23.4	153.7	91.5	0	0	0	0	0	0
4. Rape	0	0	0	0	0	80.2	184.8	153.7	0	0	0	0
5. CABBAGE MPR	0	0	0	0	0	0	68.4	169.1	217.7	205	5.2	0
6. Okura MBL	0	0	0	0	0	0	91.4	205.2	191.5	0	0	0
Net scheme irr.req.												
in mm/day	0	0	0	0	0.2	1.3	3.9	6.8	6	1.1	0	0
in mm/month	0	0	0	1.2	7.7	39.6	121	210.4	180	34.8	0.3	0
in l/s/h	0	0	0	0	0.03	0.15	0.45	0.79	0.69	0.13	0	0
Irrigated area	0	0	0	5	5	90	95	95	80	75	5	0
(% of total area)												
Irr.req. for actual area	0	0	0	0.09	0.57	0.17	0.48	0.83	0.87	0.17	0.02	0
(l/s/h)												

Example: August

Net scheme irrigation requirement in mm/month;
244 x 0.5 + 233.4 x 0.2 + 153.7 x 0.15 + 169.1 x 0.05 + 205.2 x 0.05 = 210.45 mm/month

Net scheme irrigation requirement in mm/day;
210.45 / 31 = 6.8 mm/day

Net scheme irrigation requirement in lit/s/h;
6.8mm / 1000mm x 10000m2 x 1000lit /86400s = 0.79 lit/s/h

Irrigation Requirement for actual area;
0.79 / 0.95 = 0.83 lit/s/h

Irrigation water requirement at the intake is:
0.83 / 06 / 0.3 = 4.61 lit/s/ha

In case of 8 hours, Monday to Friday (5 days) irrigation:
4.61 x 7 / 5 x 24/8 = 19.36 l/s/ha.

In case of 8 hours, once a week irrigation:
4.61 x 7 x 24/8 = 96.81l/s/ha.

It is not very practical to vary the irrigation depth and frequency too much. With, in particular, surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the schedule all the time.

Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval; in other words, to keep the irrigation depth and the interval constant over the growing season.

According to the calculation by FAO CROPWAT, irrigation requirement is calculated for every ten days and for each crop. Since it is very difficult to arrange irrigation schedule exactly to meet to the result of FAO CROPWAT, it is recommended to simplify the irrigation schedule.

(2) Crop Water Requirements

Table 3 shows the result of calculation of Crop Water Requirement for green maize.

Planting date : June 15

Harvesting date : October 12

Table 3 Crop Water Requirement (Green Maize)

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	2	Init	0.30	1.57	9.4	0	9.4
Jun	3	Init	0.30	1.61	16.1	0	16.1
Jul	1	Deve	0.36	1.99	19.9	0.2	19.7
Jul	2	Deve	0.63	3.57	35.7	0	35.7
Jul	3	Deve	0.94	5.47	60.2	0	60.1
Aug	1	Mid	1.24	7.44	74.4	0	74.4
Aug	2	Mid	1.32	8.19	81.9	0	81.8
Aug	3	Mid	1.32	8.41	92.5	0.4	92.0
Sep	1	Mid	1.32	8.62	86.2	0.6	85.6
Sep	2	Late	1.30	8.69	86.9	0.9	86.0
Sep	3	Late	0.99	6.63	66.3	2.4	64.0
Oct	1	Late	0.60	4.12	41.2	1.4	39.7
Oct	2	Late	0.37	2.55	5.1	0.3	5.1
					675.7	6.3	669.7

Example: August, 3rd decade, maize

ETc mm/dec;

ETc mm/day x 11 days = 8.41 x 11 = 92.5 mm/dec

Irrigation requirement mm/dec;

ETc mm/dec – Eff rain mm/dec = 92.5 – 0.4 = 92.1 mm/dec

- Calculation of Peak Irrigation Requirement of August (lit/s/ha);

Crop Irrigation Requirement (lit/s/ha) = 92.0 mm/dec

Crop Irrigation Requirement (lit/s/ha) = 92.0 /1000 x 10000 x 1000 / 11 /86400 = 0.97 lit/s/ha

Net Irrigation Requirement = 0.97 / 0.6 = 1.61 lit/s/ha

- Irrigation Requirement at the field

In case of 8 hours, Monday to Friday (5 days) irrigation:
1.61 x 7 / 5 x 24/8 = 6.72 lit/s/ha.

In case of 8 hours, once a week irrigation:
1.61 x 7 x 24/8 = 33.81 lit/s/ha.

- Gross Irrigation Requirement at the intake;

In case of 8 hours, Monday to Friday (5 days) irrigation:
6.72 / 0.3 = 22.40 lit/s/ha

In case of 8 hours, once a week irrigation:
33.81 / 0.3 = 112.7 lit/s/ha.

(3) Crop Irrigation Schedule

Table 4 shows irrigation schedule in case of full replenishment at critical depletion. Irrigation water should be supplied required amount before indicated date. From the table, the shortest irrigation interval is 12 days. Therefore, irrigation interval should be shorter than 12 days.

Table 4 Crop irrigation schedule (maize)

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			Mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
20-Jul	36	Dev	0	1	100	56	80.9	0	0	134.8	0.43
5-Aug	52	Dev	0	1	100	57	97.3	0	0	162.2	1.17
18-Aug	65	Mid	0	1	100	59	102.7	0	0	171.1	1.52
30-Aug	77	Mid	0	1	100	57	99.9	0	0	166.5	1.61
11-Sep	89	Mid	0	1	100	59	102.6	0	0	170.9	1.65
26-Sep	104	End	0	1	100	66	115.4	0	0	192.4	1.48
12-Oct	End	End	0	1	100	39					

Ks: Water Stress Coefficient

When the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. Where, there is no water stress, Ks = 1.0

ETa: Adjusted ETc, When Ks = 1.0, Eta = 100% (1.0)

In case of full replenishment at critical depletion, deficit = 0, loss = 0

Deficit or loss happens when fixed amount and interval such as 40mm application every 7 days.

Gr. Irr = Net Irr / 0.6

Example 5-Aug. to 18 Aug., 13 days

Gr. Irr = 102.7 / 0.6 = 171.17 mm

Flow = 171.17 / 1000 x 10000 x 1000 / 13 / 86400 = 1.52 lit/s/ha

Example Output of CROPWAT

Table A2-2 Meteorological data of Mbala

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	° C	° C	%	km/day	hours	MJ/m2/day	mm/day
January	14.7	23.3	86	216	6	19.2	3.53
February	14.8	23.7	81	225	5.8	19.1	3.71
March	15	24.5	79	277	6.2	19.2	3.89
April	14.7	24.8	79	372	8.6	21.4	4.18
May	13	24.8	68	432	11	22.9	4.9
June	10.8	24.3	56	441	10.9	21.5	5.25
July	10.5	24.2	51	475	11	22.1	5.62
August	12	25.7	50	467	11.1	24.1	6.21
September	13.8	27.4	47	415	10.1	24.5	6.7
October	15.1	27.7	50	389	9.8	25.1	6.7
November	15.1	25.2	71	285	7.3	21.2	4.62
December	14.8	23.4	81	225	5.7	18.6	3.67
Average	13.7	24.9	67	351	8.6	21.6	4.92

	Rain	Eff rain
	mm	mm
January	237	189.6
February	209.5	167.6
March	233.3	186.6
April	126	100.8
May	16.6	13.3
June	1.8	1.4
July	0.2	0.2
August	0.5	0.4
September	4.7	3.8
October	20.1	16.1
November	137.3	109.8
December	252.1	201.7
Total	1239.1	991.3

Table A2-3 Cropping pattern of the scheme.

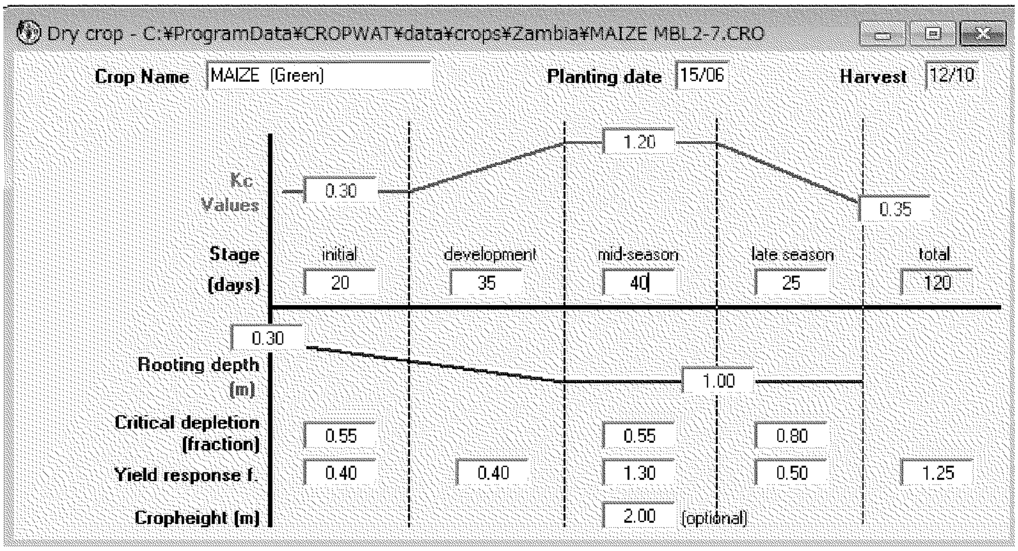
Crop name	Planting date	Harvesting date	Area %
Green Maize	15/6	12/10	50
Tomato	15/6	2/10	20
Egg plant	15/3	17/6	5
Rape	10/6	23/8	15
Cabbage	15/7	1/11	5
Okura	10/7	27/9	5

Table A2-4 Soil data

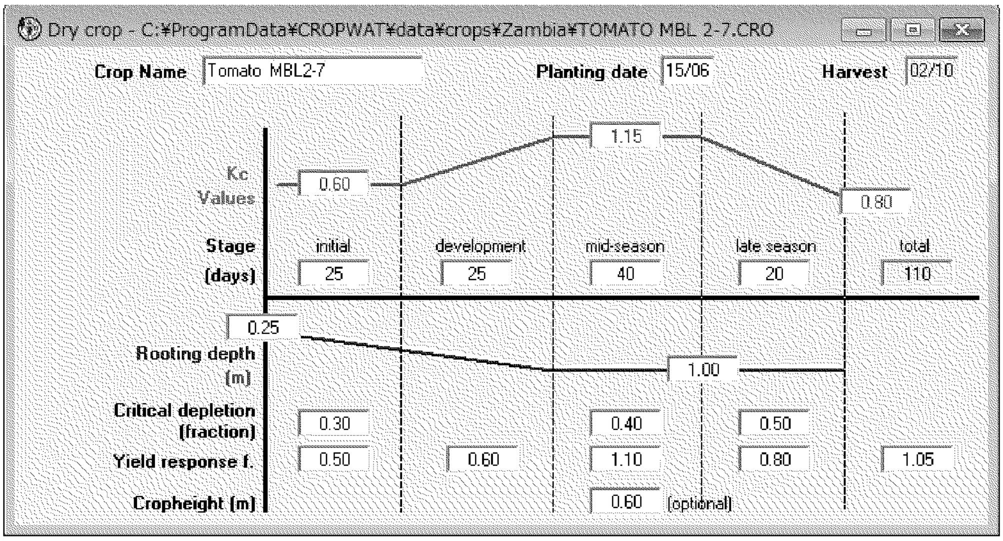
Soil name	Medium (loam)	
Total available soil moisture (FC-WP)	290	mm/meter
Maximum rain infiltration rate	40	mm/day
Maximum rooting depth	60	centimeters
Initial soil moisture depletion (as % TAM)	0	%
Initial available soil moisture	290	mm/meter

Table A2-5 Crop data

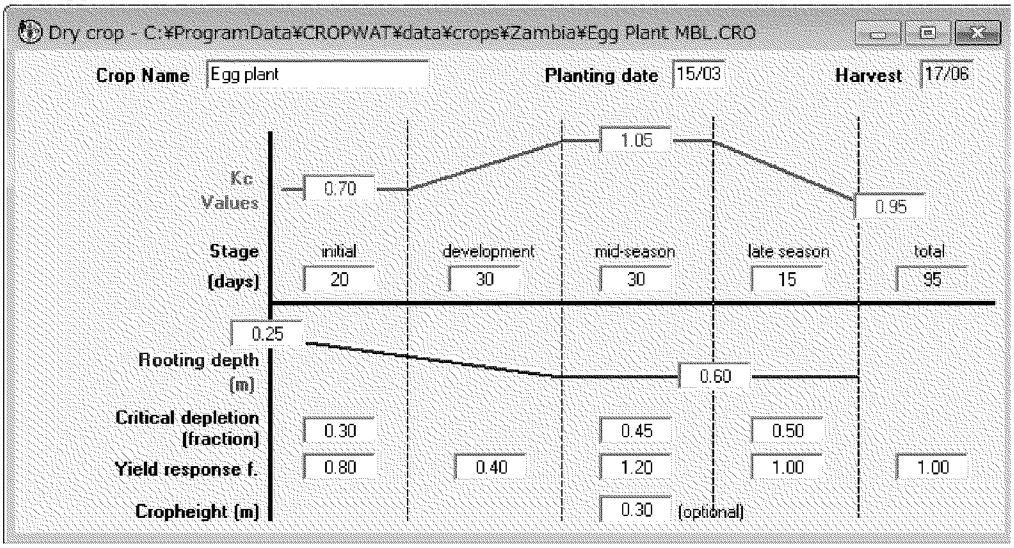
(1) Green Maize



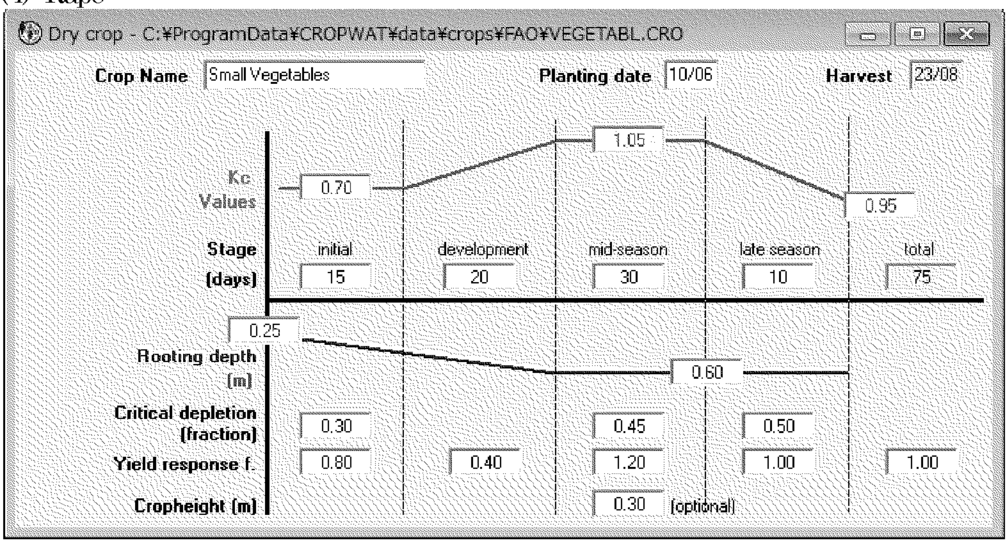
(2) Tomato



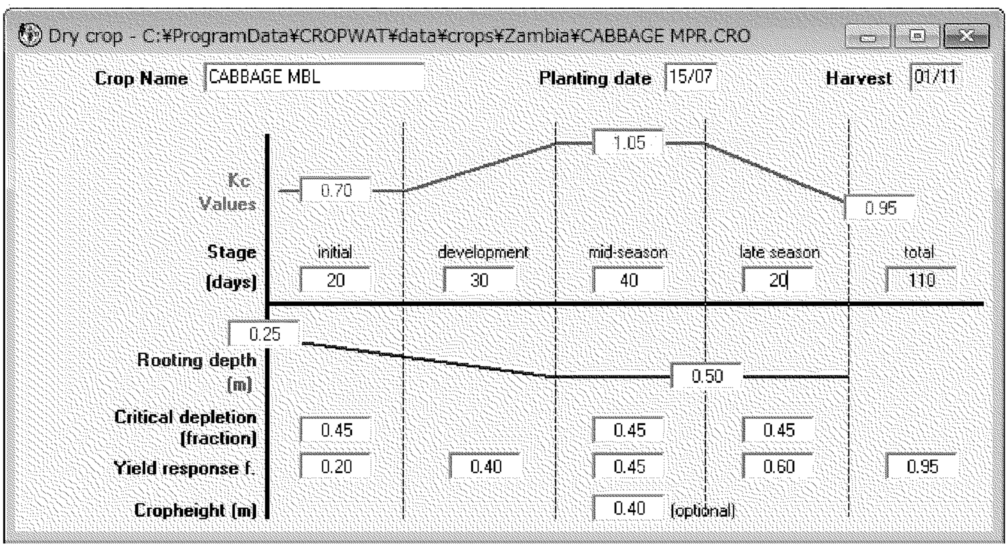
(3) Egg Plant



(4) Rape



(5) Cabbage



(6) Okura

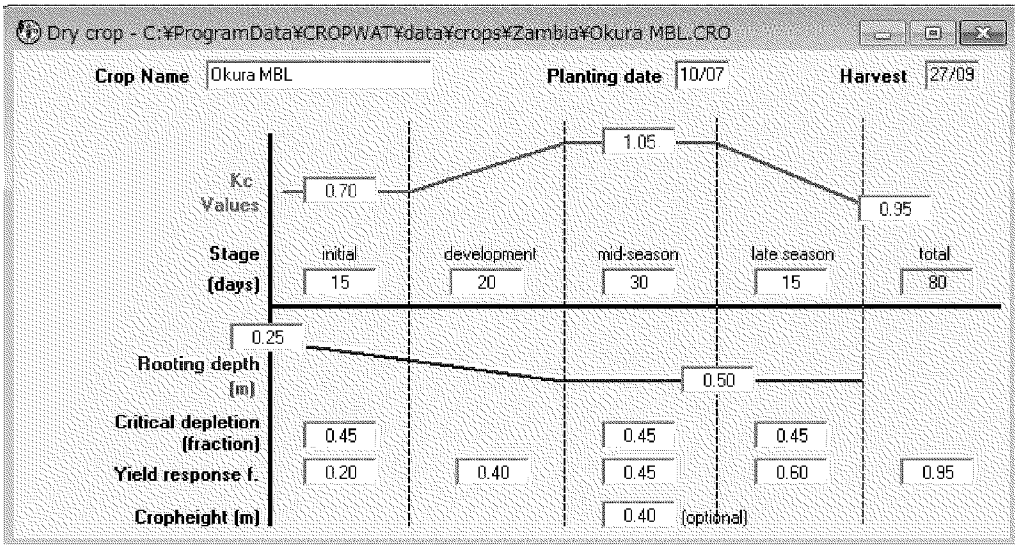
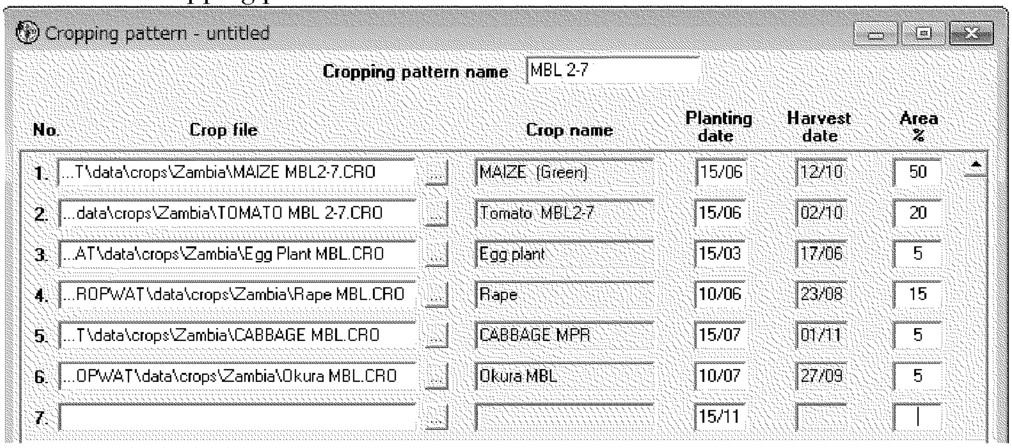


Table A2-6 Cropping pattern



Cropping pattern - untitled

Cropping pattern name: MBL 2-7

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1.	...T\data\crops\Zambia\MAIZE MBL2-7.CRO	MAIZE (Green)	15/06	12/10	50
2.	...data\crops\Zambia\TOMATO MBL 2-7.CRO	Tomato MBL2-7	15/06	02/10	20
3.	...AT\data\crops\Zambia\Egg Plant MBL.CRO	Egg plant	15/03	17/06	5
4.	...ROPWAT\data\crops\Zambia\Rape MBL.CRO	Rape	10/06	23/08	15
5.	...T\data\crops\Zambia\CABBAGE MBL.CRO	CABBAGE MPR	15/07	01/11	5
6.	...OPWAT\data\crops\Zambia\Okura MBL.CRO	Okura MBL	10/07	27/09	5
7.			15/11		

Table A2-7 Crop water requirement

(1) Green Maize

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	2	Init	0.3	1.57	9.4	0	9.4
Jun	3	Init	0.3	1.61	16.1	0	16.1
Jul	1	Deve	0.36	1.99	19.9	0.2	19.7
Jul	2	Deve	0.63	3.57	35.7	0	35.7
Jul	3	Deve	0.94	5.47	60.2	0	60.1
Aug	1	Mid	1.24	7.44	74.4	0	74.4
Aug	2	Mid	1.32	8.19	81.9	0	81.8
Aug	3	Mid	1.32	8.41	92.5	0.4	92
Sep	1	Mid	1.32	8.62	86.2	0.6	85.6
Sep	2	Late	1.3	8.69	86.9	0.9	86
Sep	3	Late	0.99	6.63	66.3	2.4	64
Oct	1	Late	0.6	4.12	41.2	1.4	39.7
Oct	2	Late	0.37	2.55	5.1	0.3	5.1
					675.7	6.3	669.7

(2) Tomato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	2	Init	0.6	3.15	18.9	0	18.9
Jun	3	Init	0.6	3.22	32.2	0	32.2
Jul	1	Deve	0.6	3.31	33.1	0.2	33
Jul	2	Deve	0.77	4.3	43	0	43
Jul	3	Deve	1.03	6	66	0	66
Aug	1	Mid	1.23	7.38	73.8	0	73.8
Aug	2	Mid	1.24	7.67	76.7	0	76.6
Aug	3	Mid	1.24	7.87	86.6	0.4	86.1
Sep	1	Mid	1.24	8.07	80.7	0.6	80.1
Sep	2	Late	1.17	7.84	78.4	0.9	77.5
Sep	3	Late	0.99	6.64	66.4	2.4	64
Oct	1	Late	0.88	6.02	12	0.3	12
					667.9	4.9	663.3

(2) Egg Plant

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	2	Init	0.7	2.73	16.4	40.3	0
Mar	3	Init	0.7	2.79	30.7	56	0
Apr	1	Deve	0.74	3.01	30.1	43.2	0
Apr	2	Deve	0.87	3.63	36.3	33.6	2.7
Apr	3	Deve	1	4.44	44.4	23.9	20.5
May	1	Mid	1.1	5.13	51.3	11.8	39.6
May	2	Mid	1.11	5.42	54.2	0.9	53.3
May	3	Mid	1.11	5.55	61	0.7	60.3
Jun	1	Late	1.08	5.56	55.6	1.5	54.1
Jun	2	Late	1.03	5.43	38	0	38
					418.1	211.9	268.4

(3) Rape

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Init	0.7	3.59	3.6	0.1	3.6
Jun	2	Init	0.7	3.67	36.7	0	36.7
Jun	3	Deve	0.74	4	40	0	40
Jul	1	Deve	0.94	5.19	51.9	0.2	51.8
Jul	2	Mid	1.11	6.25	62.5	0	62.5
Jul	3	Mid	1.12	6.54	72	0	71.9
Aug	1	Mid	1.12	6.76	67.6	0	67.6
Aug	2	Late	1.1	6.8	68	0	68
Aug	3	Late	1.03	6.58	19.8	0.1	19.5
					422.2	0.6	421.6

(4) Cabbage

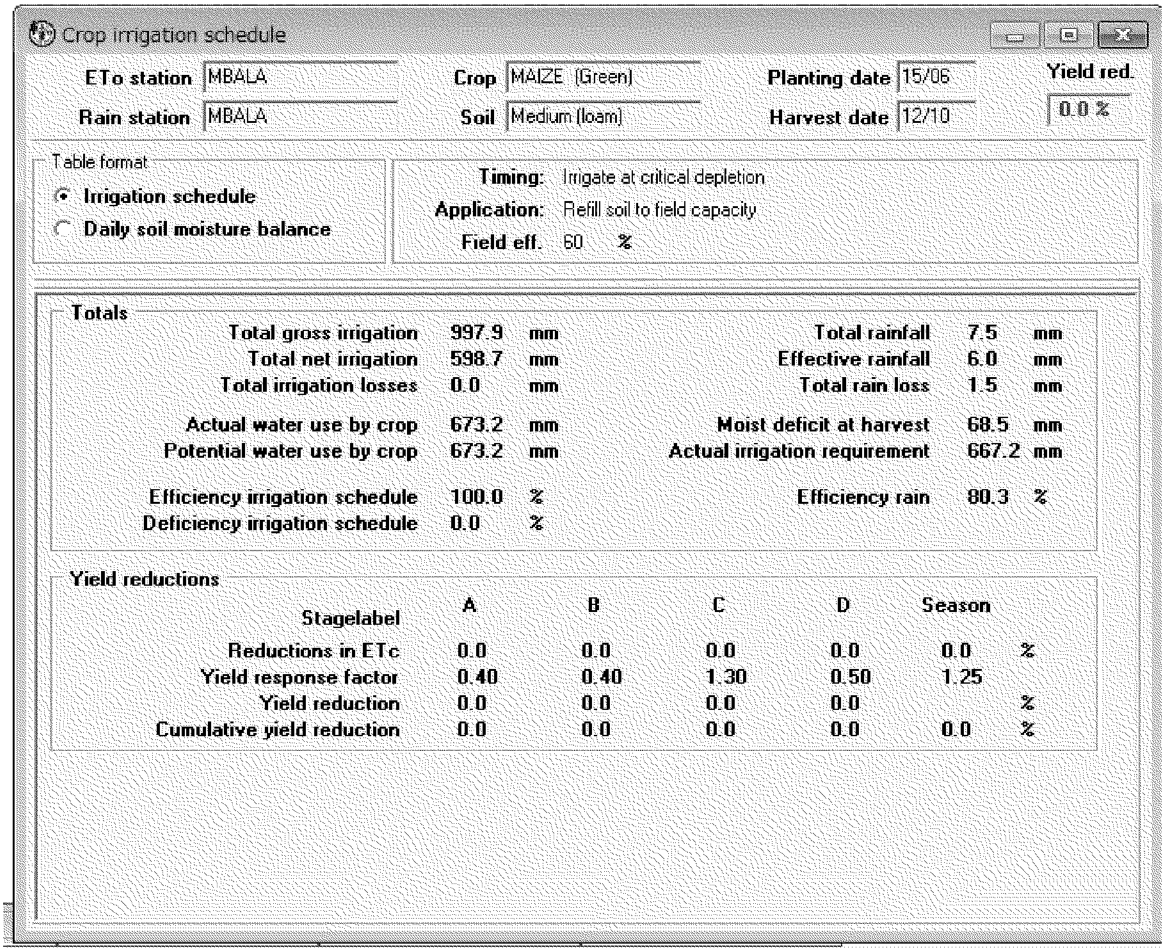
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	2	Init	0.7	3.94	23.6	0	23.6
Jul	3	Init	0.7	4.07	44.8	0	44.7
Aug	1	Deve	0.74	4.44	44.4	0	44.3
Aug	2	Deve	0.87	5.41	54.1	0	54
Aug	3	Deve	1.02	6.47	71.2	0.4	70.7
Sep	1	Mid	1.11	7.25	72.5	0.6	71.9
Sep	2	Mid	1.11	7.45	74.5	0.9	73.6
Sep	3	Mid	1.11	7.45	74.5	2.4	72.1
Oct	1	Mid	1.11	7.6	76	1.4	74.5
Oct	2	Late	1.09	7.53	75.3	1.5	73.8
Oct	3	Late	1.03	6.35	69.8	13.2	56.6
Nov	1	Late	1	5.25	5.2	2.6	5.2
					685.9	23.2	665.4

(5) Okura

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	0.7	3.85	3.8	0	3.8
Jul	2	Init	0.7	3.94	39.4	0	39.4
Jul	3	Deve	0.75	4.39	48.2	0	48.2
Aug	1	Deve	0.96	5.8	58	0	58
Aug	2	Mid	1.12	6.94	69.4	0	69.3
Aug	3	Mid	1.12	7.16	78.8	0.4	78.3
Sep	1	Mid	1.12	7.35	73.5	0.6	72.9
Sep	2	Late	1.1	7.36	73.6	0.9	72.7
Sep	3	Late	1.04	6.95	48.6	1.6	46.3
					493.3	3.7	488.9

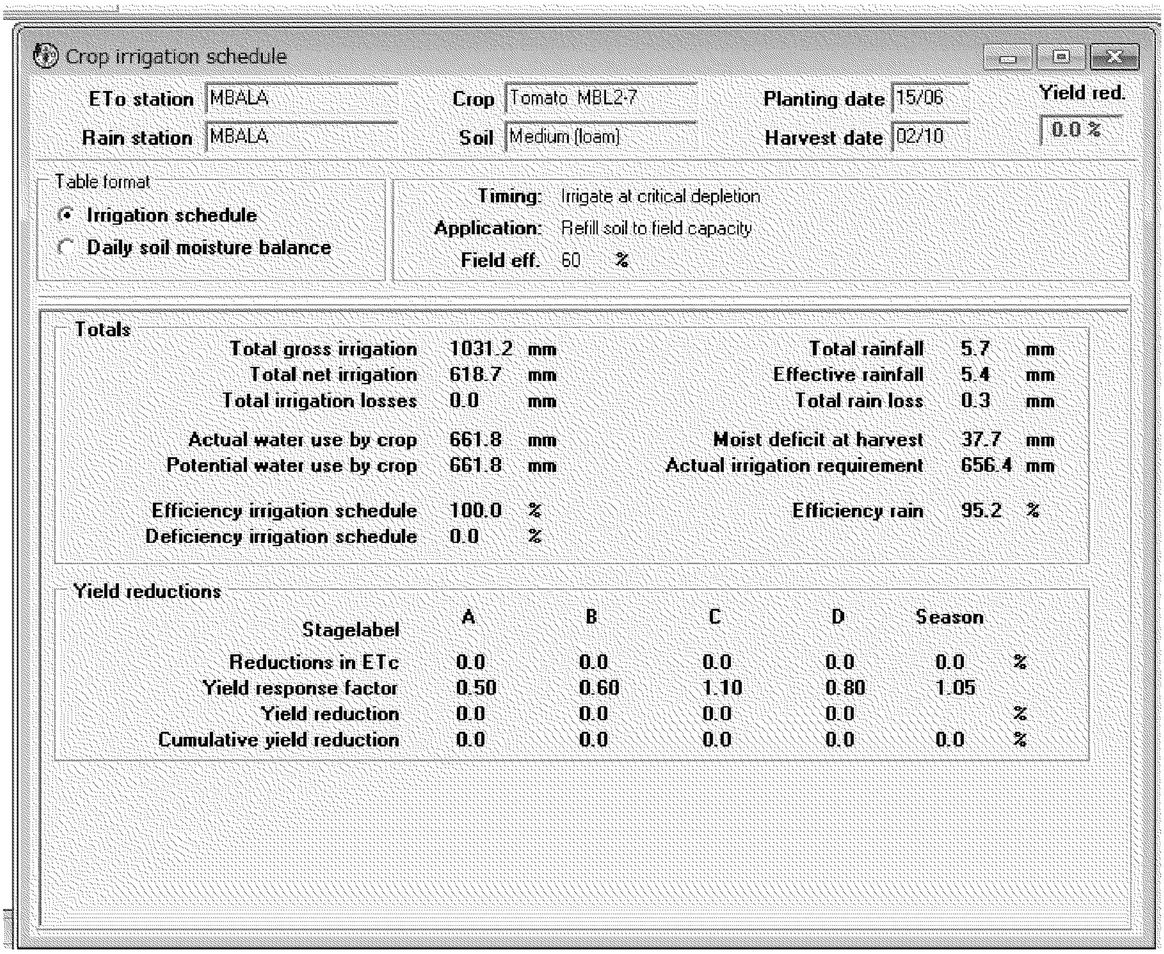
Table A2-8 Crop irrigation schedule

(1) Green Maize



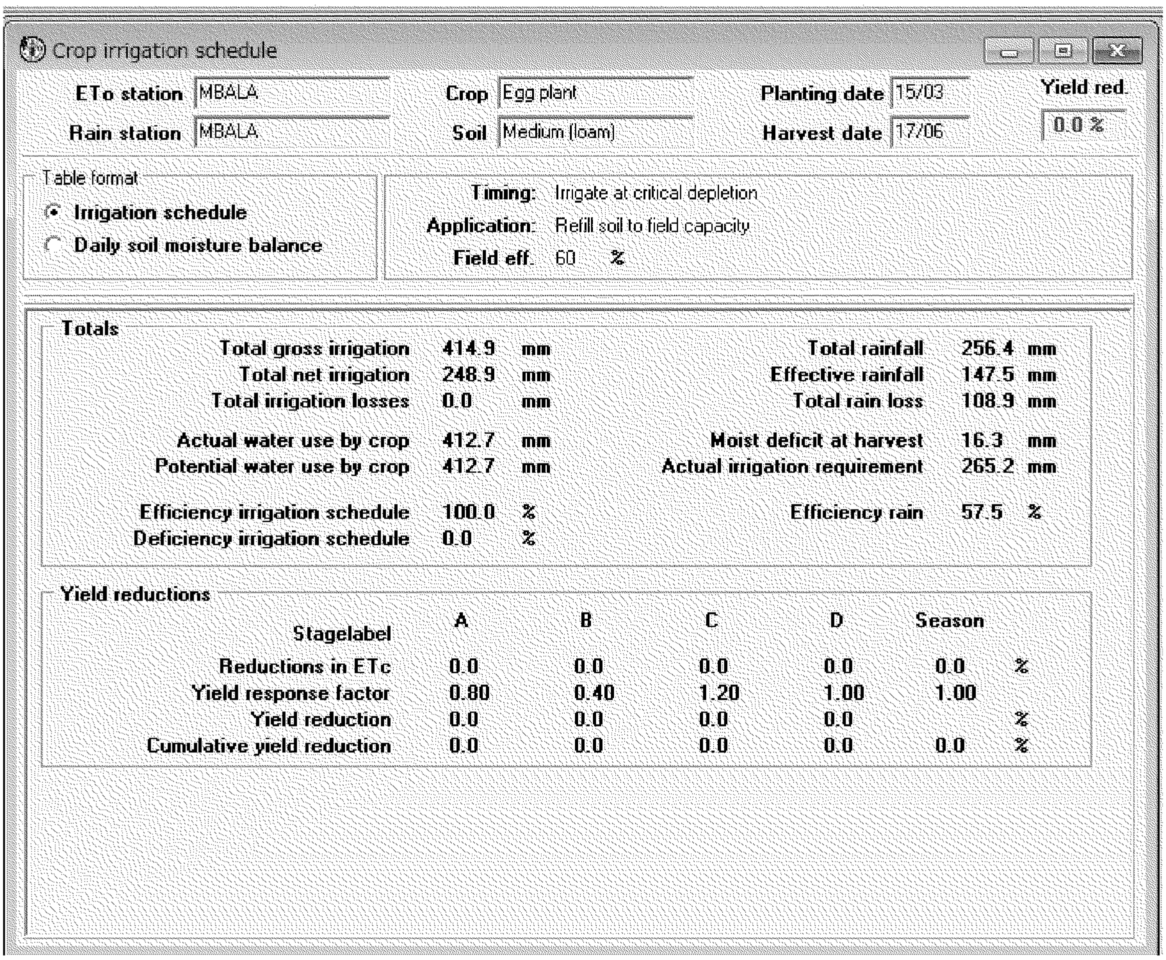
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
20-Jul	36	Dev	0	1	100	56	80.9	0	0	134.8	0.43
5-Aug	52	Dev	0	1	100	57	97.3	0	0	162.2	1.17
18-Aug	65	Mid	0	1	100	59	102.7	0	0	171.1	1.52
30-Aug	77	Mid	0	1	100	57	99.9	0	0	166.5	1.61
11-Sep	89	Mid	0	1	100	59	102.6	0	0	170.9	1.65
26-Sep	104	End	0	1	100	66	115.4	0	0	192.4	1.48
12-Oct	End	End	0	1	100	39					

(2) Tomato



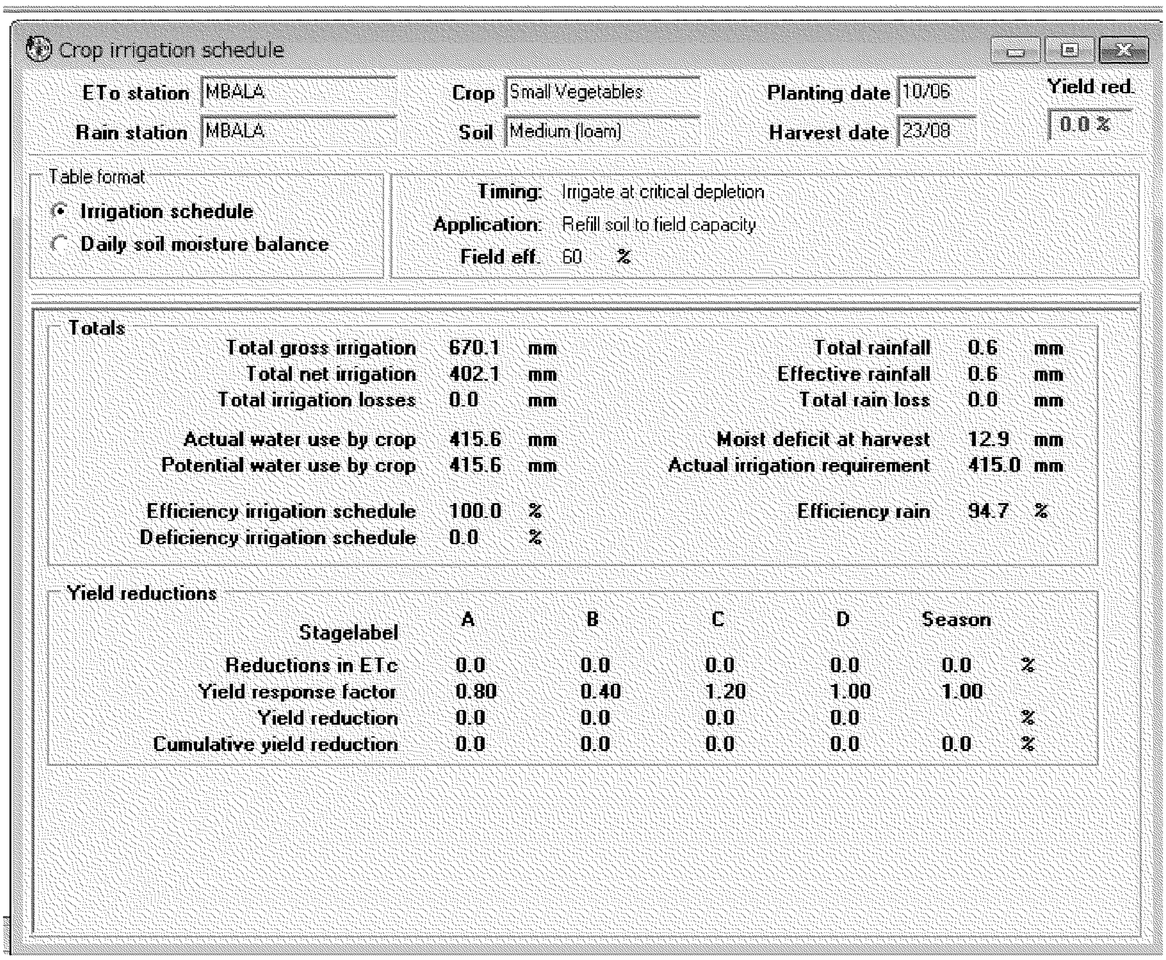
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
23-Jun	9	Init	0	1.00	100	31	28.5	0	0	47.6	0.61
4-Jul	20	Init	0	1.00	100	32	35.7	0	0	59.5	0.63
16-Jul	32	Dev	0	1.00	100	33	45.6	0	0	76	0.73
28-Jul	44	Dev	0	1.00	100	40	65.2	0	0	108.6	1.05
7-Aug	54	Mid	0	1.00	100	40	69.6	0	0	116.1	1.34
17-Aug	64	Mid	0	1.00	100	44	75.8	0	0	126.3	1.46
26-Aug	73	Mid	0	1.00	100	40	69.9	0	0	116.6	1.5
4-Sep	82	Mid	0	1.00	100	41	71.3	0	0	118.8	1.53
13-Sep	91	End	0.5	1.00	100	41	71	0	0	118.4	1.52
25-Sep	103	End	0	1.00	100	49	86.1	0	0	143.4	1.38
2-Oct	End	End	0	1.00	100	22					

(3) Egg Plant



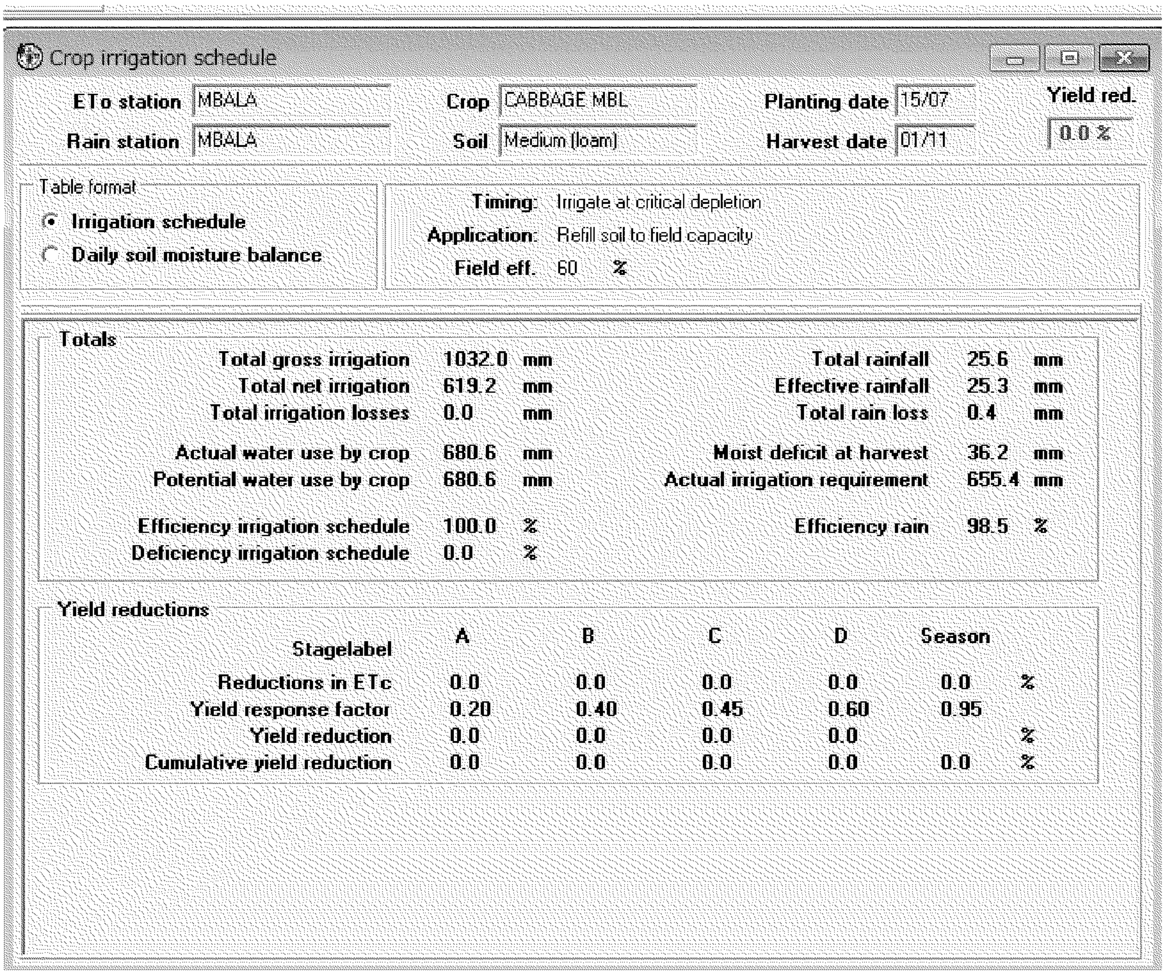
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
13-May	60	Mid	0.5	1.00	100	47	81.4	0	0	135.7	0.26
28-May	75	Mid	0	1.00	100	46	80.8	0	0	134.7	1.04
13-Jun	91	End	0	1.00	100	50	86.7	0	0	144.5	1.05
17-Jun	End	End	0.5	1.00	100	9					

(4) Rape



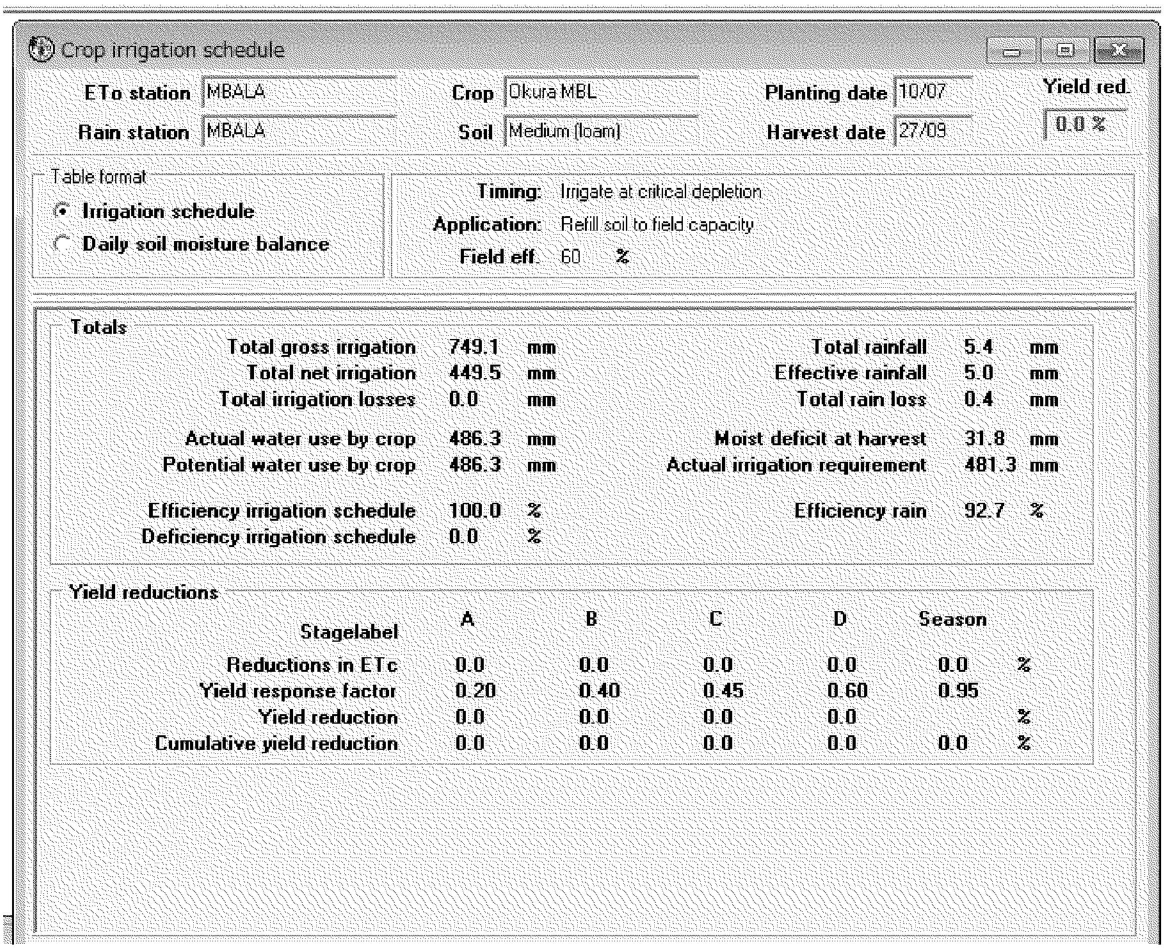
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
17-Jun	8	Init	0	1.00	100	31	29.3	0	0	48.8	0.71
28-Jun	19	Dev	0	1.00	100	34	43	0	0	71.7	0.75
13-Jul	34	Dev	0	1.00	100	46	78.5	0	0	130.8	1.01
26-Jul	47	Mid	0	1.00	100	48	83	0	0	138.3	1.23
7-Aug	59	Mid	0	1.00	100	46	80	0	0	133.4	1.29
20-Aug	72	End	0	1.00	100	51	88.3	0	0	147.2	1.31
23-Aug	End	End	0	1.00	100	7					

(5) Cabbage



Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
24-Jul	10	Init	0	1.00	100	46	39.9	0	0	66.4	0.77
5-Aug	22	Dev	0	1.00	100	49	50.7	0	0	84.4	0.81
16-Aug	33	Dev	0	1.00	100	45	54.6	0	0	91	0.96
27-Aug	44	Dev	0.3	1.00	100	49	66.4	0	0	110.6	1.16
6-Sep	54	Mid	0	1.00	100	48	69	0	0	115	1.33
15-Sep	63	Mid	0	1.00	100	45	65.7	0	0	109.5	1.41
25-Sep	73	Mid	0	1.00	100	50	72.5	0	0	120.8	1.4
4-Oct	82	Mid	0	1.00	100	45	65.3	0	0	108.8	1.4
13-Oct	91	End	1	1.00	100	46	66.3	0	0	110.6	1.42
24-Oct	102	End	0	1.00	100	48	68.9	0	0	114.9	1.21
1-Nov	End	End	0	1.00	100	25					

(6) Okura



Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
20-Jul	11	Init	0	1.00	100	45	43.2	0	0	72	0.76
2-Aug	24	Dev	0	1.00	100	49	59.8	0	0	99.6	0.89
13-Aug	35	Dev	0	1.00	100	46	67.2	0	0	112	1.18
23-Aug	45	Mid	0.3	1.00	100	48	69.8	0	0	116.3	1.35
2-Sep	55	Mid	0	1.00	100	49	71.7	0	0	119.5	1.38
11-Sep	64	Mid	0	1.00	100	45	65.7	0	0	109.6	1.41
21-Sep	74	End	0	1.00	100	50	72.1	0	0	120.2	1.39
27-Sep	End	End	0	1.00	100	22					

Reference 1: FAO Irrigation and Drainage Paper No.56 P.104 - 108

TABLE 11

Lengths of crop development stages* for various planting periods and climatic regions (days)

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
a. Small Vegetables							
Broccoli	35	45	40	15	135	Sept	Calif. Desert, USA
Cabbage	40	60	50	15	165	Sept	Calif. Desert, USA
Carrots	20	30	50/30	20	100	Oct/Jan	Arid climate
	30	40	60	20	150	Feb/Mar	Mediterranean
	30	50	90	30	200	Oct	Calif. Desert, USA
Cauliflower	35	50	40	15	140	Sept	Calif. Desert, USA
Celery	25	40	95	20	180	Oct	(Semi)Arid
	25	40	45	15	125	April	Mediterranean
	30	55	105	20	210	Jan	(Semi)Arid
Crucifers[1]	20	30	20	10	80	April	Mediterranean
	25	35	25	10	95	February	Mediterranean
	30	35	90	40	195	Oct/Nov	Mediterranean
Lettuce	20	30	15	10	75	April	Mediterranean
	30	40	25	10	105	Nov/Jan	Mediterranean
	25	35	30	10	100	Oct/Nov	Arid Region
	35	50	45	10	140	Feb	Mediterranean
Onion (dry)	15	25	70	40	150	April	Mediterranean
	20	35	110	45	210	Oct; Jan.	Arid Region; Calif.
Onion (green)	25	30	10	5	70	April/May	Mediterranean
	20	45	20	10	95	October	Arid Region
	30	55	55	40	180	March	Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20	20	15/25	5	60/70	Apr; Sep/Oct	Mediterranean
	20	30	40	10	100	November	Arid Region
Radish	5	10	15	5	35	Mar/Apr	Medit.; Europe
	10	10	15	5	40	Winter	Arid Region
b. Vegetables – Solanum Family *(Solanaceae)*							
Egg plant	30	40	40	20	130\14	October	Arid Region
	30	45	40	25	0	May/June	Mediterranean
Sweet peppers (bell)	25/30	35	40	20	125	April/June	Europe and Medit.
	30	40	110	30	210	October	Arid Region
Tomato	30	40	40	25	135	January	Arid Region
	35	40	50	30	155	Apr/May	Calif., USA
	25	40	60	30	155	Jan	Calif. Desert, USA
	35	45	70	30	180	Oct/Nov	Arid Region
	30	40	45	30	145	April/May	Mediterranean
c. Vegetables - Cucumber Family *(Cucurbitaceae)*							
Cantaloupe	30	45	35	10	120	Jan	Calif., USA
	10	60	25	25	120	Aug	Calif., USA
Cucumber	20	30	40	15	105	June/Aug	Arid Region
	25	35	50	20	130	Nov; Feb	Arid Region
Pumpkin, Winter squash	20	30	30	20	100	Mar, Aug	Mediterranean
	25	35	35	25	120	June	Europe
Squash, Zucchini	25	35	25	15	100	Apr; Dec.	Medit.; Arid Reg.
	20	30	25	15	90	May/June	Medit.; Europe

continued...

* Lengths of crop development stages provided in this table are indicative of general conditions, but may vary substantially from region to region, with climate and cropping conditions, and with crop variety. The user is strongly encouraged to obtain appropriate local information.

[1] Crucifers include cabbage, cauliflower, broccoli, and Brussel sprouts. The wide range in lengths of seasons is due to varietal and species differences.

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Sweet melons	25	35	40	20	120	May	Mediterranean
	30	30	50	30	140	March	Calif., USA
	15	40	65	15	135	Aug	Calif. Desert, USA
	30	45	65	20	160	Dec/Jan	Arid Region
Water melons	20	30	30	30	110	April	Italy
	10	20	20	30	80	Mat/Aug	Near East (desert)
d. Roots and Tubers							
Beets, table	15	25	20	10	70	Apr/May	Mediterranean
	25	30	25	10	90	Feb/Mar	Mediterranean & Arid
Cassava: year 1	20	40	90	60	210	Rainy	Tropical regions
year 2	150	40	110	60	360	season	
Potato	25	30	30/45	30	115/130	Jan/Nov	(Semi)Arid Climate
	25	30	45	30	130	May	Continental Climate
	30	35	50	30	145	April	Europe
	45	30	70	20	165	Apr/May	Idaho, USA
	30	35	50	25	140	Dec	Calif. Desert, USA
Sweet potato	20	30	60	40	150	April	Mediterranean
	15	30	50	30	125	Rainy seas.	Tropical regions
Sugarbeet	30	45	90	15	180	March	Calif., USA
	25	30	90	10	155	June	Calif., USA
	25	65	100	65	255	Sept	Calif. Desert, USA
	50	40	50	40	180	April	Idaho, USA
	25	35	50	50	160	May	Mediterranean
	45	75	80	30	230	November	Mediterranean
	35	60	70	40	205	November	Arid Regions
e. Legumes (*Leguminosae*)							
Beans (green)	20	30	30	10	90	Feb/Mar	Calif., Mediterranean
	15	25	25	10	75	Aug/Sep	Calif., Egypt, Lebanon
Beans (dry)	20	30	40	20	110	May/June	Continental Climates
	15	25	35	20	95	June	Pakistan, Calif.
	25	25	30	20	100	June	Idaho, USA
Faba bean,	15	25	35	15	90	May	Europe
broad bean	20	30	35	15	100	Mar/Apr	Mediterranean
- dry	90	45	40	60	235	Nov	Europe
- green	90	45	40	0	175	Nov	Europe
Green gram, cowpeas	20	30	30	20	110	March	Mediterranean
Groundnut	25	35	45	25	130	Dry season	West Africa
	35	35	35	35	140	May	High Latitudes
	35	45	35	25	140	May/June	Mediterranean
Lentil	20	30	60	40	150	April	Europe
	25	35	70	40	170	Oct/Nov	Arid Region
Peas	15	25	35	15	90	May	Europe
	20	30	35	15	100	Mar/Apr	Mediterranean
	35	25	30	20	110	April	Idaho, USA
Soybeans	15	15	40	15	85	Dec	Tropics
	20	30/35	60	25	140	May	Central USA
	20	25	75	30	150	June	Japan

continued...

Table 11 continued.

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)							
Artichoke	40 20	40 25	250 250	30 30	360 325	Apr (1st yr) May (2nd yr)	California (cut in May)
Asparagus	50 90	30 30	100 200	50 45	230 365	Feb Feb	Warm Winter Mediterranean
g. Fibre Crops							
Cotton	30 45 30 30	50 90 50 50	60 45 60 55	55 45 55 45	195 225 195 180	Mar-May Mar Sept April	Egypt; Pakistan; Calif. Calif. Desert, USA Yemen Texas
Flax	25 30	35 40	50 100	40 50	150 220	April October	Europe Arizona
h. Oil Crops							
Castor beans	25 20	40 40	65 50	50 25	180 135	March Nov.	(Semi)Arid Climates Indonesia
Safflower	20 25 35	35 35 55	45 55 60	25 30 40	125 145 190	April Mar Oct/Nov	California, USA High Latitudes Arid Region
Sesame	20	30	40	20	100	June	China
Sunflower	25	35	45	25	130	April/May	Medit.; California
i. Cereals							
Barley/Oats/ Wheat	15 20 15 40 40 20	25 25 30 30 60 50	50 60 65 40 60 60	30 30 40 20 40 30	120 135 150 130 200 160	November March/Apr July Apr Nov Dec	Central India 35-45 °L East Africa Calif. Desert, USA
Winter Wheat	20[2] 30 160	60[2] 140 75	70 40 75	30 30 25	180 240 335	December November October	Calif., USA Mediterranean Idaho, USA
Grains (small)	20 25	30 35	60 65	40 40	150 165	April Oct/Nov	Mediterranean Pakistan; Arid Reg.
Maize (grain)	30 25 20 20 30 30	50 40 35 35 40 40	60 45 40 40 50 50	40 30 30 30 30 50	180 140 125 125 150 170	April Dec/Jan June October April April	East Africa (alt.) Arid Climate Nigeria (humid) India (dry, cool) Spain (spr, sum.); Calif. Idaho, USA
Maize (sweet)	20 20 20 30 20	20 25 30 30 40	30 25 50/30 30 70	10 10 10 10[3] 10	80 80 90 110 140	March May/June Oct/Dec April Jan	Philippines Mediterranean Arid Climate Idaho, USA Calif. Desert, USA
Millet	15 20	25 30	40 55	25 35	105 140	June April	Pakistan Central USA

continued...

[2] These periods for winter wheat will lengthen in frozen climates according to days having zero growth potential and wheat dormancy . Under general conditions and in the absence of local data, fall planting of winter wheat can be presumed to occur in northern temperate climates when the 10-day running average of mean daily air temperature decreases to 17° C or December 1, whichever comes first. Planting of spring wheat can be presumed to occur when the 10-day running average of mean daily air temperature increases to 5° C. Spring planting of maize-grain can be presumed to occur when the 10-day running average of mean daily air temperature increases to 13° C.

[3] The late season for sweet maize will be about 35 days if the grain is allowed to mature and dry.

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Sorghum	20 20	35 35	40 45	30 30	130 140	May/June Mar/April	USA, Pakis., Med. Arid Region
Rice	30 30	30 30	60 80	30 40	150 180	Dec; May May	Tropics; Mediterranean Tropics
j. Forages							
Alfalfa, total season[4]	10	30	var.	var.	var.		last -4°C in spring until first -4°C in fall
Alfalfa[4] 1st cutting cycle	10 10	20 30	20 25	10 10	60 75	Jan Apr (last -4° C)	Calif., USA. Idaho, USA.
Alfalfa[4], other cutting cycles	5 5	10 20	10 10	5 10	30 45	Mar Jun	Calif., USA. Idaho, USA.
Bermuda for seed	10	25	35	35	105	March	Calif. Desert, USA
Bermuda for hay (several cuttings)	10	15	75	35	135	---	Calif. Desert, USA
Grass Pasture[4]	10	20	--	--	--		7 days before last -4°C in spring until 7 days after first -4°C in fall
Sudan, 1st cutting cycle	25	25	15	10	75	Apr	Calif. Desert, USA
Sudan, other cutting cycles	3	15	12	7	37	June	Calif. Desert, USA
k. Sugar Cane							
Sugarcane, virgin	35 50 75	60 70 105	190 220 330	120 140 210	405 480 720		Low Latitudes Tropics Hawaii, USA
Sugarcane, ratoon	25 30 35	70 50 105	135 180 210	50 60 70	280 320 420		Low Latitudes Tropics Hawaii, USA
l. Tropical Fruits and Trees							
Banana, 1st yr	120	90	120	60	390	Mar	Mediterranean
Banana, 2nd yr	120	60	180	5	365	Feb	Mediterranean
Pineapple	60	120	600	10	790		Hawaii, USA
m. Grapes and Berries							
Grapes	20 20 20 30	40 50 50 60	120 75 90 40	60 60 20 80	240 205 180 210	April Mar May April	Low Latitudes Calif., USA High Latitudes Mid Latitudes (wine)
Hops	25	40	80	10	155	April	Idaho, USA
n. Fruit Trees							
Citrus	60	90	120	95	365	Jan	Mediterranean
Deciduous Orchard	20 20 30	70 70 50	90 120 130	30 60 30	210 270 240	March March March	High Latitudes Low Latitudes Calif., USA

continued...

[4] In climates having killing frosts, growing seasons can be estimated for alfalfa and grass as: <u>alfalfa</u>: last -4°C in spring until first -4°C in fall (Everson, D.O., M. Faubion and D.E. Amos 1978. "Freezing temperatures and growing seasons in Idaho." Univ. Idaho Agric. Exp. station bulletin 494. 18 p.)
<u>grass</u>: 7 days before last -4°C in spring and 7 days after last -4°C in fall (Kruse E.G. and Haise, H.R. 1974. "Water use by native grasses in high altitude Colorado meadows." USDA Agric. Res. Service, Western Region report ARS-W-6-1974. 60 pages)

Table 11 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Olives	30	90	60	90	270[5]	March	Mediterranean
Pistachios	20	60	30	40	150	Feb	Mediterranean
Walnuts	20	10	130	30	190	April	Utah, USA
o. Wetlands - Temperate Climate							
Wetlands (Cattails, Bulrush)	10 180	30 60	80 90	20 35	140 365	May November	Utah, USA; killing frost Florida, USA
Wetlands (short veg.)	180	60	90	35	365	November	frost-free climate

[5] Olive trees gain new leaves in March. See footnote 24 of Table 12 for additional information, where the K_c continues outside of the "growing period".

Primary source: FAO Irrigation and Drainage Paper 24 (Doorenbos and Pruitt, 1977), Table 22.

Reference 2: FAO Irrigation and Drainage Paper No.56 P.110 - 114

TABLE 12

Single (time-averaged) crop coefficients, K_c, and mean maximum plant heights for non stressed, well-managed crops in subhumid climates ($RH_{min} \approx 45\%$, $u_2 \approx 2$ m/s) for use with the FAO Penman-Monteith ET_o.

Crop	$K_{c\ ini}$ [1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
a. Small Vegetables	**0.7**	**1.05**	**0.95**	
Broccoli		1.05	0.95	0.3
Brussel Sprouts		1.05	0.95	0.4
Cabbage		1.05	0.95	0.4
Carrots		1.05	0.95	0.3
Cauliflower		1.05	0.95	0.4
Celery		1.05	1.00	0.6
Garlic		1.00	0.70	0.3
Lettuce		1.00	0.95	0.3
Onions - dry		1.05	0.75	0.4
- green		1.00	1.00	0.3
- seed		1.05	0.80	0.5
Spinach		1.00	0.95	0.3
Radish		0.90	0.85	0.3
b. Vegetables – Solanum Family (*Solanaceae*)	**0.6**	**1.15**	**0.80**	
Egg Plant		1.05	0.90	0.8
Sweet Peppers (bell)		1.05[2]	0.90	0.7
Tomato		1.15[2]	0.70-0.90	0.6
c. Vegetables – Cucumber Family (*Cucurbitaceae*)	**0.5**	**1.00**	**0.80**	
Cantaloupe	0.5	0.85	0.60	0.3
Cucumber – Fresh Market	0.6	1.00[2]	0.75	0.3
– Machine harvest	0.5	1.00	0.90	0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Squash, Zucchini		0.95	0.75	0.3
Sweet Melons		1.05	0.75	0.4
Watermelon	0.4	1.00	0.75	0.4
d. Roots and Tubers	**0.5**	**1.10**	**0.95**	
Beets, table		1.05	0.95	0.4
Cassava – year 1	0.3	0.80[3]	0.30	1.0
– year 2	0.3	1.10	0.50	1.5
Parsnip	0.5	1.05	0.95	0.4
Potato		1.15	0.75[4]	0.6
Sweet Potato		1.15	0.65	0.4
Turnip (and Rutabaga)		1.10	0.95	0.6
Sugar Beet	0.35	1.20	0.70[5]	0.5

continued...

1 These are general values for $K_{c\ ini}$ under typical irrigation management and soil wetting. For frequent wettings such as with high frequency sprinkle irrigation or daily rainfall, these values may increase substantially and may approach 1.0 to 1.2. $K_{c\ ini}$ is a function of wetting interval and potential evaporation rate during the initial and development periods and is more accurately estimated using Figures 29 and 30, or Equation 7-3 in Annex 7, or using the dual $K_{cb\ ini} + K_e$.

2 Beans, Peas, Legumes, Tomatoes, Peppers and Cucumbers are sometimes grown on stalks reaching 1.5 to 2 meters in height. In such cases, increased K_c values need to be taken. For green beans, peppers and cucumbers, 1.15 can be taken, and for tomatoes, dry beans and peas, 1.20. Under these conditions h should be increased also.

3 The midseason values for cassava assume non-stressed conditions during or following the rainy season. The $K_{c\ end}$ values account for dormancy during the dry season.

4 The $K_{c\ end}$ value for potatoes is about 0.40 for long season potatoes with vine kill.

5 This $K_{c\ end}$ value is for no irrigation during the last month of the growing season. The $K_{c\ end}$ value for sugar beets is higher, up to 1.0, when irrigation or significant rain occurs during the last month.

Table 12 continued

Crop	$K_{c\ ini}$ [1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
e. Legumes (*Leguminosae*)	**0.4**	**1.15**	**0.55**	
Beans, green	0.5	1.05[2]	0.90	0.4
Beans, dry and Pulses	0.4	1.15[2]	0.35	0.4
Chick pea		1.00	0.35	0.4
Fababean (broad bean) – Fresh	0.5	1.15[2]	1.10	0.8
– Dry/Seed	0.5	1.15[2]	0.30	0.8
Grabanzo	0.4	1.15	0.35	0.8
Green Gram and Cowpeas		1.05	0.60-0.35[6]	0.4
Groundnut (Peanut)		1.15	0.60	0.4
Lentil		1.10	0.30	0.5
Peas – Fresh	0.5	1.15[2]	1.10	0.5
– Dry/Seed		1.15	0.30	0.5
Soybeans		1.15	0.50	0.5-1.0
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	0.5	1.00	0.80	
Artichokes	0.5	1.00	0.95	0.7
Asparagus	0.5	0.95[7]	0.30	0.2-0.8
Mint	0.60	1.15	1.10	0.6-0.8
Strawberries	0.40	0.85	0.75	0.2
g. Fibre Crops	**0.35**			
Cotton		1.15-1.20	0.70-0.50	1.2-1.5
Flax		1.10	0.25	1.2
Sisal[8]		0.4-0.7	0.4-0.7	1.5
h. Oil Crops	**0.35**	**1.15**	**0.35**	
Castorbean (*Ricinus*)		1.15	0.55	0.3
Rapeseed, Canola		1.0-1.15[9]	0.35	0.6
Safflower		1.0-1.15[9]	0.25	0.8
Sesame		1.10	0.25	1.0
Sunflower		1.0-1.15[9]	0.35	2.0
i. Cereals	0.3	**1.15**	**0.4**	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4[10]	1
Winter Wheat - with frozen soils	0.4	1.15	0.25-0.4[10]	1
- with non-frozen soils	0.7	1.15	0.25-0.4[10]	
Maize, Field (grain) *(field corn)*		1.20	0.60,0.35[11]	2
Maize, Sweet *(sweet corn)*		1.15	1.05[12]	1.5
Millet		1.00	0.30	1.5
Sorghum – grain		1.00-1.10	0.55	1-2
– sweet		1.20	1.05	2-4
Rice	1.05	1.20	0.90-0.60	1

continued...

6 The first $K_{c\ end}$ is for harvested fresh. The second value is for harvested dry.
7 The K_c for asparagus usually remains at $K_{c\ ini}$ during harvest of the spears, due to sparse ground cover. The $K_{c\ mid}$ value is for following regrowth of plant vegetation following termination of harvest of spears.
8 K_c for sisal depends on the planting density and water management (e.g., intentional moisture stress).
9 The lower values are for rainfed crops having less dense plant populations.
10 The higher value is for hand-harvested crops.
11 The first $K_{c\ end}$ value is for harvest at high grain moisture. The second $K_{c\ end}$ value is for harvest after complete field drying of the grain (to about 18% moisture, wet mass basis).
12 If harvested fresh for human consumption. Use $K_{c\ end}$ for field maize if the sweet maize is allowed to mature and dry in the field.

Table 12 continued

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
j. Forages				
Alfalfa Hay – averaged cutting effects	0.40	0.95[13]	0.90	0.7
– individual cutting periods	0.40[14]	1.20[14]	1.15[14]	0.7
– for seed	0.40	0.50	0.50	0.7
Bermuda hay – averaged cutting effects	0.55	1.00[13]	0.85	0.35
– Spring crop for seed	0.35	0.90	0.65	0.4
Clover hay, Berseem – averaged cutting effects	0.40	0.90[13]	0.85	0.6
– individual cutting periods	0.40[14]	1.15[14]	1.10[14]	0.6
Rye Grass hay – averaged cutting effects	0.95	1.05	1.00	0.3
Sudan Grass hay (annual) – averaged cutting effects	0.50	0.90[14]	0.85	1.2
– individual cutting periods	0.50[14]	1.15[14]	1.10[14]	1.2
Grazing Pasture - Rotated Grazing	0.40	0.85-1.05	0.85	0.15-0.30
- Extensive Grazing	0.30	0.75	0.75	0.10
Turf grass - cool season[15]	0.90	0.95	0.95	0.10
- warm season[15]	0.80	0.85	0.85	0.10
k. Sugar Cane	0.40	1.25	0.75	3
l. Tropical Fruits and Trees				
Banana – 1st year	0.50	1.10	1.00	3
– 2nd year	1.00	1.20	1.10	4
Cacao	1.00	1.05	1.05	3
Coffee – bare ground cover	0.90	0.95	0.95	2-3
– with weeds	1.05	1.10	1.10	2-3
Date Palms	0.90	0.95	0.95	8
Palm Trees	0.95	1.00	1.00	8
Pineapple[16] – bare soil	0.50	0.30	0.30	0.6-1.2
– with grass cover	0.50	0.50	0.50	0.6-1.2
Rubber Trees	0.95	1.00	1.00	10
Tea – non-shaded	0.95	1.00	1.00	1.5
– shaded[17]	1.10	1.15	1.15	2
m. Grapes and Berries				
Berries (bushes)	0.30	1.05	0.50	1.5
Grapes – Table or Raisin	0.30	0.85	0.45	2
– Wine	0.30	0.70	0.45	1.5-2
Hops	0.3	1.05	0.85	5

continued...

13 This $K_{c\ mid}$ coefficient for hay crops is an overall average $K_{c\ mid}$ coefficient that averages K_c for both before and following cuttings. It is applied to the period following the first development period until the beginning of the last late season period of the growing season.

14 These K_c coefficients for hay crops represent immediately following cutting; at full cover; and immediately before cutting, respectively. The growing season is described as a series of individual cutting periods (Figure 35).

15 Cool season grass varieties include dense stands of bluegrass, ryegrass, and fescue. Warm season varieties include bermuda grass and St. Augustine grass. The 0.95 values for cool season grass represent a 0.06 to 0.08 m mowing height under general turf conditions. Where careful water management is practiced and rapid growth is not required, K_c's for turf can be reduced by 0.10.

16 The pineapple plant has very low transpiration because it closes its stomates during the day and opens them during the night. Therefore, the majority of ET_c from pineapple is evaporation from the soil. The $K_{c\ mid} < K_{c\ ini}$ since $K_{c\ mid}$ occurs during full ground cover so that soil evaporation is less. Values given assume that 50% of the ground surface is covered by black plastic mulch and that irrigation is by sprinkler. For drip irrigation beneath the plastic mulch, K_c's given can be reduced by 0.10.

17 Includes the water requirements of the shade trees.

Table 12 continued

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
n. Fruit Trees				
Almonds, no ground cover	0.40	0.90	0.65[18]	5
Apples, Cherries, Pears[19]				
- no ground cover, killing frost	0.45	0.95	0.70[18]	4
- no ground cover, no frosts	0.60	0.95	0.75[18]	4
- active ground cover, killing frost	0.50	1.20	0.95[18]	4
- active ground cover, no frosts	0.80	1.20	0.85[18]	4
Apricots, Peaches, Stone Fruit[19, 20]				
- no ground cover, killing frost	0.45	0.90	0.65[18]	3
- no ground cover, no frosts	0.55	0.90	0.65[18]	3
- active ground cover, killing frost	0.50	1.15	0.90[18]	3
- active ground cover, no frosts	0.80	1.15	0.85[18]	3
Avocado, no ground cover	0.60	0.85	0.75	3
Citrus, no ground cover[21]				
- 70% canopy	0.70	0.65	0.70	4
- 50% canopy	0.65	0.60	0.65	3
- 20% canopy	0.50	0.45	0.55	2
Citrus, with active ground cover or weeds[22]				
- 70% canopy	0.75	0.70	0.75	4
- 50% canopy	0.80	0.80	0.80	3
- 20% canopy	0.85	0.85	0.85	2
Conifer Trees[23]	1.00	1.00	1.00	10
Kiwi	0.40	1.05	1.05	3
Olives (40 to 60% ground coverage by canopy)[24]	0.65	0.70	0.70	3-5
Pistachios, no ground cover	0.40	1.10	0.45	3-5
Walnut Orchard[19]	0.50	1.10	0.65[18]	4-5

continued...

18 These $K_{c\ end}$ values represent K_c prior to leaf drop. After leaf drop, $K_{c\ end} \approx 0.20$ for bare, dry soil or dead ground cover and $K_{c\ end} \approx 0.50$ to 0.80 for actively growing ground cover (consult Chapter 11).

19 Refer to Eq. 94, 97 or 98 and footnotes 21 and 22 for estimating K_c for immature stands.

20 Stone fruit category applies to peaches, apricots, pears, plums and pecans.

21 These K_c values can be calculated from Eq. 98 for $K_{c\ min} = 0.15$ and $K_{c\ full} = 0.75, 0.70$ and 0.75 for the initial, mid season and end of season periods, and $f_{c\ eff} = f_c$ where f_c = fraction of ground covered by tree canopy (e.g., the sun is presumed to be directly overhead). The values listed correspond with those in Doorenbos and Pruitt (1977) and with more recent measurements. The midseason value is lower than initial and ending values due to the effects of stomatal closure during periods of peak ET. For humid and subhumid climates where there is less stomatal control by citrus, values for $K_{c\ ini}$, $K_{c\ mid}$, and $K_{c\ end}$ can be increased by 0.1 - 0.2, following Rogers et al. (1983).

22 These K_c values can be calculated as $K_c = f_c\ K_{c\ ngc} + (1 - f_c)\ K_{c\ cover}$ where $K_{c\ ngc}$ is the K_c of citrus with no active ground cover (calculated as in footnote 21), $K_{c\ cover}$ is the K_c for the active ground cover (0.95), and f_c is defined in footnote 21. The values listed correspond with those in Doorenbos and Pruitt (1977) and with more recent measurements. Alternatively, K_c for citrus with active ground cover can be estimated directly from Eq. 98 by setting $K_{c\ min} = K_{c\ cover}$. For humid and subhumid climates where there is less stomatal control by citrus, values for $K_{c\ ini}$, $K_{c\ mid}$, and $K_{c\ end}$ can be increased by 0.1 - 0.2, following Rogers et al. (1983).

For non-active or only moderately active ground cover (active indicates green and growing ground cover with LAI > about 2 to 3), K_c should be weighted between K_c for no ground cover and K_c for active ground cover, with the weighting based on the "greenness" and approximate leaf area of the ground cover.

23 Confers exhibit substantial stomatal control due to reduced aerodynamic resistance. The K_c can easily reduce below the values presented, which represent well-watered conditions for large forests.

Table 12 continued

Crop	$K_{c\ ini}$[1]	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)
o. Wetlands – temperate climate				
Cattails, Bulrushes, killing frost	0.30	1.20	0.30	2
Cattails, Bulrushes, no frost	0.60	1.20	0.60	2
Short Veg., no frost	1.05	1.10	1.10	0.3
Reed Swamp, standing water	1.00	1.20	1.00	1-3
Reed Swamp, moist soil	0.90	1.20	0.70	1-3
p. Special				
Open Water, < 2 m depth or in subhumid climates or tropics		1.05	1.05	
Open Water, > 5 m depth, clear of turbidity, temperate climate		0.65[25]	1.25[25]	

[24] These coefficients represent about 40 to 60% ground cover. Refer to Eq. 98 and footnotes 21 and 22 for estimating K_c for immature stands. In Spain, Pastor and Orgaz (1994) have found the following monthly K_c's for olive orchards having 60% ground cover: 0.50, 0.50, 0.65, 0.60, 0.55, 0.50, 0.45, 0.45, 0.55, 0.60, 0.65, 0.50 for months January through December. These coefficients can be invoked by using $K_{c\ ini}$ = 0.65, $K_{c\ mid}$ = 0.45, and $K_{c\ end}$ = 0.65, with stage lengths = 30, 90, 60 and 90 days, respectively for initial, development, midseason and late season periods, and using K_c during the winter ("off season") in December to February = 0.50.

[25] These K_c's are for deep water in temperate latitudes where large temperature changes in the water body occur during the year, and initial and peak period evaporation is low as radiation energy is absorbed into the deep water body. During fall and winter periods ($K_{c\ end}$), heat is released from the water body that increases the evaporation above that for grass. Therefore, $K_{c\ mid}$ corresponds to the period when the water body is gaining thermal energy and $K_{c\ end}$ when releasing thermal energy. These K_c's should be used with caution.

Primary sources: **$K_{c\ ini}$: Doorenbos and Kassam (1979)**
$K_{c\ mid}$ and $K_{c\ end}$: Doorenbos and Pruitt (1977); Pruitt (1986); Wright (1981, 1982), Snyder et al., (1989)

COMMUNITY-BASED SMALLHOLDER IRRIGATION

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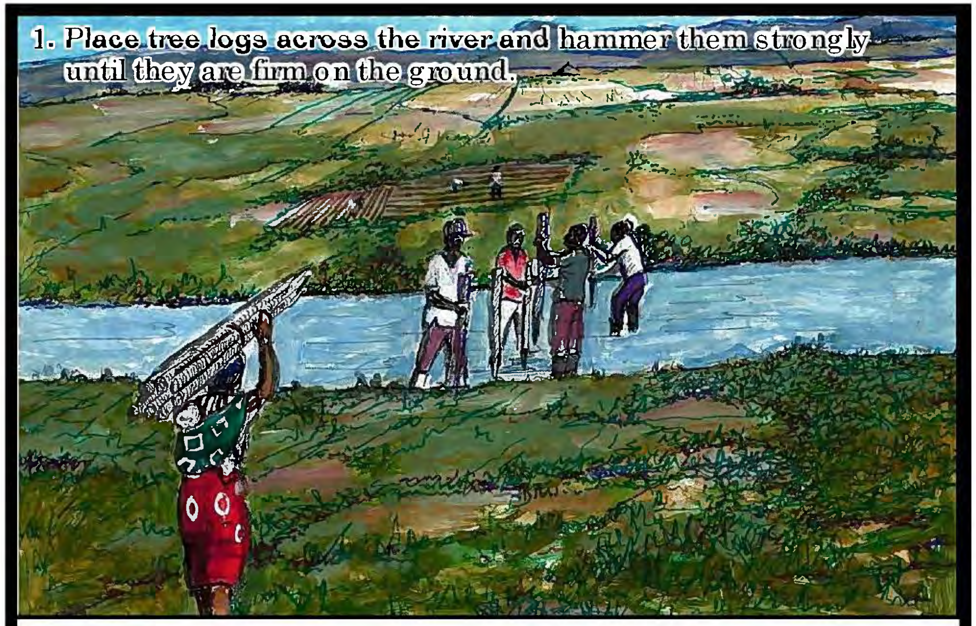
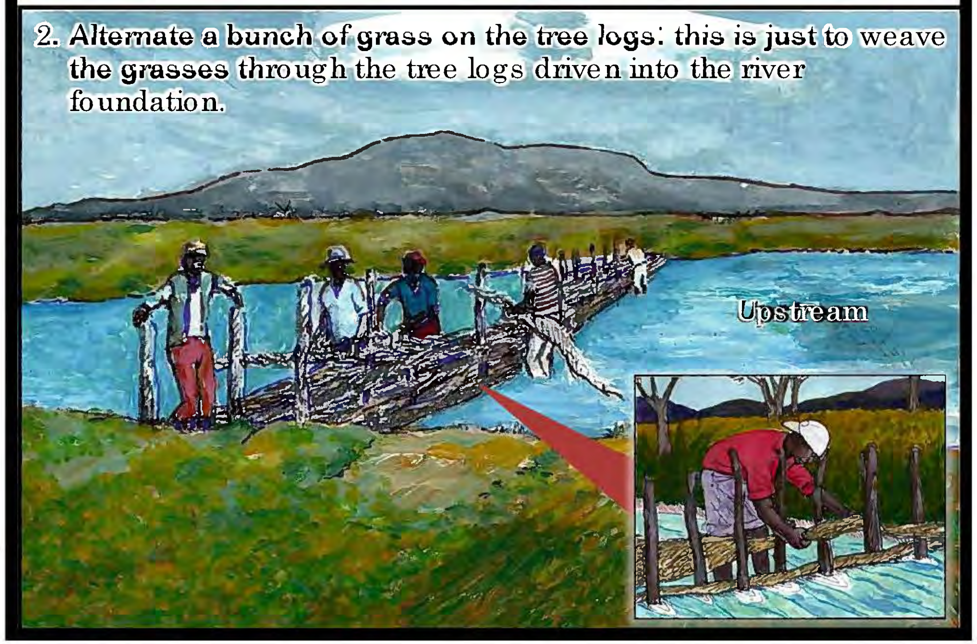
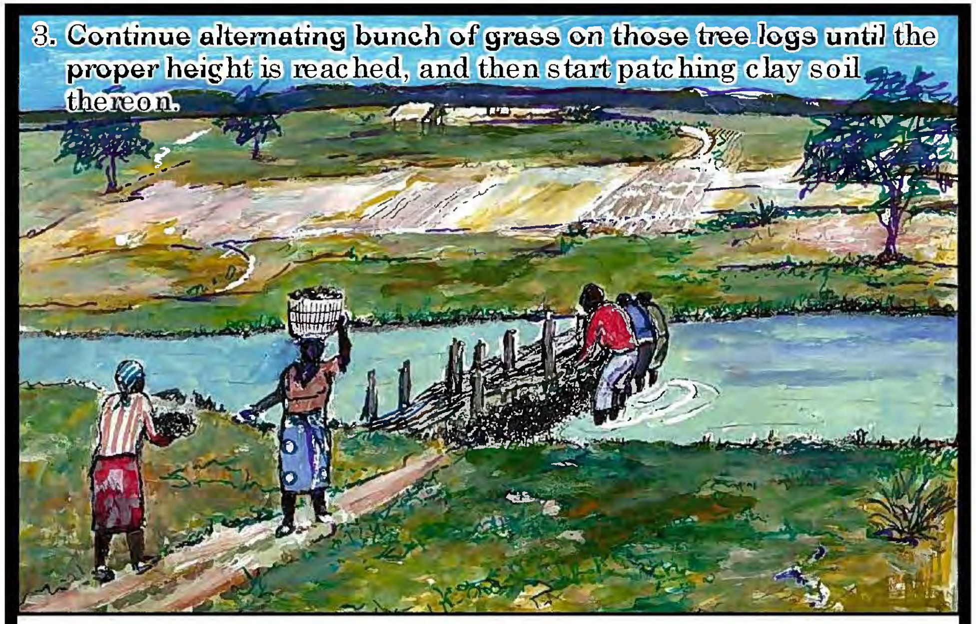
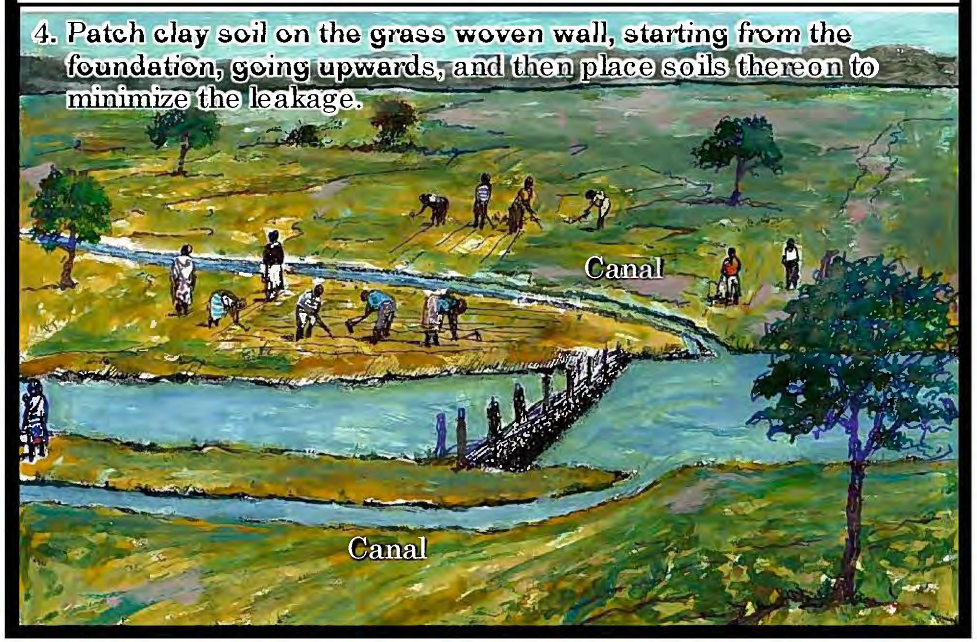
Single-Line Type Where Stream is Wide & Shallow

AP-I-D-1





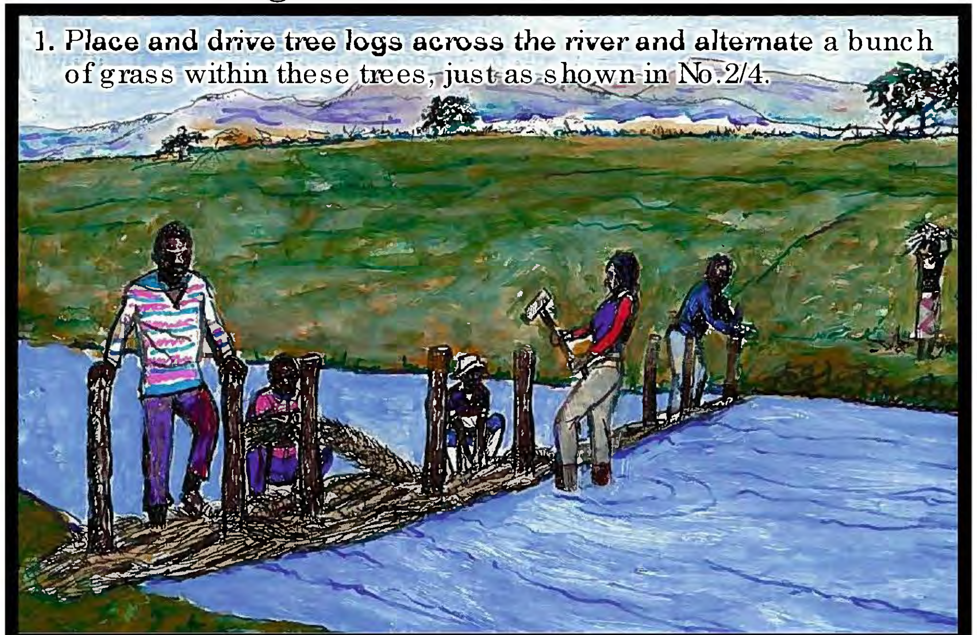




COMMUNITY-BASED SMALLHOLDER IRRIGATION

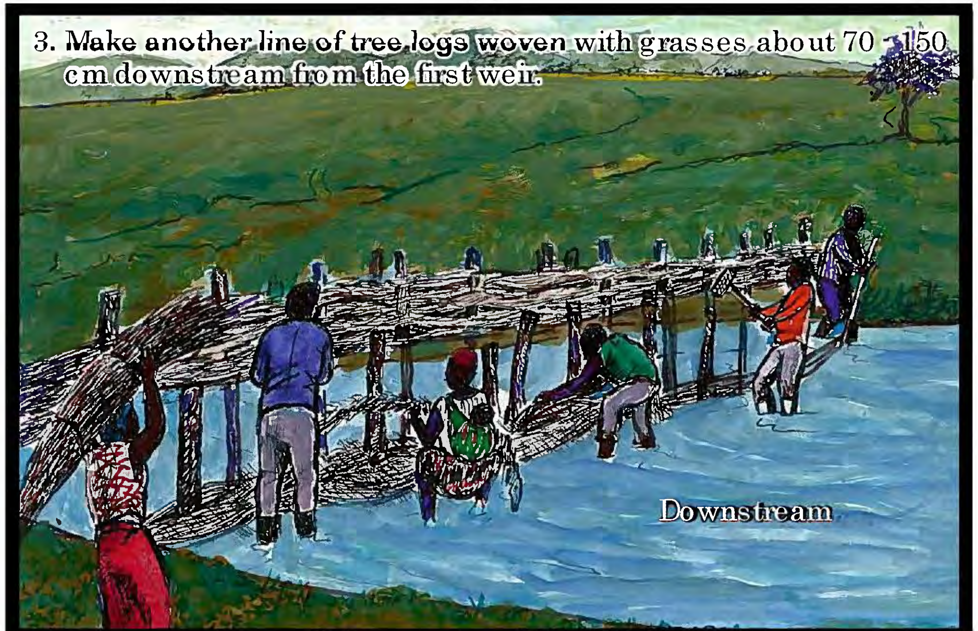
Promote Irrigation as a Part of Our Culture!!!

Double-Line Type to Minimize Leakage

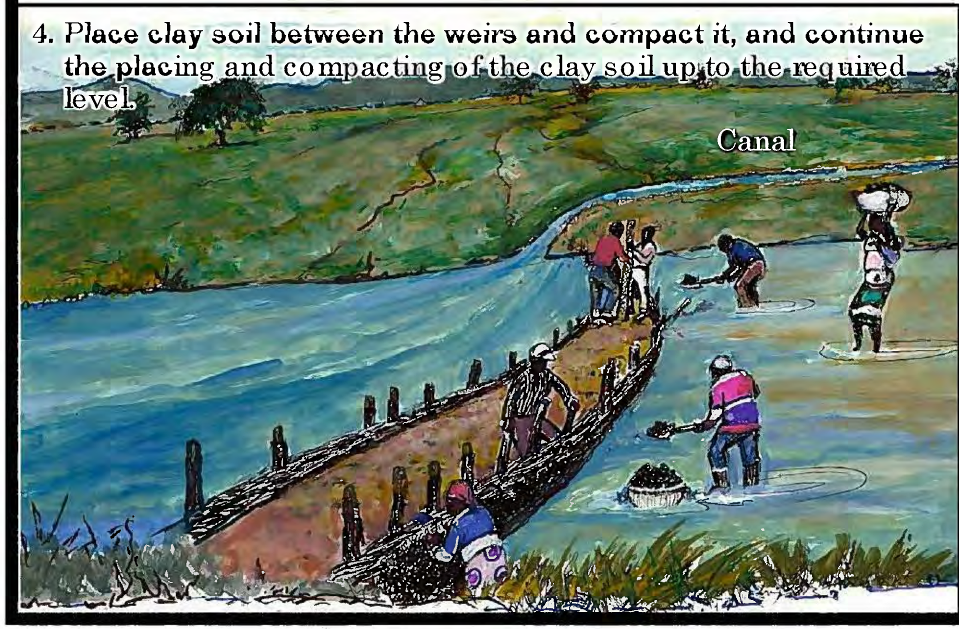


1. Place and drive tree logs across the river and alternate a bunch of grass within these trees, just as shown in No.2/4.

2. After completing putting grass alternately, put clay soil starting from foundation up to the top, and then ordinary soil on top of the clay and compact it just same as No.2/4.



3. Make another line of tree logs woven with grasses about 70 - 150 cm downstream from the first weir.



4. Place clay soil between the weirs and compact it, and continue the placing and compacting of the clay soil up to the required level.

AP-I-D-2

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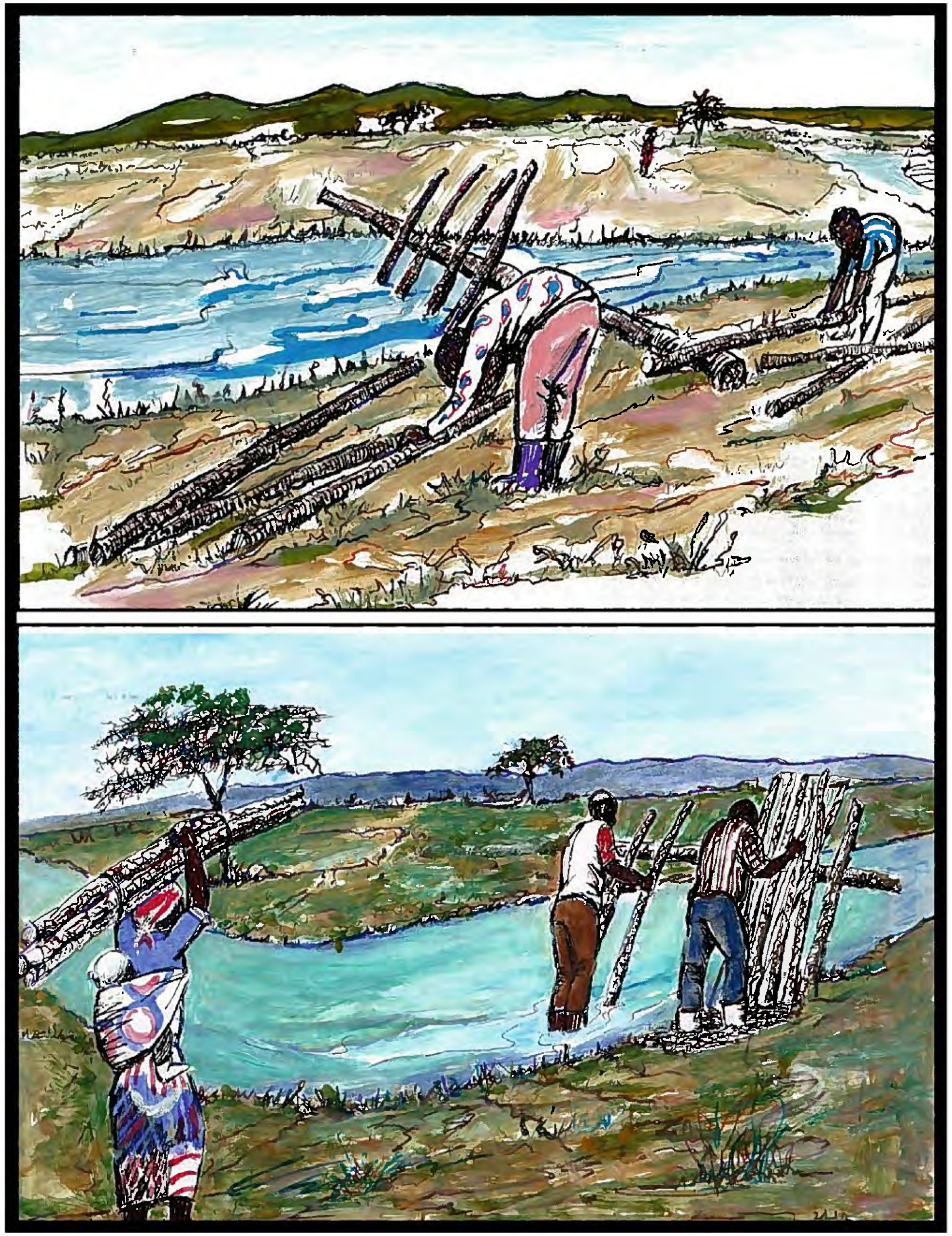
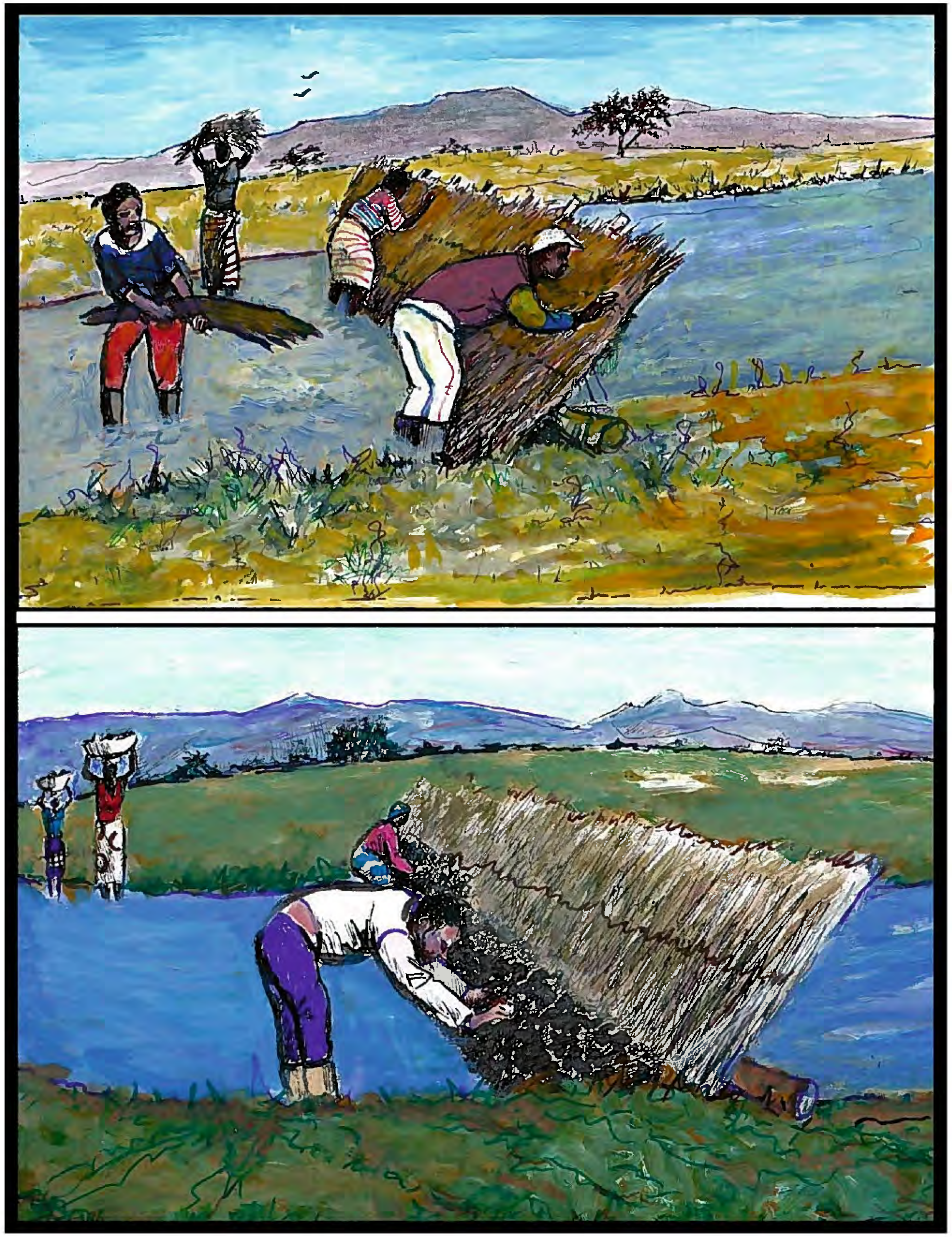


Inclined Type where Stream is Narrow & Deep



COMMUNITY-BASED SMALLHOLDER IRRIGATION

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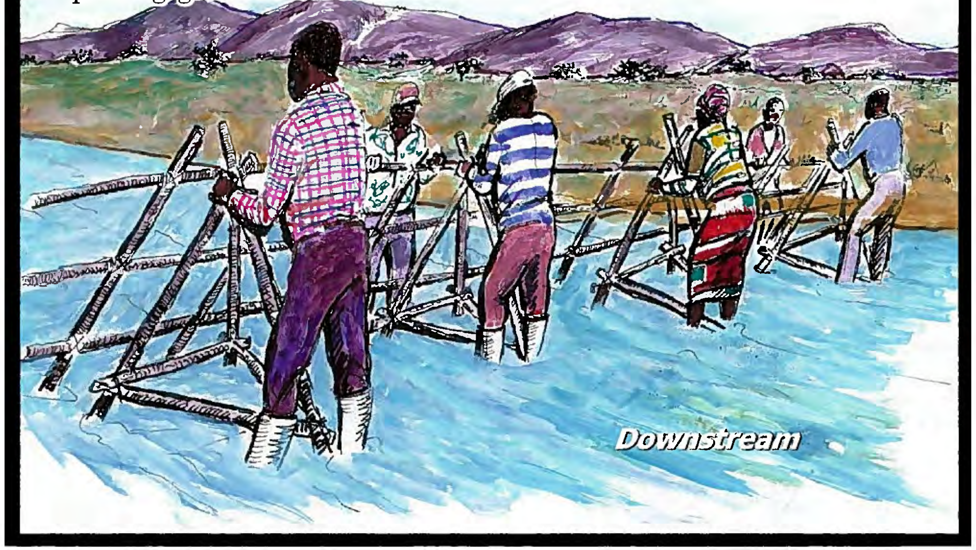
Trigonal Type on Rocky Foundation

1. Cut tree or bamboo logs to a required size, depending on the height, which we want to tap water. Then construct number of trigonal stand structures depending on the width of the river.

2. Place these trigonal stands across the river, and connect them by using horizontal members and tying them firmly. Then start putting grasses on the horizontal members.



3. Continue putting the grass on top of the horizontal members and put another layer of horizontal members again to tie them in position.

4. Place clay soil on top of the grass firmly starting from the bottom up to the required level.

AP-I-D-4