Design and construction details for Mtoko dam, Zimbabwe

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MTOKO DAM

DESIGN AND CONSTRUCTION DETAILS

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Summary

This report contains details of a proposed dam to be built 7km northwest of Mtoko in Rhodesia. The construction programme will occupy two dry seasons. The dam is to be built of earth with local labour and will hold 19000m$^3$ of water when full. It has been designed to supply 4300m$^3$ over a period of 12 months. The balance of 14700m$^3$ allows for seepage and evaporation losses.

The embankment will be built across a natural valley. A spillway will be cut out of the northern side of this valley and planted to grass. A trickle tube will be installed to discharge water in excess of the storage required. Water for domestic and stock use is to be drawn off through a sand filter and via a 50mm pipe routed underneath the centre of the embankment. This water can then be chlorinated and pumped to storage tanks, or fed direct to cattle watering troughs, as required.

The design and its implementation

The design called for a 95% reliable domestic and stock water supply of 4300m$^3$ over 12 months. For design purposes, therefore, this was treated as a major storage project. Annex B describes the hydrologic details. Since the reliability required was 95%, precipitation was ignored when calculating the net evapo-seepage losses. Throughout the design, constant reference was made to the requirements laid down in the Rhodesian Handbook$^1$.

Annex C describes the spillway design. The discharge parameters for the spillway outfall were worked out assuming a slope of 6%. In the event however, it was found possible to achieve a 5% gradient by land forming, thus giving some improvement over the figures quoted. On the other hand, because of the topographic difficulties of designing a more gently sloping spillway, a maximum velocity of 2.5m s$^{-1}$ was accepted for the outfall water, although the classification code of the topsoil in the area indicated that a figure of 2m s$^{-1}$ was more appropriate. The final design is therefore a compromise between slightly increased water velocities and a slightly decreased gradient. It is an essential part of the design that a good stand of rhizomiferous grass be maintained on the spillway bed.

Details of the embankment design are described in Annex D. Since there was no local source of clay suitable for constructing a core, a homogeneous embankment was chosen. The local subsoil, while not ideal for this type of embankment, is nevertheless satisfactory. A crest width of 2m is wide enough for construction machinery,

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$^1$ Handbook of basic instructions for dam construction. Department of Conservation and Extension, Rhodesia (now Zimbabwe).
and since no road was planned to cross the dam, this width is narrow enough to avoid excessive earth-moving costs. The design incorporates a stone toe filter with seepage channels leading to a concreted section of the stream bed. This concreted channel is taken far enough to dissipate the discharge from the trickle tube and to prevent erosion.

The design of the trickle tube and outlet pipe is covered in Annex E. During the wettest month of the year (January) a daily average of 1315m$^3$ of water will enter the storage area. This is easily coped with by the 0.15m deep pondage, and will be discharged by the trickle tube whose capacity is 2600m$^3$ day$^{-1}$.

The present design incorporates a 50mm outlet pipe, but this can be changed to a 75mm diameter pipe if the subsequent pumping, storage and distribution arrangements require it. It is very important that neither the trickle tube nor the outlet pipe should be routed through the embankment; they must be sunk into their own trenches under it. The casting of the staunching rings should be closely supervised. On no account should any kind of valve be attached to the trickle tube.

The borrow pit (see Annex F) has been designed in such a way that many labourers can excavate it simultaneously. Although it is expected that an excavation of 0.5m should suffice, the pit can easily be made deeper if more material is required during construction. The berm of 10m is that recommended by the Rhodesian Handbook.

Volumes of cut and fill were calculated by normal surveying methods. Details are to be found in Annex G.

In working out the construction schedule (see Annex H) careful attention was paid to the movement and location of the subsoil material to be used for the earthworks, to ensure that hauling runs were kept as short as possible. During the first season, construction should be so timed as to allow the grass to be planted on the spillway at the commencement of the rains. Some local workers should be hired to look after this grass during the following wet season. As regards the embankment, it cannot be over-emphasised that it should be built up in thin well-compacted layers. On no account should a bulldozer be used — in fact the bulldozer can be sent back as soon as the cut-off trench and borrow pit areas have been ripped. As before, labourers should be retained to look after the grass planted on the embankment and training wall to ensure that it becomes well established during the second wet season.

Instructions for maintenance (Annex J) have been abstracted from the Rhodesian Handbook.
Annex A: Principal Data

Catchment
Length: 2450m
Slope: 0.04 m⁻¹
Cover: cultivated / grassland
Area: 302 Ha
Rational Formula C Factor: 0.36
Soils: 5G/6G/11

Rainfall and Runoff
Return Period: 50 yr
Time of Concentration: 28.1 min
Rainfall: 936 mm yr⁻¹
Intensity: 112 mm hr⁻¹
Yield (Conex): 178000 m³ yr⁻¹
Flood: 33.8 cumecs

Storage
Purpose: domestic and stock
Reliability: 95%
Demand: 4300 m³ yr⁻¹
Residual: 500 m³
Seepage: 50 mm month⁻¹
Evaporation: 1901 mm yr⁻¹
NES: 2501 mm yr⁻¹
Total Storage: 19000 m³
Critical Period: 12 months
Max Depth of Water: 5.4 m
Water Surface Area: 10700 m²

Embankment
Type: homogeneous
Material: coarse sand / sandy clay loam
Batters: 2½:1
Crest Width: 2 m
Settlement Allowance: 0.075 m m⁻¹
Total Length: 140 m
Cut-off Trench Bottom Width: 2 m
Cut-off Trench Batters: 2½:1
Cut-off Trench Depth: 1.5 m
Height:
  clearance: 0.5 m
  surcharge: 0.73 m
  wave action: 0.17 m
  freeboard (total of above): 1.4 m
  pondage: 0.15 m
  storage: 5.4 m
  Total Height: 6.95 m
Spillway

Outfall
Gradient: 0.06 m⁻¹
Cover: grass 250 – 600 mm tall
Batter: 1½:1
Roughness (n): 0.05
Max Velocity: 2.5 m s⁻¹
Depth of Flow: 0.37 m
Width: 36.6 m
Hydraulic Radius: 0.36
Wetted Perimeter: 37.3 m

Inlet
Elevation: 97.55 m
Width: 36 m
Depth of Flow (surcharge): 0.73 m

Training Wall
Length: 116 m
Crest Width: 1 m
Batters: 1½:1

Trickle Tube and Outlet Pipe
Excess Catchment Water: 0.005 cumecs

Annex B: Hydrologic Design Details

1 STORAGE DESIGN

Purpose of Storage
Domestic supply and stock water.

Reliability Required
95%

Water Demand

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand (m³/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.25</td>
</tr>
<tr>
<td>Feb</td>
<td>0.25</td>
</tr>
<tr>
<td>Mar</td>
<td>0.3</td>
</tr>
<tr>
<td>Apr</td>
<td>0.375</td>
</tr>
<tr>
<td>May</td>
<td>0.45</td>
</tr>
<tr>
<td>Jun</td>
<td>0.5</td>
</tr>
<tr>
<td>Jul</td>
<td>0.5</td>
</tr>
<tr>
<td>Aug</td>
<td>0.45</td>
</tr>
<tr>
<td>Sep</td>
<td>0.375</td>
</tr>
<tr>
<td>Oct</td>
<td>0.3</td>
</tr>
<tr>
<td>Nov</td>
<td>0.3</td>
</tr>
<tr>
<td>Dec</td>
<td>0.25</td>
</tr>
</tbody>
</table>

All in litres x 10⁶ month⁻¹ giving a total of 4300 m³ over 12 months.

Type
Since, with losses, the total water stored will exceed 5000 m³, this will rate as a Major Storage Design.
Critical Storage Period
Since the annual rainfall exceeds 650mm, this will be 12 months.

Storage Requirements
The soil classification map for the area shows the soils to be a mixture of 5G, 6G and 11 types. These comprise coarse-grained sands, loamy sands, sandy clay loams, and sandy clays. Seepage losses were estimated at 50mm month\(^{-1}\). Climatological data for the area shows the annual evaporation to be 1901mm. The net evapo-seepage loss is therefore calculated as:

\[
NES = \left( \frac{1901}{12} + 50 \right) \times 12 = 2501\text{mm yr}^{-1}
\]

A residual amount of water to be left in the storage area after demand and evapo-seepage losses have been met was arbitrarily chosen to be 500m\(^3\). Using the depth-storage curve for the site (see attached Handout LS4B) a total storage requirement of 19000m\(^3\) was found to be necessary. This gives a maximum water depth of 5.4m, with a surface area (measured from the site plan by planimeter) of 10700m\(^2\).

2 CATCHMENT YIELD

Catchment Area
The boundaries of the catchment were delineated using stereo photo-interpretation and are shown on the attached aerial photograph (Handout LS5). Comparison with a 1:50000 Ordnance Map of the area yielded a photo scale of 1:23,786. The area of the catchment was then measured on the aerial photo with a planimeter and found to be 302ha.

Mean Annual Rainfall
Climatological data for the area shows this to be 936mm.

Catchment Yield
Using the Rhodesian Handbook tables, a catchment of 302ha with a mean annual rainfall of 936mm should give a minimum annual yield of 178000m\(^3\).

3 FLOOD RUNOFF

Catchment Coefficient
The maximum length of the catchment was measured as 2450m with a drop of 100m from top to bottom. This represents an approximate average gradient of 4%. The cover was interpreted from the aerial photograph as mainly cultivated land with some natural grassland. The soils have already been described. There
are many different tables giving values of 'C' from slope, catchment cover and soil texture. A figure of 0.36 was chosen\(^2\).

**Rainfall Intensity**
The climatological data given in the attached handout (LS3B) was used to plot a graph of log intensity vs. log duration for a 50yr return period (see Figure 3.1). The time of concentration is given by:

\[
T = 0.02L^{0.77}S^{-0.385}
\]

where \(L\) = catchment length in m
\(S\) = catchment slope in m m\(^{-1}\)

Substituting for \(L\) and \(S\):

\[
T = 0.02 \times (2450)^{0.77} \times (0.04)^{-0.385} = 28.1\text{min}
\]

From Figure 3.1 the intensity at 28.1min was found to be 112 mm hr\(^{-1}\).

**Calculation of Runoff**
The Rational Formula was used\(^3\). In the metric form this is:

\[
Q = CIA / 360
\]

Substituting for \(C\), \(I\), and \(A\):

\[
Q = (0.36 \times 112 \times 302) / 360 = 33.8\text{ cumecs}
\]

**Annex C: Spillway Design Details**

1. **FLOOD ESTIMATION**
The 50yr flood, estimated by the Rational Method, was 34 cumecs.

2. **OUTFALL CALCULATIONS**

**Gradient**
The outfall water has to drop about 5.5m to the streambed. The route to be taken by this water was mapped out on the contoured site plan. It was difficult to achieve a gradient of less than 6%, although the final drawings have managed to bring this nearer to

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\(^2\) See Table 7.1 in Hudson, N. *Soil Conservation*. BT Batsford Ltd. 1981.

\(^3\) See Section 7.4.1 in Hudson, N. *Soil Conservation*. BT Batsford Ltd. 1981.
5%. However, for design purposes, a figure of 0.06 m\(^{-1}\) was adopted.

**Cover**
It is essential that a good stand of resilient grass should cover the spillway and its banks. Couch grass was chosen, as recommended by the Rhodesian Handbook. A stand 250 – 600 mm high should give a roughness factor ‘n’ of 0.05.

**Discharge Velocity**
The maximum velocity of flow down a grassed spillway should not exceed 2.5 m s\(^{-1}\) if erosion is to be avoided.

**Dimensions**
The width and depth of flow were calculated from Manning formula:

\[
u = \frac{1}{n R^{2/3} S^{1/2}}
\]

where \(u\) = velocity of flow, \(n\) = roughness factor, \(R\) = hydraulic radius, \(S\) = slope.
Rearranging:

\[ R^{2/3} = \frac{u}{S^{1/2}} \]

Substituting for \( u, n, \) and \( S:\)

\[ R^{2/3} = \frac{(2.5 \times 0.05)}{0.06^{1/2}} = 0.51032 \]

Therefore \( \log R = 1.5 \log 0.51032 = -0.4383, \) and \( R = 0.36449. \)

Now \( R = A / P \) where \( A = \) cross-sectional area

\( P = \) wetted perimeter

And \( Q = uA \) where \( Q = \) flow

Therefore \( A = \frac{Q}{u} = \frac{34}{2.5} = 13.6m^2 \)

If \( L = \) width of spillway and \( H = \) depth of water:

\( LH = A, \) and \( L + 2H = P \)

Knowing \( R \) and \( A, \) then \( P = A / R, = 13.6 / 0.36449, = 37.312m \)

Substituting for \( P: \)

\( L = 37.321 - 2H \)

Substituting for \( L \) and \( A \) in \( LH = A: \)

\( (37.312 - 2H)H = 13.6 \)

Therefore \( 2H^2 - 37.312H + 13.6 = 0 \)

Solving the quadratic:

\( H = (37.312 - \sqrt{(37.312^2 - 4 \times 2 \times 13.6}) / (2 \times 2) = 0.372 \)

Therefore \( H = 0.372m \) and \( L = 36.568m \)

A spillway width of 36m was adopted, with side slopes having a batter of 1½:1.

### 3 INLET CALCULATIONS

The discharge over the spillway crest was assumed to obey a broad-crested weir formula:

\[ Q = CLH^{3/2} \]  \( \text{where } C = 1.5 \)

\( L = \) crest width

\( H = \) depth of flow
Rearranging:

\[ H^{3/2} = \frac{Q}{CL} = \frac{34}{1.5L} \]

It was decided to adopt the same inlet and crest width as the outfall width, so \( L = 36 \text{m} \). Thus:

\[ H^{3/2} = 0.6291 \]

Therefore \( \log H = 0.6 \log 0.6291 \)

Therefore \( H = 0.73 \text{m} \)

This depth \( H \) is also termed the surcharge.

4 TRAINING WALL

To maintain uniform flow down the spillway, it was necessary to design a training wall. From the site plan the length of this wall was found to be 116m. A crest width of 1m was chosen with batters of 1½:1.

Annex D: Embankment Design Details

1 TYPE AND MATERIAL

Test borings showed the subsoil to be a silty sand as classified by the Unified Soil Classification system. This material is fairly suitable for building the homogeneous type of embankment. A further consideration is that, with unskilled labour, the homogeneous embankment is the easiest to construct.

2 DIMENSIONS

Clearance
The standard minimum dimension for a dam of this size was chosen, \( i.e. 0.5 \text{m} \).

Surcharge
This was calculated under Spillway: Inlet Calculations and found to be 0.73m.

Wave Action
This was calculated from the Hawksley formula:

\[ H = 0.014 \sqrt{L} \]

where \( L = \text{maximum fetch in metres} \)
From the site plan, the fetch was measured as 150m, so:

\[ H = 0.014 \sqrt{150} = 0.17 \text{m} \]

**Pondage**
A depth equal to the trickle tube diameter was chosen, \textit{i.e.} 0.15m.

**Storage**
This had already been worked out during the hydrologic design. The maximum depth of water was 5.4m.

**Freeboard**
This is the sum of clearance, surcharge, and wave action. In this case these total 1.4m.

**Total Height**
Adding the above, the total height of the embankment is 6.95m.

**Crest Width**
This was calculated from the formula:

\[ W = H / 15 + 1.5 \quad \text{where} \quad H = \text{maximum height of the embankment} \]

≅2m.

**Batters**
For the soil group SM, and for stored water depths between 3m and 7m, the recommended batters for the upstream and downstream slopes are 2½:1.

**Settlement Allowance**
The Rhodesian Handbook recommends a settlement allowance of 0.075m m\(^{-1}\)

**Cut-off Trench**
A bottom width of 2m was chosen to allow easy passage for both a tractor and an ox-team. Batters of 2½:1 were chosen. Owing to the subsoil material not being the ideal type for an embankment core it was thought advisable to take the cut-off trench to a depth of 1.5m.
Annex E: Trickle Tube and Outlet Pipe
Design Details

1 TRICKLE TUBE

Diameter
The estimated runoff of the catchment in any one year was estimated at 178000m³, of which 19000m³ was to be stored in the dam. This leaves 159000m³, which is approximately equivalent to 0.005 cumecs. A 150mm diameter pipe, which is a common size and easy to obtain, will cope with a flow of 0.03 cumecs, six times the average catchment excess.

Inlet
For a 150mm diameter pipe the Rhodesian Handbook recommends a drop inlet chamber of 300mm x 500mm by 750mm deep. The top of the inlet chamber should be 0.15m below maximum water level.

Position
The trickle tube should be laid in a trench perpendicular to the centre line of the embankment 1m below high water level on the opposite side to the spillway. The tube should be encased in 150mm concrete with 1m diameter concrete rings 4m from the embankment centre, and with a 1.5m diameter collar at the cut-off trench.

2 OUTLET PIPE

Diameter
A standard 50mm diameter pipe should be sufficient for a peak flow of twice the June daily average demand (i.e. 0.00039 cumecs).

Inlet
Since the water is for direct animal consumption and indirect (viz. a chlorination plant is envisaged) human consumption, the water quality should be as high as possible. The inlet should therefore incorporate a 1m x 1m x 1m box sand filter.

Position
The outlet pipe should be laid in a trench below the highest part of the embankment. The pipe should be encased in 250mm diameter concrete with 850mm diameter staunching rings (also of concrete) every 3m, and a curtain concrete wall 1.25m wide set on the centre of the cut-off trench floor.
Annex F: Borrow Pit Design Details

Location
The downstream edge of the borrow pit should be 10m away from the upstream toe of the embankment, within the storage basin.

Size
Trapezoidal with parallel sides of 35m and 75m separated by a distance of 40m. A depth of 0.5m will provide approximately 1000m$^3$ of material. Batters 2½:1.

Annex G: Volume Calculations

1 EMBANKMENT

The trapezoidal formula was used to calculate the volume of material in the embankment itself (not including the cut-off trench). This formula is:

\[ v = \frac{d}{6} (A_1 + 4M + A_2) \]

where
- \( V \) = volume in m$^3$
- \( d \) = perpendicular distance between the end faces in m
- \( A_1 \) = area of one face in m$^2$
- \( M \) = area of midsection in m$^2$
- \( A_2 \) = area of second face in m$^2$

2 CUT-OFF TRENCH

The volume was calculated by multiplying the cross-sectional area (8.625m$^2$) by the total length (140m). The result is shown in Figure 3.5.

3 SPILLWAY

Cross-sections were drawn at various points along the spillway (see Figure 3.6) and the areas of these were used in the trapezoidal formula or in a simplification of it:

\[ V = \frac{d}{2} (A_1 + A_2) \]

according to convenience. The results are shown in Figure 3.5.
4 TRAINING WALL

The volume was worked out in the same way as that of the cut-off trench \textit{viz.} by multiplying the cross-sectional area (4.875m$^2$) by the total length (116m). Again the result is to be found in Figure 3.5.

5 BORROW PIT

The dimensions of the borrow pit were designed to make up the shortfall in material required for the embankment. So far we have:

<table>
<thead>
<tr>
<th></th>
<th>CUT m$^3$</th>
<th>FILL m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spillway</td>
<td>9200</td>
<td>9632</td>
</tr>
<tr>
<td>Cut-off trench</td>
<td>1208</td>
<td>1208</td>
</tr>
<tr>
<td>Training Wall</td>
<td></td>
<td>566</td>
</tr>
<tr>
<td></td>
<td>10408</td>
<td>11406</td>
</tr>
</tbody>
</table>

The shortfall is approximately 1000m$^3$. The volume of the borrow pit, if dug to 0.5m deep, is 1041m$^3$.

Annex H: Construction Details

1 EQUIPMENT

Bulldozer (for the initial periods only), tractor with scraper blade, water bowser, water pump, ramps, disc harrow or scarifier, wheelbarrows, picks, shovels, hoes, puddling staves, levelling equipment, marker pegs, axes, cement mixer, post augur, hammers, wire tensioners, buckets.

2 MATERIALS REQUIRED

Sand, cement, graded aggregate (25mm), fencing posts, barbed wire, staples, 150mm piping, 50mm piping, filter sand, 50mm gate valve, fumigant, grass seed, fertiliser and/or kraal manure, diesel fuel, water, large stones, bricks.

3 PERSONNEL REQUIRED

One foreman (with previous experience of earth dam building), 40 labourers, 1 bulldozer operator, 1 bricklayer/plasterer, 1 plumber, 1 surveyor and 1 staffman, 1 tractor driver, 2 herdsmen with their cattle.
4 TIMING

The whole construction should be carried out over two dry seasons (May to October). During the first season the spillway should be cut and grassed, and then the embankment and other works can be completed in the second year. This is to ensure adequate grass establishment on the spillway before the dam starts to fill up.

5 MARKING OUT

Establish a concrete beacon at the TBM (see Figure 3.2).

Mark out the embankment centre line with pegs and with two strong poles some distance from either end to act as site line flags.

Peg the upstream and downstream embankment toes, and ends.

Peg the spillway outer edge.

Peg the training wall toes and end.

Peg the cut-off trench and borrow pit.

Peg the high water level.

6 CONSTRUCTION — FIRST SEASON

Fumigate, excavate and fill in, all anthills in the vicinity of the embankment, training wall and spillway.

Remove all trees, stumps and roots (filling in the holes afterwards) from the areas to be occupied by the embankment, training wall and spillway, and borrow pit.

Chop down all trees to stump level from the rest of the basin area up to the high water level mark.

Use the bulldozer to remove all the topsoil (to a depth of 250mm) from the spillway area and training wall area and push it slightly uphill of the spillway outer edge.

Use the bulldozer to remove all the topsoil from the borrow pit area and push it to just beyond the southern edge of the pit. This soil should not cover the route to be taken by the trickle tube.

Use the bulldozer to excavate the spillway to just below the finished level (RL 97.55 – 0.25) pushing some of the material to the north side of the basin and the rest beyond the downhill toe of the training wall. Do not push any material onto the area to be occupied by the embankment.
Replace the topsoil to bring the spillway to the current height (RL 97.55 at the crest, sloping down at 5% to the outfall).

Plant a dense cover of rhizomiferous grass (e.g. Cynodon dactylon) over the spillway, and fertilise if necessary.

Fence off the spillway area to keep cattle out.

7 CONSTRUCTION — SECOND SEASON

Check that all the marker pegs are still in position — replace any that are missing.

Use the bulldozer to remove the topsoil (to a depth of 0.25m) from the embankment area pushing it beyond the downstream toe of the embankment.

Use the bulldozer tines to rip the cut-off trench and borrow pit areas.

Excavate the cut-off trench and use the material to start building the downstream toe of the embankment. At the same time, start building the training wall using material excavated from the spillway after having scarified the ground surface with a tractor and disc harrow.

Excavate the trickle tube and outlet pipe trenches. Keep them as narrow as possible so that the concrete may be cast straight into the soil. The staunching rings should be cast square, again straight into the earth, using a 4:2:1 mix. Fill up the trenches with layers of subsoil, well puddled with 50mm staves.

Fill in the cut-off trench with 150mm layers of material taken from the north side of the basin. Use the water if necessary to bring the moisture content of the material to within ± 3% of the optimum for achieving maximum dry density. Use cattle or oxteams driven backwards and forwards to compact each layer.

When the cut-off trench has been filled, scarify the whole area to be covered by the embankment.

Build up the embankment in thin layers (not exceeding 150mm), using water if necessary as before, and compacting with cattle. Use the material from the spillway first and then excavate from the borrow pit. Avoid any large stones or boulders. Check the moisture content frequently. Construction should proceed from the toes inwards. Check the batters regularly and keep the top level. Make sure that haul distances are as short as possible for efficient working.

Construction of the training wall should follow the same pattern as that of the embankment.
Remember to allow for settlement; the embankment will end with a hump in its crest at the deepest point. Give the crest a slight upstream tilt.

Use the topsoil heaped south of the training wall to spread over the downstream slope of the embankment and over the training wall.

Use the borrow pit topsoil to cover the crest and top upstream face of the embankment.

Use well-graded aggregate to form the apex of the downstream toe.

Use large stones (of not less than 25kg weight each) to stone pitch the northern end of the embankment at the spillway crest. The stones should be closely packed with the long axis of each stone set at right angles to the embankment. The voids between the stones should be filled with topsoil and planted with rhizomoferous grass.

Plant rhizomoferous grass (e.g. Cynodon dactylon) on the training wall and on all faces of the embankment that will be exposed when the dam is full.

Construct the drop inlet chamber, filter chamber, seepage channels, and concrete trickle-tube-leadaway channel. The downstream wall of the drop inlet chamber should be raised 300mm for vortex suppression. A wire mesh cover should be fitted to prevent twigs etc. blocking the trickle tube.

Fence off the embankment to stop cattle damaging the grass.

Inspect and check the work, and issue a maintenance form to the headman.
Duration (min) | 5 | 10 | 20 | 30 | 45 | 60 | 90 | 120
---|---|---|---|---|---|---|---|---
Amount (mm) | 15.2 | 29.9 | 43.2 | 53.3 | 66 | 73.7 | 81.3 | 86.4
Intensity (mm/hr) | 183 | 168 | 130 | 107 | 88 | 74 | 54 | 43
Log duration | 0.70 | 1.00 | 1.30 | 1.48 | 1.65 | 1.78 | 1.95 | 2.08
Log intensity | 2.26 | 2.23 | 2.11 | 2.03 | 1.94 | 1.87 | 1.73 | 1.63

Time of Concentration $T = 0.02L^{0.77} S^{-0.385}$

When $L = 2450$ m, $S = 0.04$, and $T = 28.1$ min. Log $T = 1.45$

At Log $T = 1.45$, Log $I = 2.05$, and $I = 112$ mm hr$^{-1}$

![Intensity vs Duration Curve](image)

**Figure 3.1: Log Intensity vs. Log Duration Curve**
Figure 3.2: Site Plan
Figures 3.3 and 3.4: Embankment Cross Sections
Figure 3.5: Dimensions for Calculating Volumes
Figure 3.6: Spillway Cross Sections
Annex J: Maintenance Details

MAINTENANCE OF YOUR EARTH DAM

1 Introduction

The dam on your farm is now complete, with the exception of those points mentioned by the Engineer and/or Extension Officer in his covering letter to this memorandum.

However, it will not necessarily stay complete, unless regular inspection and maintenance works are carried out by you. Your dam is like your tractor; it is now up to you to ensure by regular service (that is, maintenance) that it will not require major repairs. If it does require these extensive repair works we will try to give you advice on rebuilding, if possible, but by regular maintenance you can avoid the necessity for large expenditure.

The Department of Conservation and Extension, like your tractor supplier, is always ready at any time to give you advice on maintenance and listed below are some points you should watch.

2 Maintenance of fences

Stock must not be allowed to graze on the dam wall or spillway and its outfall, as erosion will occur. The dam should be fenced off to prevent this and fences must be kept in good order.

3 Maintenance of grass cover on walls and spillways

The establishment of a good grass cover over the dam wall and on earth spillways must be achieved at all costs before the rains. This can be done by spreading about an inch of topsoil and adding 2 to 3 bags of ammonium sulphate to the acre. Only good runner grasses should be used, and the types recommended are as follows:

(a) On upstream face: Cynodon dactylon
(b) On crest and downstream face: Cynodon dactylon
(c) On spillways: Cynodon dactylon

Long-turfed grasses such as Hyparrhenia or Rapoko are quite useless, and must be kept cut short, otherwise they choke out the good runner grasses and, even more seriously, conceal ant and vermin workings. Trees and shrubs and their roots must be removed from the banks as they cause leakage and attract termites.
Failure to achieve this grass cover in good time, particularly on the earth spillways and their returns to the stream bed, can necessitate extensive repairs later.

In subsequent years, the grass cover should be re-established on bare spots as they occur.

4 Repair of erosion

(a) Embankment The first rains will invariably cause gullying or rilling of the embankment. These gullies, as they form, should be repaired by ramming in grass sods, complete with soil. Treated this way, the gullying can actually help to speed up the grass cover, but if ignored may endanger the dam.

(b) Spillways Spillway erosion usually starts from tracks and footpaths in the outfall area. These must be sought out and blanked off.

During the floods, spillways should be checked almost daily, and any gullies or waterfalls eliminated as they form. Concentrations of flow or unprotected drops must be avoided. Fertiliser bags filled with topsoil and grass roots, grass sods or mats formed of reeds or long coarse grass, can be used for filling in these danger spots. Advice should always be sought in cases of serious erosion, but first-aid measures should be put in hand straight away.

5 Settlement

The crest level of a dam should be checked frequently in the early life, and at least annually thereafter, to ensure that adequate freeboard is being maintained.

Settlement cracks frequently form after construction. Hair-cracks, parallel with the crest, are not serious if closed up to prevent water entering; large cracks, however, may indicate slipping foundations, which can cause sudden and complete failure. Transverse cracks are dangerous if they extend below the water line. Advice should always be obtained in cases of severe cracking, as a matter of urgency.

6 Seepage

Nearly all earth dams seep to some extent and unless it amounts to serious leakage, or appears on the downstream face, this need cause no alarm. There is no easy cure for a bad leak, as the trouble lies in conditions under the wall of the dam. Seepage may, however, be reduced over a long period by puddling the basin with cattle as the level drops. Wood ash or cowdung distributed over the suspect area or in the water may also help.
NEVER attempt to plug a leak on the downstream side — this is not only futile but might actually prove dangerous.

7 Drainage

Far more important than eliminating seepage is the rapid disposal of any water that does penetrate the dam. Water-logging of the downstream face or of the area below the dam may cause slipping and collapse of the dam. Dams should be built with adequate drainage, but where this has not been done and excessive wetness results, remedial steps under the advice of the engineer or extension officer should be taken. This will generally consist in the first instance of an open collector drain, about 18 inches deep, dug parallel with the toe of the dam and 3 to 4 metres from it and discharging into the stream bed. Cross drains from the toe of the dam to this collector should connect in from very wet spots.

If any portion of the dam should be slushy or actually slip, it should be replaced by gravel or boulders, built in level courses from ground level upwards.

This is perhaps the most important aspect of maintenance, and in the event of any trouble whatever, advice should be sought as a matter of extreme urgency.

8 Ants (termites) and vermin

Ant workings are a major cause of dam failures, frequently through their workings being concealed by long grass or bush. The embankment and the area below should be inspected regularly for this throughout the life of the dam, and for this reason vegetation should be kept under control.

If workings are found, they should be dealt with as follows:

(a) Make a hole down into the workings with an iron bar, and push a pipe down this hole — then pour a proven fumigant down the pipe. Alternatively, close up all visible holes with wads of cotton wool soaked in carbon disulphide.

(b) Seal up the workings for 48 hours.

(c) Excavate the workings and backfill with good material.

9 Conclusion

The above recommendations should also be followed in maintaining the earth banks in composite weir/earth dam structures.

By paying attention to the above, extensive damage to the dam can be avoided and costly repairs not be incurred. The dam is now
your dam and it is up to you to ensure that you keep it in good working order.

You should inspect your dam at least once a month during the dry seasons and at least twice a week during the rains.
Annex K: Project Information

HANDOUT LS2: FARM DAM DESIGN PROJECT

1 Introduction

A rural community near Mtoko in Zimbabwe wish to construct a dam to supply water mainly for stock watering and domestic use. A potential site has been found near the road that leads northwards past the local school. Based on the information provided, or any other relevant information you can find, you are asked to assess the suitability of the project and to design the earth embankment and spillway.

2 Information Available

2.1 Location
The site is located about 7km NW of Mtoko at map reference 156,815 on sheet MTOKO 1732A3 in the Rhodesian 1:50,000 series. A section of this map with the site indicated is attached. Aerial photography of the area (to unspecified scale) is available (Run No. 176, photo nos. 773-6). A copy of photo no. 774 is attached.

2.2 Climate
The attached sheet gives all the available data from the nearest reliable climate station.

2.3 Soils & Land Use
Soil types in the area may be found from the Soils Map of Rhodesia 1:1,000,000. Land use may be deduced from the aerial photography.

2.4 Site Details
The attached site plan and storage-elevation curve have already been prepared for the site. Test borings have shown that the topsoil in the area is about 250mm deep and may be classified as a well-graded sand (SW) on the Unified Soil Classification system. The subsoil is a silty sand (SM).

2.5 Water Requirements
The water required for all proposed uses is shown in the table below (in litres/month x 10^6):

<table>
<thead>
<tr>
<th>Month</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.25</td>
</tr>
<tr>
<td>February</td>
<td>0.25</td>
</tr>
<tr>
<td>March</td>
<td>0.3</td>
</tr>
<tr>
<td>April</td>
<td>0.375</td>
</tr>
<tr>
<td>May</td>
<td>0.45</td>
</tr>
<tr>
<td>June</td>
<td>0.5</td>
</tr>
<tr>
<td>July</td>
<td>0.5</td>
</tr>
<tr>
<td>August</td>
<td>0.45</td>
</tr>
<tr>
<td>September</td>
<td>0.375</td>
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<td>October</td>
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<tr>
<td>November</td>
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</tr>
<tr>
<td>December</td>
<td>0.25</td>
</tr>
</tbody>
</table>
3 Report

Your report should be in the form of a detailed design specification for the embankment and spillway. The material should be arranged in the following manner.

i) **Summary** outlining the principal features to the design you have adopted. (This should be fairly brief and to the point).

ii) **Design details** setting out the information required for construction and maintenance. It should also include any peculiarities of the design or the field conditions which might require special attention during construction or for maintenance purposes. (Do not include lengthy mathematical work — put that in the annexes).

iii) **Annexes** including hydrologic design details.

Note: 1) both sections ii) and iii) may be subdivided if necessary. 2) any assumption you have to make should be clearly stated.

SJP
23.2.78

**SOILS INFORMATION**

**Soil Type 5G**
Mainly moderately shallow, greyish-brown, coarse-grained sands, throughout the profile, to similar sandy loams over reddish brown sandy clay loams; formed on granitic rocks.

**Soil Type 6G**
Moderately deep to deep, greyish-brown, coarse-grained sands over pale loamy sands, to similar sandy loams over yellowish-red sandy clay loams or, occasionally, sandy clays; clay fraction essentially ferrallitic (no 2:1 lattice minerals), but reserves of weatherable minerals are appreciable; base saturations range from about 30 to 60%; E/C values lower than about 15me; formed on granitic rocks.

**Soil Type 11**
Non-calcic hydromorphic group: mainly sands, which are leached and strongly acid in reaction, with base saturation lower than about 50%.
MAP SHOWING LOCATION OF PROPOSED DAM

Extracted from: Rhodesia 1:50,000 Series
Sheet: Motosko 1732A/B

General location: 7 km N.W. of Motosko
<table>
<thead>
<tr>
<th>Period</th>
<th>Average</th>
<th>Greatest</th>
<th>Year</th>
<th>Least</th>
<th>Year</th>
<th>Evaporation</th>
<th>Average per month</th>
<th>Average per day</th>
<th>Maximum per day</th>
<th>Potential</th>
<th>Rainfall (inches)</th>
<th>Evapotranspiration (inches)</th>
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<td>1·01</td>
<td>1907</td>
<td>—</td>
<td>Many</td>
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<td>5·95</td>
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<td>6·82</td>
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<td>0·25</td>
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Rainfall duration (probable maximum amount of rain, inches)

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<th>30 mins.</th>
<th>45 mins.</th>
<th>60 mins.</th>
<th>90 mins.</th>
<th>120 mins.</th>
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<td>2</td>
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<td>1</td>
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<td>Frequency</td>
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<td>5 years</td>
<td>20 years</td>
<td>50 years</td>
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Extracted from: Agricultural Climate of Southern Rhodesia, Rhodesian Meteorological Service, August 1962
Photo 774. Top 3750’. Bottom 3550’. 49mm in 1:50,000. 103mm in 1:23,786

49mm = 2.45km. 35mm = 1.75km. 40mm = 2.00km. 56.0cm². 53.5cm². = 3.027km²