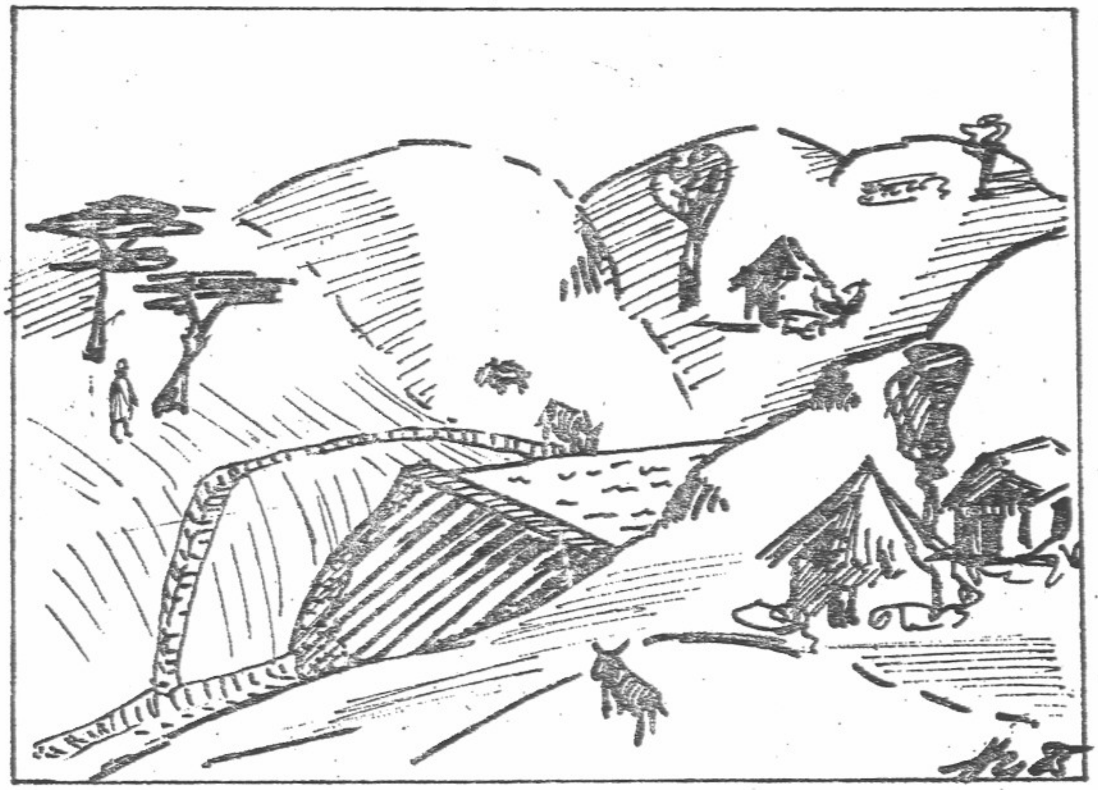
THE DESIGN AND CONSTRUCTION
OF SMALL-SCALE
EARTH MICRODAMS



A Field Manual for Assistant Technicians
Working Under the Supervision of
Agricultural or Irrigation Engineers

By
Hans Hurni PhD

Soil Conservation Research Project
Community Forests and Soil Conservation
Development Department

Ministry of Agriculture

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Summary

Small-scale earth microdams are essential components for rural development especially in drought-prone areas. They can provide water for cattle, for irrigation of gardens, fields and nurseries, and they contribute to the improvement of springs below the dam sites.

This Manual is intended to guide assistant technicians for planning and constructing this smallest type of earth dams, for situations where only rare supervision by engineers is possible. In a step-by-step approach the main specifications of such dams are given and the planning procedure explained in detail.

The Manual is based on the assumption that potential sites have been pre-selected using common sense. Procedures for calculating total catchment area, runoff amounts per season, water storage requirements, and dam specifications are given in Part I of the Manual. A line level consisting of two poles, one string and a small water level is the only surveying instrument needed for planning, apart from the meter band used for measuring distances.

Approval by a supervising engineer of the designed dam has to be received before construction can start.

The basic steps for constructing small-scale earth microdams are described in Part II of the Manual, covering issues of work organization, materials needed, appropriate organization of people, and usual work norms for payment. Excavation works such as for the core area and the spillway are described, as well as fillings and construction works for the main dam elements.

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Part I

The Design of Small-Scale Earth Microdams

1. Definitions

Small-scale earth microdams are the smallest group of the earth microdams. They have water storage capacities between 2,500 m3 and 15,000 m3, and a maximum dam height of less than 15 metres. The stored water may be used:

- For watering of cattle;
- For irrigating gardens, fields, and nurseries;
- For improving natural springs below the dam as a means to provide drinking water for the human population.
- In the close future, fishing.

Earth microdams are microdams constructed entirely from earth, usually clay soil collected around the dam site, with some stones to be used for specific elements of the dams.

The small-scale earth microdams described in this manual are microdams designed for family units. Their capacities being between 2,500 m3 and 15,000 m3, they will be irrigating a small area of 0.25 to 1.5 hectares only.

The water collected by the small-scale earth microdams is composed of surface runoff water of the watershed behind the dam, additionally supplemented by eventual spring water in the watershed.

2. Basic Knowledge for the Design of Small-Scale Earth Microdams

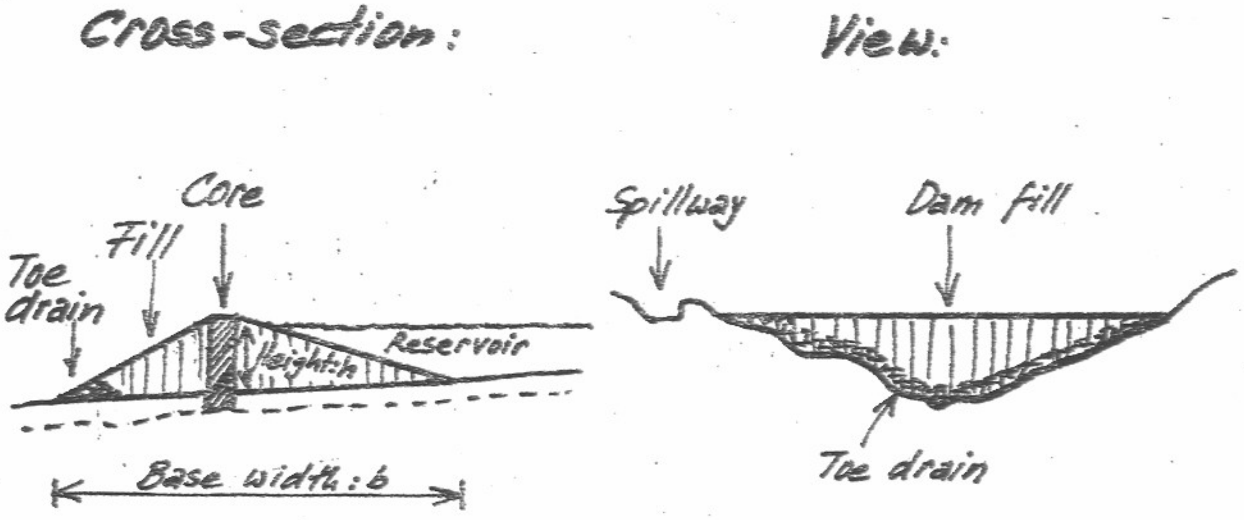
2.1. Watershed Size

When a potential dam-site is selected, it is necessary to know the size of the watershed behind the dam, because the runoff should be sufficient to fill the dam storage for a given rainfall amount, but not too much to fill it too quickly with sediments.

2.2. The Earth Microdam

According to Figure 1 the earth microdam consists of

- A core built up with pure clay soil,
- A toe drain enabling the water to drain off the dam without taking too much dam fill material,
- A fill of the main body consisting of earth,
- A spillway at the side of the dam enabling overflow water to drain safely over the slope besides the microdam.


Cross-section:

View:

Figure 1: Cross-section and front view of a typical small-scale earth microdam showing its elements.

The slope of the microdam towards the water is made with a steepness ratio of 1:3, and the slope towards the outer side with a ratio of 1:2.

The total height of the microdam is dependent on the topographical situation of the reservoir area and the volume of the water to be stored. It is measured from the deepest point in the center of the dam, and should be 1 m higher than the maximum water level of the reservoir. Thus, the freeboard of the dam is 1 m.

The volume of the dam fill is dependent on the topographical situation of the dam area and the dam height. The topography is described by slope gradients measured from the deepest point of the dam fill at the center of the core excavation (of Fig. 7, page 17).

The base width of the dam is measured at the deepest point along the river, from the edge of the toe drain to the edge of the slope towards the reservoir.

2.3. The Slope Gradients

A longitudinal slope gradient (A, in percent) is measured upstream along the river, beginning at the dam site and ending at about the rim of the storage water surface (cf Figure 2 and 3). The gradient A is recommended not to be more than 14 %.

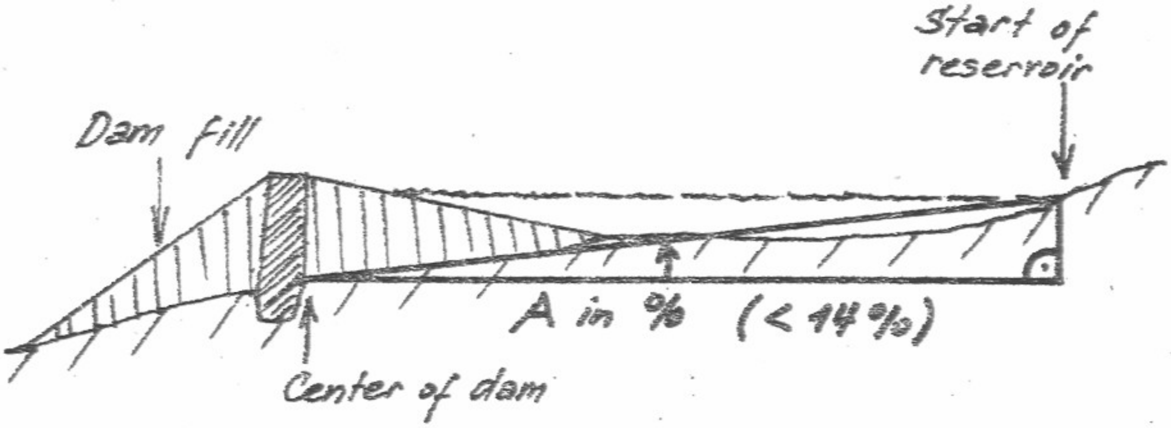


Figure 2: Longitudinal gradient, A, of reservoir area along river.

A cross-sectional slope gradient (B, in percent) is measured from the bottom of the valley towards the hillside. The survey of slope has to be repeated several times over a certain distance, say, 50 m along the stream. The survey starts at the damsite and ends near the water surface of the reservoir. The gradient B is calculated by taking the average of different measurements. The average gradient B is recommended not to be more than 27 %.

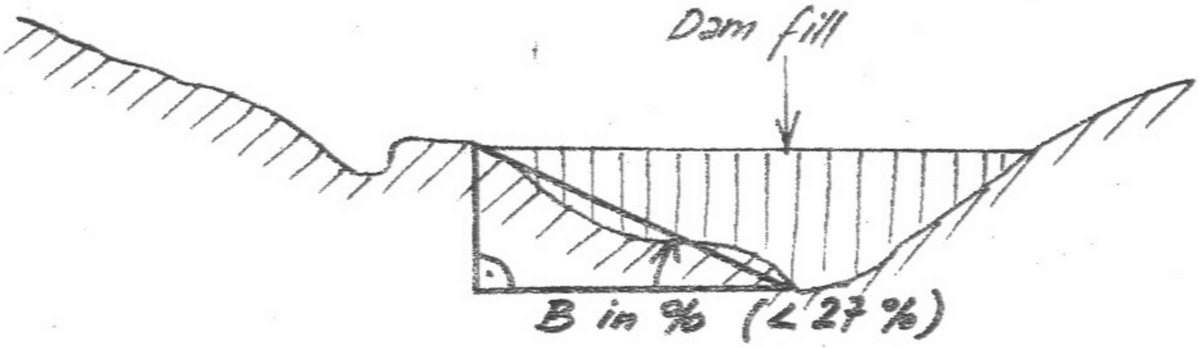


Figure 3: Cross-sectional gradient, B, of the dam fill area.

In Section 3.4. it is shown how to measure such slope gradients with line levels.

2.4. Construction Material

For the design of small-scale earth microdams the following materials are needed:

- A line level consisting of two poles, one string of 10 m length, and the small waterlevel to hang on the string;
- A meterband for watershed measurement;
- Poles or sticks of about 1 m length for marking the dam site;
- Forms as given in Appendix 1 of this Manual.

For the construction of small-scale earth microdams it is necessary to find:

- sufficient clay material for the core of the dam;
- sufficient soil material for the dam fill;
- stones and sand for the toe drain;
- necessary materials for digging and transporting clay, soil, sand and stones, such as pickaxes, shovels, digging irons, carring tools for soil.

3. Planning Procedure for Small-Scale Earth Microdams

Note:

All sections of this Chapter are summarized on a form (Appendix 1) to be filled by the assistant technician during the planning work, and approved by the responsible engineer before construction can start.

3.1. Site Pre-Selection

In cooperation with local peasant associations possible sites should be selected according to the following criteria:

- The total watershed behind the dam site should not be bigger than about 2.5 to 50 hectares, one hectare being 10,000 m2;
- The area where the dam is placed should not be too steep nor too flat, so that the volume of dam fill will be feasible for construction (not too high nor too wide);

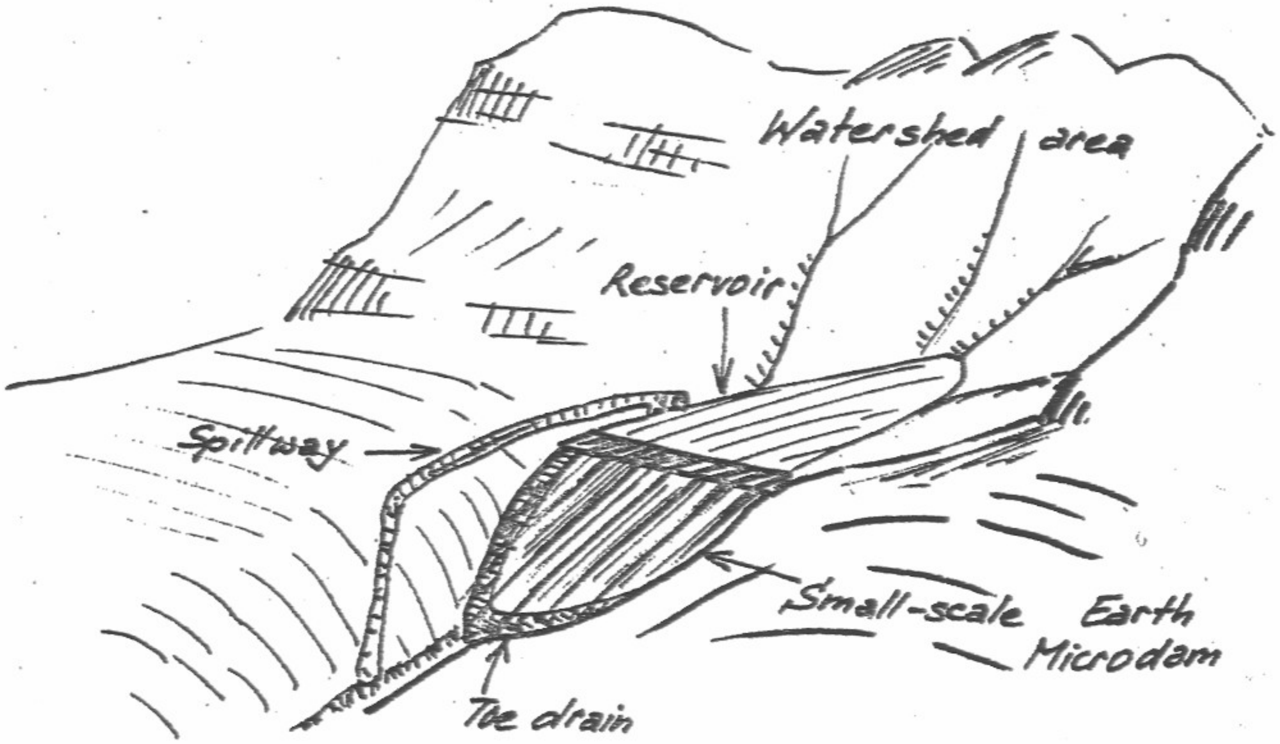


Figure 4: Typical position of a dam site in a mountain watershed area.

- Below the dam site, there should be some area which can be irrigated at a later stage;
- The dam should not be placed in an area where there is a very deep accumulation of soil below the dam fill (more than 4 m of soil will not be recommendable); ?
- The earth dam should not be constructed on rock outcrops, but only where at least 50 cm of soil is covering such rocks.

A possible situation for dam construction is given in Figure 4.

It is advisable to select 2-3 possible sites for dam construction, and to design dams for all, and finally to select the best possibility of them.

3.2. Watershed Measurement

It is supposed that a watershed has an elliptic shape, as shown in Figure 5. In order to obtain the watershed size in m2, the following measurements have to be carried out:

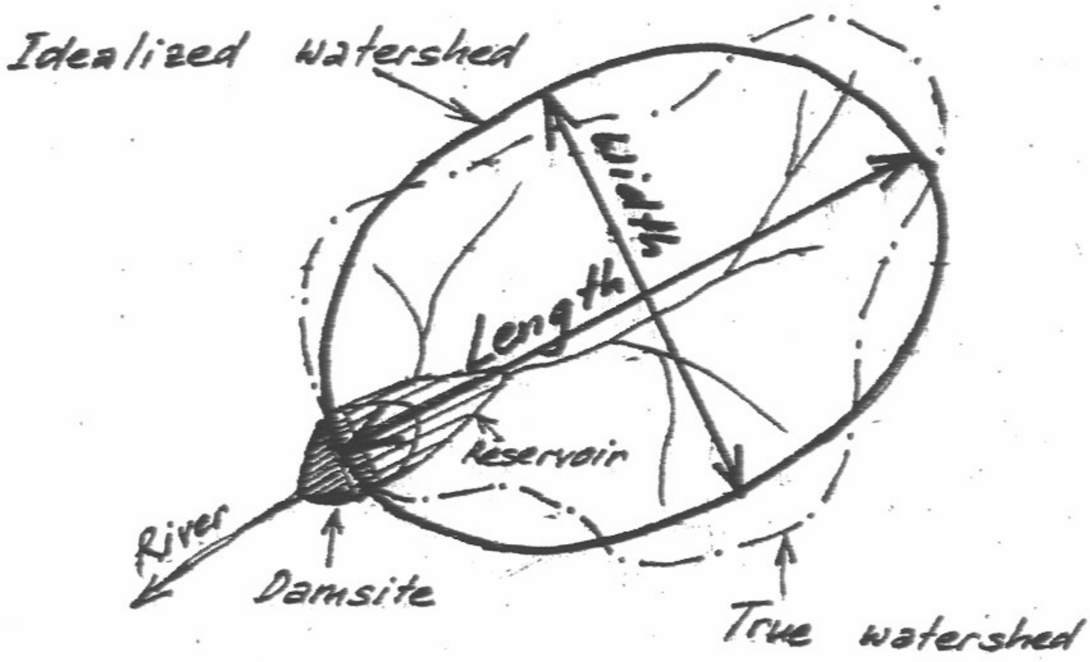


Figure 5: Watershed area idealized to an elliptic shape, with main distances to be measured in the field for area calculation.

- Total length (in metres) of the river from the possible dam site to the highest point of the watershed;
- Widest part (in metres) across the river, from one border of the watershed to the other border.

The watershed is then calculated with the formula:

$$C = \frac{(\text{Length})(\text{Width})(3.14)}{4} \quad [\text{m2}]$$

Example: A watershed area of 300 m length and 200 m width will have an approximate size of:

$$C = \frac{300 \times 200 \times 3.14}{4} = 47{,}100 \text{ m2}$$

3.3. Water Storage Requirement

It is assumed that within a small rainy season, the dam should fill up with the runoff, and have as little overflow as possible. For different climatic zones, different runoff rates and rainfall amounts will result in different total runoff from a given watershed:

Dry areas: maximum
300 mm rainfall x 10 % runoff rate = 0.03 m runoff/season

Moist areas: 10
400 mm rainfall x 15 % runoff rate = 0.06 m runoff/season

Wet areas: 15
500 mm rainfall x 20 % runoff rate = 0.10 m runoff/season

The water storage requirement S of the microdam can then be calculated with the formula:

S in m3 = (Watershed area in m2)(Runoff/season in m)

Summary: Runoff per Season:

Dry climate	0.03 m
Moist climate:	0.06 m
Wet climate:	0.10 m

Example:

A watershed area of 300m length and 200m width will have about 47,100 m2 size, and in a moist area result in a water storage requirement for the planned microdam of 47,100 m2 x 0.06 m runoff/season = 2,826 m3 water/season. Therefore, the water storage requirement for a dam will be:

S = 2,826 m3

Depending on the runoff rate per season, the possible watershed sizes for storage capacities, S, between 2,500 m3 and 15,000 m3 will vary for the different climates:

In a dry area, the watershed for a small-scale microdam may have a size between about 80,000 and 500,000 m2 (8-50 hectares), ie. be about 350 to 1000 metres long and 300 to 600 m wide.

In a moist area, the watershed for a small-scale microdam may have a size between about 40,000 and 250,000 m2 (4-25 hectares), ie. be about 300 to 600 metres long and 250 to 500 metres wide.

In a wet area, the watershed for a small-scale microdam may have a size between about 25,000 and 150,000 m2 (2.5-15 hectares), ie. be about 250 to 500 metres long and 100 to 400 metres wide.

3.4. Slope Gradients

The longitudinal gradient, A, can be measured with the line level according to the following procedure (cf Figure 6):

1. The 10 m line is staked out along the stream, starting from the dam site. Every 10 m, the string is levelled out, and the difference on the poles measured in metres, ie. 0.5 m

2. This procedure is continued until the total of all differences of each measurement is giving about 10 m vertical interval. Simultaneously, the lengths of the distances are added together.

3. The gradient A is calculated by dividing the total vertical interval of about 10 m, with the total length needed to attain such vertical interval, multiplied with 100.

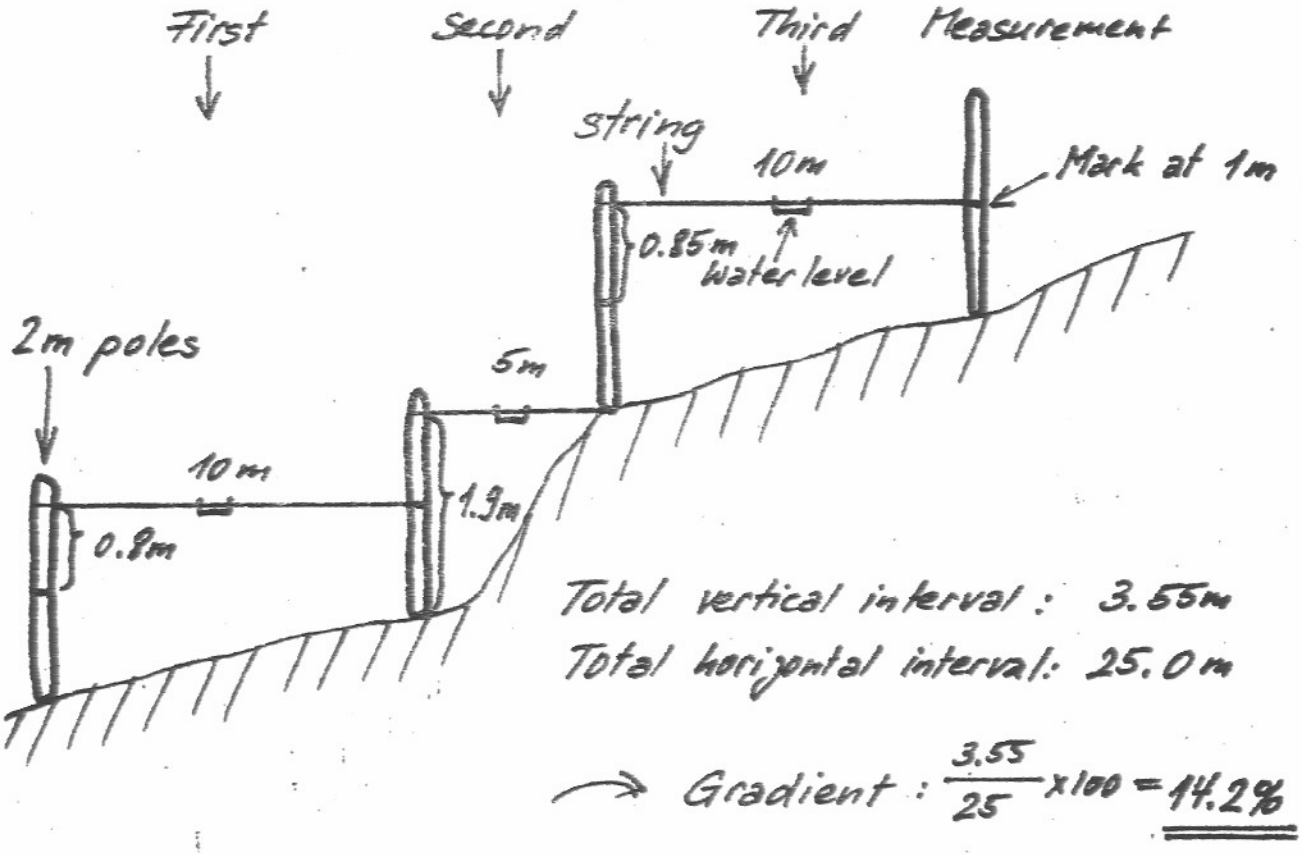


Figure 6: Vertical and horizontal intervals determined by line-levelling for the calculation of average slope gradients.

$$A = \frac{\text{Total vertical interval, in m}}{\text{Total length along river, in m}} \times 100 \text{ (\% longitudinal slope)}$$

If A is steeper than 14 %, the site is not suitable for dam construction, and a new site must be selected.

Example:

The 7 individual measurements of each 10m interval result in the following vertical intervals:

1.5m, 0.8m, 1.3m, 1.4m, 0.9m, 1.8m, 1.9m

The total vertical interval is then 9.6m on a total distance of 7 x 10m = 70m

The longitudinal gradient A is then:

$$A = \frac{9.6\text{m}}{70.0\text{m}} \times 100 = 13.7\ \%$$

The cross-sectional gradient, B, can be measured from the stream towards the borders of the watershed, following the same procedure as for A, with the exception that sometimes one may have to shorten the string of the line level to 5 m due to too steep slopes of the valley (cf Figure 6, p. 14).

If B is steeper than 27 %, the site is not suitable for dam construction, and a new site must be selected.

Example:

Horizontal distance used for measurement	5m	5m	10m	5m	5m	10m	5m	10m
Vertical Interval	1.5m	1.8m	1.4m	1.3m	1.1m	1.2m	1.3m	1.2m

Total distance: 55m
Total vertical interval: 10.8m

The cross-sectional gradient B will then be:

$$B = \frac{10.8\text{m}}{55.0\text{m}} \times 100 = 19.6\ \%$$

Both longitudinal and cross-sectional gradients A and B of the dam site are used together with the required water storage capacity, S, in the next sections to calculate the required dam height, the volume of the dam fill, and the base width of the dam fill.

3.5. Height of Dam Fill

The height of the dam, h, is calculated with three variables:

- Required water storage capacity of dam, S (m3)
- Longitudinal gradient, A (%)
- Cross-sectional gradient, B (%)

The formula is as follows:

$$h = \sqrt[3]{\frac{6\ S\ A\ B}{20,000}} + 1 \quad [\text{m}]$$

In Appendix 2, dam heights are given as a function of gradients A and B for 6 different water storage capacities in 6 Tables.

3.6. Volume of Dam Fill

The volume of the dam fill, V, is calulated with the same variables as the height of the dam.

The formula is as follows:

$$V = \frac{500\,h^{3} + 900\,h^{2}}{3\,B} \quad [m^{3}]$$

The volume of dam will not be used for the construction work itself, but it serves as a basis for checking if the construction materials are sufficient, or if the work amount for dam construction was correct or not.

In Appendix 3, volumes of dam fill are given as a function of gradients A and B for six different water storage capacities in 6 Tables.

3.7. Base Width of the Dam Fill

The base width, b, of the dam fill is calculated with the following formula:

$$b = 5\,h + 3 \quad [m]$$

According to the riser slopes of the inner and outer side of the dam, the following distances have to be staked out for planning the dam on site (cf Figure 7):

From the center point of the dam, the dam height, h, has to be measured three times to design the inner width according to the inner riser slope ratio of 1:3.

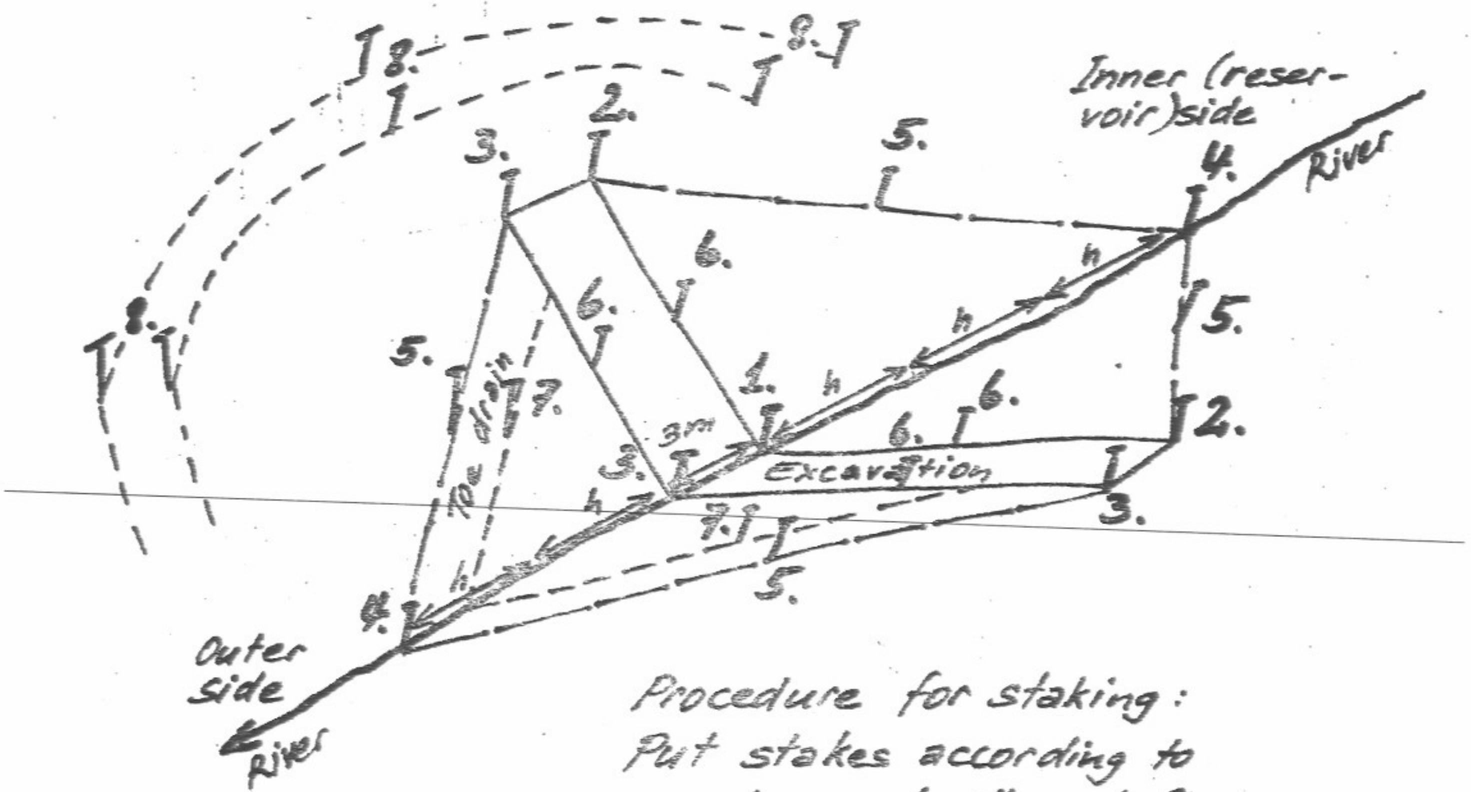
From the center point of the dam, the three metres top width have to be staked out for the core excavation.

From the end point of the three metres, the dam height, h, has to be staked out two times to design the outer width according to the outer riser slope ratio of 1:2.

3.8. Staking out of the Dam

After having obtained all variables necessary for the dam, namely the height, base width and volume of the dam, it is necessary to stake it out on the ground according to the following procedure (cf. Figure 7):

1. Select the place on the river where the center of the dam will be placed. Put a stake.
2. Use the line level and the required dam height, h, as vertical interval to mark the uppermost point of dam both sides of the river bank, ie. 8.6m. Put stakes.
3. Mark a strip 3 m wide at each end of measurement parallel to the river (=top width of dam fill). Put stakes.



Procedure for staking:
Put stakes according to numbers 1. through 8.

Figure 7a: Steps for staking out a dam area on the ground.

4. Return to center of dam fill on river, and mark towards each side up- and downstream the base width of the dam fill:
   Towards the reservoir side, mark three times the dam height, h, and towards the lower (outer) side, mark two times the dam height, h, from the end point of the 3 metre strip. Put stakes.

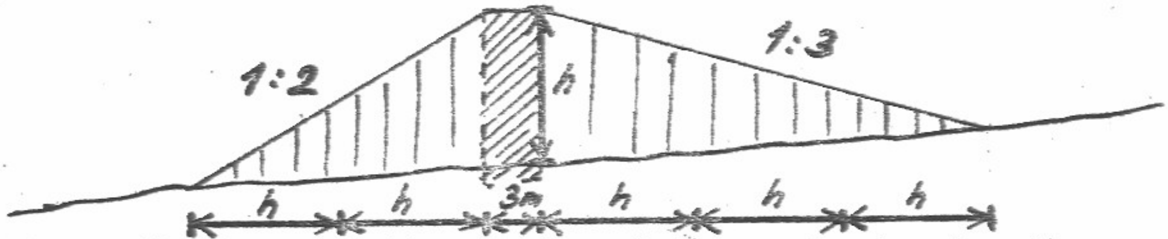


Figure 7b: Cross-sectional view of dam center to show the relation between height, h, and base width, b.

5. Draw direct lines between each of the stakes and delimit like this the area where the fill of the dam has to be placed. Put more stakes.

6. Also mark with a 3 m wide strip the area of excavation for the core of the dam, throughout the dam fill area from one top end to the other. Put stakes.

7. Mark an area 4 metres wide at the lower end of the dam for constructing the toe drain.

8. Select a suitable place on one of the sides of the dam, to be excavated one meter below the top height, as spillway for overflow of the dam.

3.9. Approval by Engineer

Before any start of work, the planned small-scale earth microdam has to be approved by the responsible agricultural or irrigation engineer in charge.

Such engineer has to be called to the site as soon as all staking is accomplished, and additional points like supply of clay, soil, sand and stones are clarified in the area.

Part II

The Construction of Small-Scale Earth Microdams

4. Organizational

4.1. Construction Materials

Digging tools are the most important instruments for excavation of earth, clay, sand, and stones.

Hand-barrows are needed for transportation of the materials from the excavation site to the dam fill site. Two persons may carry one barrow, which can be constructed from corrugated iron sheets, or with the help of sacks or other materials.

Finally, buckets have to be used for the transport of water needed to moisten the dam fill for better compaction.

For the supervision of the works, it is necessary to make available a set of 2.5m long sticks for delimitation of working areas on the dam for each group. Line-levels are also required for adjustment of the dam fill slopes.

4.2. Work Organization

Groups of 25-50 people are organized as single units for the dam construction. Each group obtains a specific area of activity, ie. to excavate a certain area of core, or to fill a certain area of dam, cf. Figure 9. The work norms for each group can then be measured in that specific area, and payments made to this group according to the work accomplished.

Group leaders are responsible for making current records of the activities of each member of the group. Every day, they have to record who was participating in the work, so that the total man-days can be summarized, and the total work accomplished recorded for monthly payments. Group leaders are provided with special forms for their records.

Assistant field technicians are responsible for the overall design and construction, they assign the groups to the working areas and measure the work accomplished by each group during a given period.

4.3. Work Norms

For excavation of the core area and the spillway, one third of a metrecube is considered one work day, ie. the amount that one man can dig in one day. Therefore, 1/3 m3 of excavation of core area corresponds to the payment of one daily food ratio. Per one metrecube of excavation 3 work days are accounted to the group.

For constructing the toe drain and for making the dam fill, no payment is made for the preparation and transport of the materials (sand, stones, soil). Payment is made for the dam fill only, where again 1/3 m3 is considered one work day and the daily food ratio given for such amount of dam fill. Per one metrecube of dam fill 3 work days are accounted to the group.

5. Excavations

5.1. The Core Area

Throughout the whole dam, a strip of 3m width has to be excavated down to the rock, in order to prevent seeping of water through possible sediment, cf Figure 1. This core area will later be filled with pure clay material for sealing.

Each working group is given a certain area for excavation, and the volume of their work accomplished is measured in m3 using width in metres, length in metres and average depth in metres and multiplying the three to get metrecubes of excavation.

5.2. The Spillway

The spillway will be constructed after dam completion, when the fill has been finished, but before the rainy season has started. may be you can use the excavation of the spillway to fill up the embankment [illegible]

The spillway will be 1 metre lower than the highest point of the dam fill. The line level can be used to make a level from this point to the border of the dam fill, where the digging will start and lowered one metre. The spillway has to be excavated from solid soil or even rock, so that no gullying can happen.

The spillway should never be made into dam fill area, because this may create a gully in very short time and could lead to the collapse of the dam within minutes of overflow. Spillways are always cut in firm rock or soil at the side of the dam.

Spillways have to be long enough that the water flow does not touch the dam fill, cf. Figures 4 and 7. Their size has to be designed in a way that the biggest runoff coming through the former river can be safely drained as outflow from the reservoir.

Local peasants can provide the information about the largest height of runoff ever seen in the original river. This cross-section of highest runoff has to be calculated in m2, and the spillway cross-section made bigger than this calculated area, taking into account that the flow height of water in the spillway should not be more than 0.5 m. Therefore, the cross-section of highest runoff, in m2, has to be divided by 0.5 in order to obtain the width of the spillway.

6. Fillings and Constructions

6.0 Summary of dam soils [illegible]

6.1. The Core Area

The core area is a section through the whole dam which consists of clay material to prevent seepage through the dam, cf. Figures 1 & 7. This section is started by filling the core excavation, then always filled up in the center with the growth of the dam fill.

Stakes are used across the whole dam to mark this core area. Groups are told to use the purest soil clay material for this core area, while the looser soil has to be used to make the dam fill outside the core area.

At the top of the dam, only such pure material will be used, because then the dam will not be wide any more.

6.2. The Toe Drain

At the downward part of the dam fill, a toe drain has to be made as shown in Figure 8. This drain consists of about 1.5m high stones, gravel, and sand, and will help to keep the dam material in place, when seepage has started through the dam.

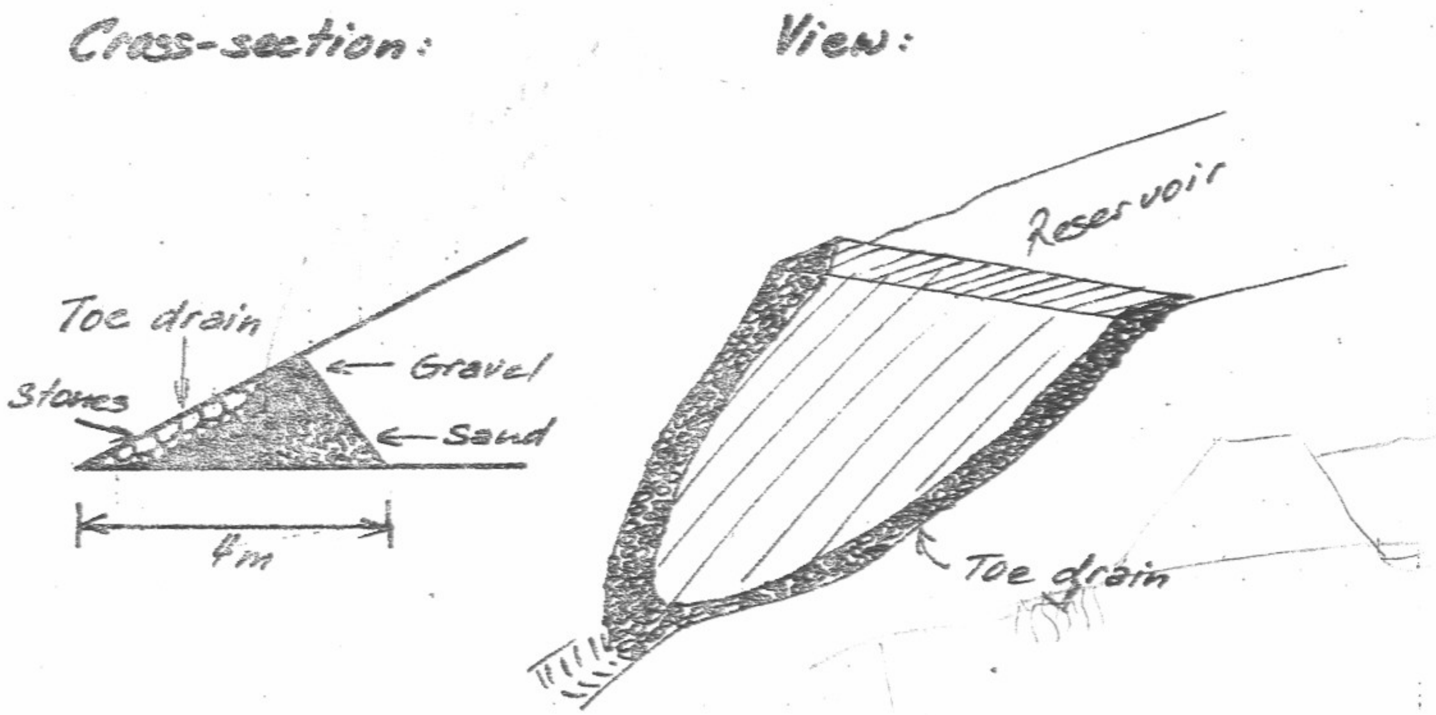


Figure 8: Toe drain cross-section and front areas

The toe drain will be constructed first, together with the core excavation and core fill, along the lines staked out as lower end of dam fill area (cf Figure 7).

The work performed by each group is measured in m3 of toe drain construction, and payments made accordingly.

6.3. The Dam Fill

The dam fill is the largest amount of work to be carried out. This is the area between the core fill and the toe drain, and between the core fill and the upper end of the dam toward the reservoir side. Most of the dam volume consists of this dam fill.

Materials to be used is soil material, preferably from the reservoir area, since this will increase the water storage capacity of the dam.

Each group will be assigned a strip of area over the dam which they will fill, water, and compact, and from which their work amount will be calculated accordingly using the work norms described.

Figure 9 shows how individual group work can be organized and their work amount measured with the help of poles entered into the dam. Group strips are usually about 2m wide and go all across the dam.

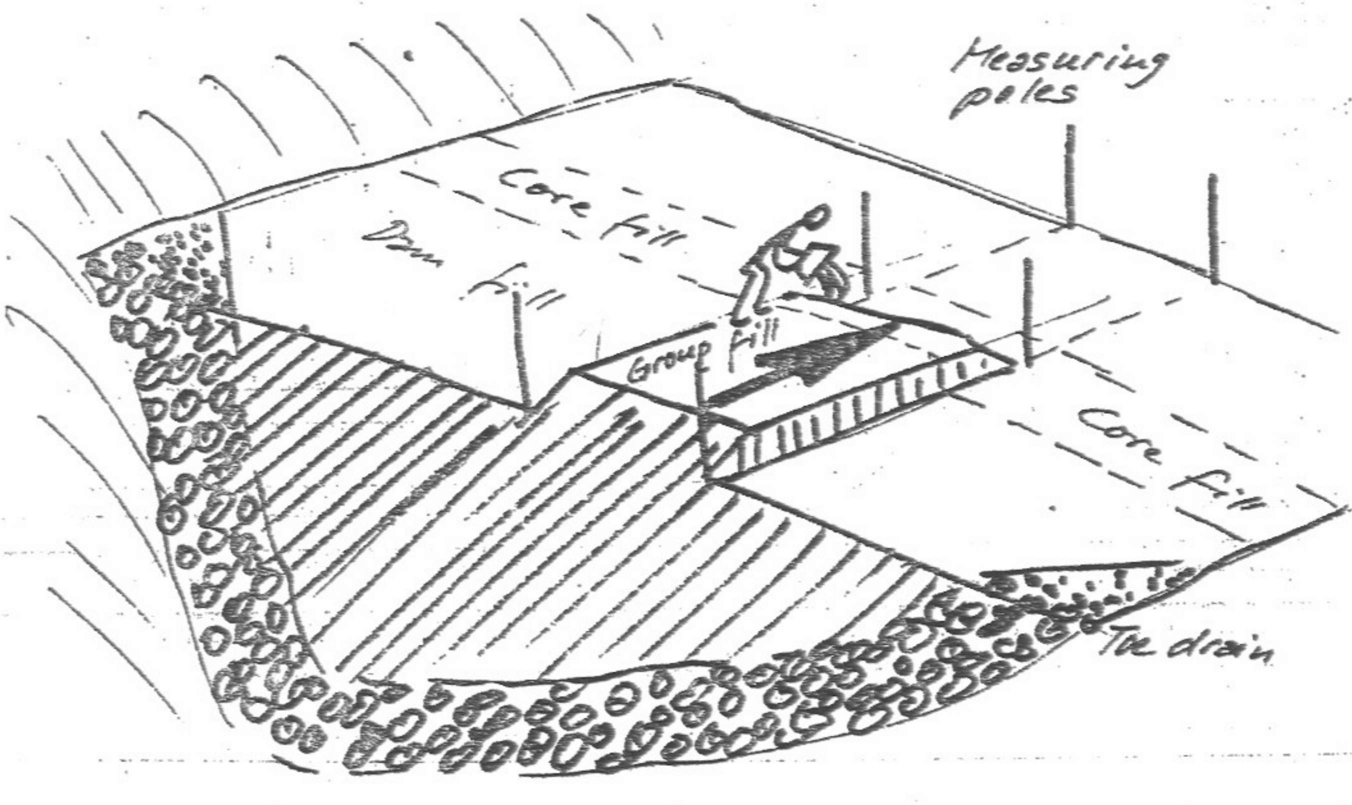


Figure 9a: Group organisation for dam fill

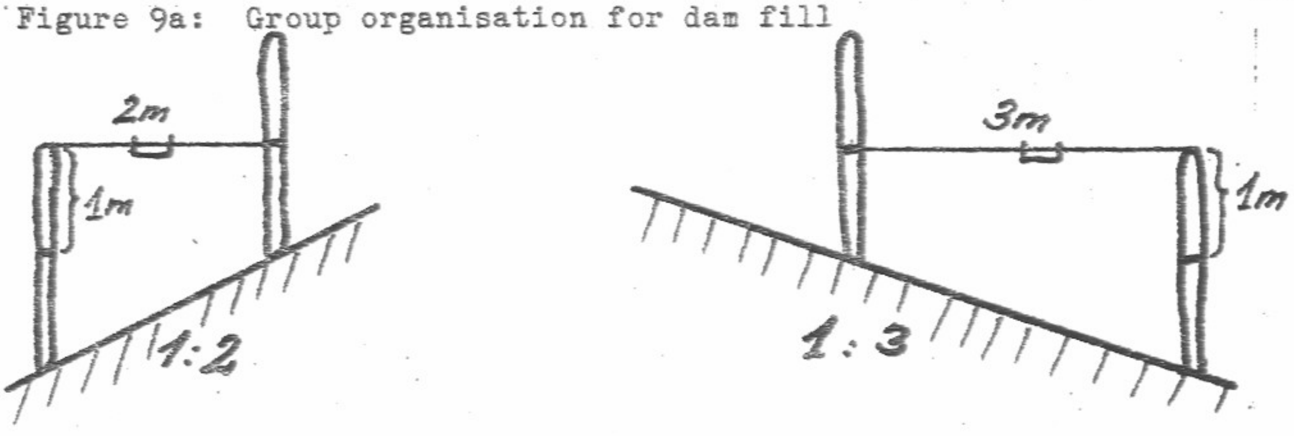


Figure 9b: Detailed sketch to show how riser slopes of 1:2 and 1:3 are measured with the line level.

The assistant technician has to control carefully that

(a) the soil types for core and fill are correct;
(b) the fill is well watered and compacted;
(c) the riser slopes on the inner and outer side of the dam are made according to the specifications given.

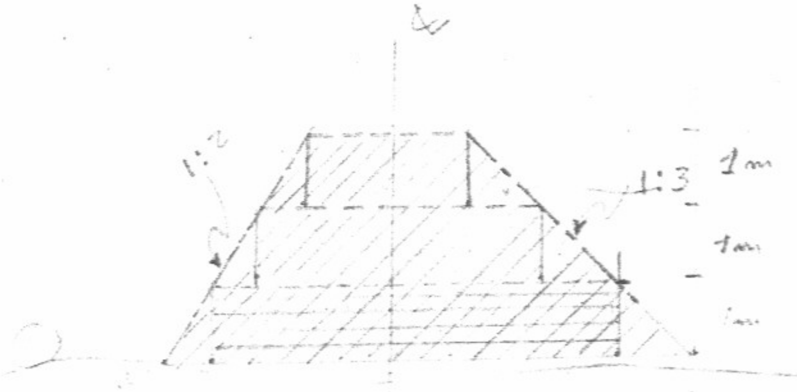
The inner slope of the dam needs a riser of 1:3, which can be controlled with the line level according to Figure 6, with the exception that the horizontal distance has to be 3m only and the vetrical interval 1m for a correct riser slope of 1:3. This riser is similar to 33 % gradient.

The outer slope of the dam needs a riser of 1:2, ie. will be steeper than the inner slope. Again, the line level can be used for supervision. The horizontal distance for the rope only has to be 2m here and the vertical difference 1m for a correct riser slope of 1:2. Such riser is similar to 50 % gradient.

At the end of every day, both slopes have to be checked, and the watering and compacting controlled carefully.

Compacting will be done using the people who walk over the fill, and water should be applied when the soil is too dry and when there is no rain.

For watering, 20% of the group will have to carry the water while the rest will carry soil material.



Appendix 1

Field Form for Planning a Small-Scale Earth Microdam

1. Select potential dam site

Name of place: ....
Name of small valley: ....
Name of Peasant Association : ....
Wereda:.................. Awraja: ....
Name of Assistant Technician: ....
Date: ....

2. Measure watershed length and maximum width:

Total length along river: .... metres (1)

Maximum width across river : .... metres (2)

Watershed Area: C = (1) x (2) m2

C = ... x ..... m2 = ... m2

3. Calculate water storage requirement:

3.1 Select rainfall regime/runoff expected:

a) Dry area : 0.03m/season = Q(dry)
b) Moist area: 0.06m/season = Q(moist)
c) Wet area : 0.10m/season = Q(wet)

3.2 Calculate total runoff for storage S:

S = C (see 2.) x Q (see 3.1.) = ... m2 x ...... m/season

S = ... m3/season

3.3 If S is smaller than 2'500m3: Select bigger catchment or, if possible, a site situated more down stream and start new form;

3.4 If S is bigger than 15'000m3: Select smaller catchment or, if possible, a site situated more upstream and start new form.

4. Calculate slope gradients of reservoir area:

4.1 Longitudinal gradient along river:
(see section 3.3 of Manual)

$$A = \frac{\text{Vertical interval in m}}{\text{Horizontal interval in m}} \times 100$$

A = ... %

4.2 Cross-sectional gradient across river:

$$B = \frac{\text{Vertical interval in m}}{\text{Horizontal interval in m}} \times 100$$

B = ... %

4.3 If A is bigger than 14%: Select gentler watershed and start new form

4.4 If B is bigger than 27%: Select gentler watershed and start new form

5. Height of Dam Fill

The height h of dam fill in the center of the dam can be calculated with the formula:

$$h = \sqrt[3]{\frac{6\ S\ A\ B}{20{,}000}} + 1 \quad [m]$$

Appendix 2 gives Tables 1-6 to calculate h for given values of S, A, and B. The nearest figures have to be selected.

Conversion for measured values into nearest values:

S = ...m3: nearest value in Tables 1-6: S=..........m3
A = ... %: nearest value in Tables 1-6: A=.......... %
B = ... %: nearest value in Tables 1-6: B=.......... %

Resulting Dam Fill Height:

From formula: h = ... m From tables 1-6: h = ... m

6. Volume of Dam Fill

The volume V of the dam can be calculated with the formula:

$$V = \frac{500\ h3 + 900\ h2}{3\ B} \quad [m3]$$

Appendix 3 gives Tables 7-12 to calculate V for given values of S, A, and B. Nearest figures have to be selected as for the height, h (see above).

Resulting Dam Volume:

From formula: V =........m3 From Tables 7-12: V =.........m3

7. Base Width of Dam Fill

The base width b of the dam fill can be calculated with the formula:

$$b = 5\ h + 3\ [m]$$

Resulting base width:

b = ... m

8. Staking Out of the Dam:

	Date
1) Centre of dam selected?	....
2) Dam height surveyed and marked on both sideslopes?	...
3) Top width of 3 m marked on both sideslopes?	....
4) Base width of dam marked on both sides of center point?	....
5) Lines around dam staked out?	....
6) Excavation area for core of dam marked?	....
7) Spillway surveyed and staked out?	....

9. Approval by Engineer:

Seen and approved for construction:

Name: ....

Date: ....

Place: ....

Signature: ....

Appendix 2

Assessing the Height, h, of Small-Scale Earth Microdams

Three variables are needed to calculate the dam height, h:

- Storage capacity, S, in m3
- Longitudinal gradient, A, in %
- Cross-sectional gradient, B, in %

For your planned site:

1. Write the storage, S, obtained in Section 3.3. of the Manual to the nearest of the figures below

2,500	5,000	7,500	10,000	12,500	15,000

2. Write the gradient A of Section 3.4. to the nearest of the figures below:

2.5	5.0	7.5	10.0	12.5

3. Write the gradient B of Section 3.4. to the nearest of the figures below:

2.5	5.0	7.5	10.0	15.0	20.0	25.0

Always use the upper figure now for obtaining the dam height, h, in Tables 1-6.

a) First select correct storage, S, and go to correct Table
b) Proceed from correct A value downwards, and correct B value horizontally until the lines cross
c) The figure given at the crossing is the correct dam height, h, in metres.

Table 1: Maximum dam height in metres for a storage capacity of 2,500 m3

S = 2,500 m3 h = ?		Longitudinal slope gradient, A, in				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	2.7	3.1	3.4	3.7	4.1
	5.0	3.1	3.6	4.1	4.4	4.8
	7.5	3.4	4.1	4.5	4.8	5.4
	10.0	3.6	4.4	4.8	5.2	5.8
	15.0	4.1	4.8	5.4	5.8	6.5
	20.0	4.4	5.2	5.8	6.3	7.1
	25.0	4.6	5.5	6.2	6.7	7.6

Table 2: Maximum dam height in metres for a storage capacity of 5,000 m3

S = 5,000 m3 h = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	3.1	3.6	4.1	4.4	4.8
	5.0	3.6	4.4	4.8	5.2	5.8
	7.5	4.1	4.8	5.4	5.8	6.5
	10.0	4.4	5.2	5.8	6.3	7.1
	15.0	4.8	5.8	6.5	7.1	7.9
	20.0	5.2	6.3	7.1	7.7	8.7
	25.0	5.5	6.7	7.5	8.2	9.3

Table 3: Maximum dam height in metres for a storage capacity of 7,500 m3

S = 7,500 m3 h = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	3.4	4.1	4.5	4.8	5.4
	5.0	4.1	4.8	5.4	5.8	6.5
	7.5	4.5	5.4	6.1	6.5	7.3
	10.0	4.8	5.8	6.5	7.1	7.9
	15.0	5.4	6.5	7.3	7.9	8.9
	20.0	5.8	7.1	7.9	8.6	9.8
	25.0	6.2	7.5	8.5	9.3	10.4

Table 4: Maximum dam height in metres for a storage capacity of 10,000 m3

S = 10,000 m3 h = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-	2.5	3.6	4.4	4.8	5.2	5.8
sectional	5.0	4.4	5.2	5.8	6.3	7.1
slope	7.5	4.8	5.8	6.5	7.1	7.9
gradient,	10.0	5.2	6.3	7.1	7.7	8.7
B, in %	15.0	5.8	7.1	7.9	8.6	9.7
	20.0	6.3	7.7	8.6	9.4	10.6
	25.0	6.7	8.2	9.3	10.1	11.4

Table 5: Maximum dam height in metres for a storage capacity of 12,500 m3

S = 12,500 m3 h = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-	2.5	3.8	4.6	5.2	5.5	6.2
sectional	5.0	4.6	5.5	6.2	6.7	7.5
slope	7.5	5.2	6.2	6.9	7.5	8.5
gradient,	10.0	5.5	6.7	7.5	8.2	9.2
B, in %	15.0	6.2	7.5	8.5	9.3	10.4
	20.0	6.7	8.2	9.3	10.1	11.4
	25.0	7.2	8.7	9.9	10.8	12.2

Table 6: Maximum dam height in metres for a storage capacity of 15,000 m3

S = 15,000 m3 h = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-	2.5	4.1	4.8	5.4	5.8	6.5
sectional	5.0	4.8	5.8	6.5	7.1	7.9
slope	7.5	5.4	6.5	7.3	7.9	8.9
gradient,	10.0	5.8	7.1	7.9	8.6	9.7
B, in %	15.0	6.5	7.9	8.9	9.7	11.1
	20.0	7.1	8.6	9.7	10.6	12.1
	25.0	7.5	9.3	10.4	11.4	12.9

Appendix 3

Assessing the Volume, V, of Small-scale Earth Microdams

Please read the introductory note of Appendix 2 and process the same way as for dam heights, using Tables 7-12 below:

Table 7: Microdam volume, V, in metrecubes for a storage capacity of 2,500 m3

S = 2,500 m3 V = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	2132	3162	4051	4864	6359
	5.0	1581	2432	3179	3872	5161
	7.5	1351	2119	2803	3441	4633
	10.0	1216	1936	2580	3183	4317
	15.0	1059	1720	2316	2878	3940
	20.0	968	1592	2158	2695	3713
	25.0	906	1504	2051	2568	3556

Table 8: Microdam volume, V, in metrecubes for a storage capacity of 5,000 m3

S = 5,000 m3 V = ?		Longitudinal slope gradient, A, in %				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	3162	4864	6359	7745	10321
	5.0	2432	3872	5161	6366	8634
	7.5	2119	3441	4633	5756	7880
	10.0	1936	3183	4317	5389	7425
	15.0	1720	2878	3940	4950	6877
	20.0	1592	2694	3713	4684	6544
	25.0	1540	2568	3556	4500	6312

Table 9: Microdam volume, V, in metrecubes for a stora
capacity of 7,500 m3

S = 7,500 m3 V = ?		Longitudinal slope gradient, A, in				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	4051	6359	8408	10321	13897
	5.0	3179	5160	6948	8634	11820
	7.5	2083	4633	6299	7880	10883
	10.0	2580	4317	5910	7425	10315
	15.0	2316	3940	5442	6877	9628
	20.0	2158	3712	5157	6544	9208
	25.0	2051	3556	4961	6313	8917

Table 10: Microdam volume,V, in metrecubes for a storag
capacity of 10,000 m3

S = 10,000 m3 V = ?		Longitudinal slope gradient, A, in				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	4864	7745	10321	12733	17268
	5.0	3872	6366	8634	10779	14851
	7.5	3441	5756	7880	9901	13754
	10.0	3183	5389	7425	9368	13087
	15.0	2878	4950	6877	8725	12278
	20.0	2694	4684	6544	8333	11783
	25.0	2568	4500	6313	8059	11437

Table 11: Microdam volume, V, in metrecubes for a stora
capacity of 12,500 m3

S = 12,500 m3 V = ?		Longitudinal slope gradient, A, in				
		2.5	5.0	7.5	10.0	12.5
Cross-sectional slope gradient, B, in %	2.5	5629	9058	12141	15039	20503
	5.0	4529	7519	10252	12844	17778
	7.5	4047	6834	9403	11852	16537
	10.0	3759	6422	8889	11250	15781
	15.0	3417	5926	8268	10521	14861
	20.0	3211	5625	7891	10075	14297
	25.0	3068	5416	7627	9765	13903