48. Small earth dams

This Technical Brief is concerned with the typical small dam (up to about three metres high) which is built across a stream to form a reservoir. It provides guidance on planning, design and construction, but professional help should always be sought before building any dam whose failure could endanger lives, property or the environment. Care must also be taken to avoid the health hazards of reservoirs, including schistosomiasis and polluted water; and the rights of existing users of the water and land must be protected.

A reservoir is useful where the available flow in the stream is sometimes less than the flow required for water supply or irrigation, and water can be stored from a time when there is surplus, for example, from a wet season to a dry season. In addition to the simple earth dam, alternatives to consider are using the sub-surface (groundwater) dam (see *The Worth of Water,* pages 97-100) or using wells. These may be preferable for environmental and water-quality reasons.

Simple earth dams can be built where there is an impervious foundation, such as unfissured rock, or a clay subsoil. The channel upstream should preferably have a gentle slope, to give a large reservoir for a given height of dam. An ideal dam site is where the valley narrows, to reduce the width of the dam.

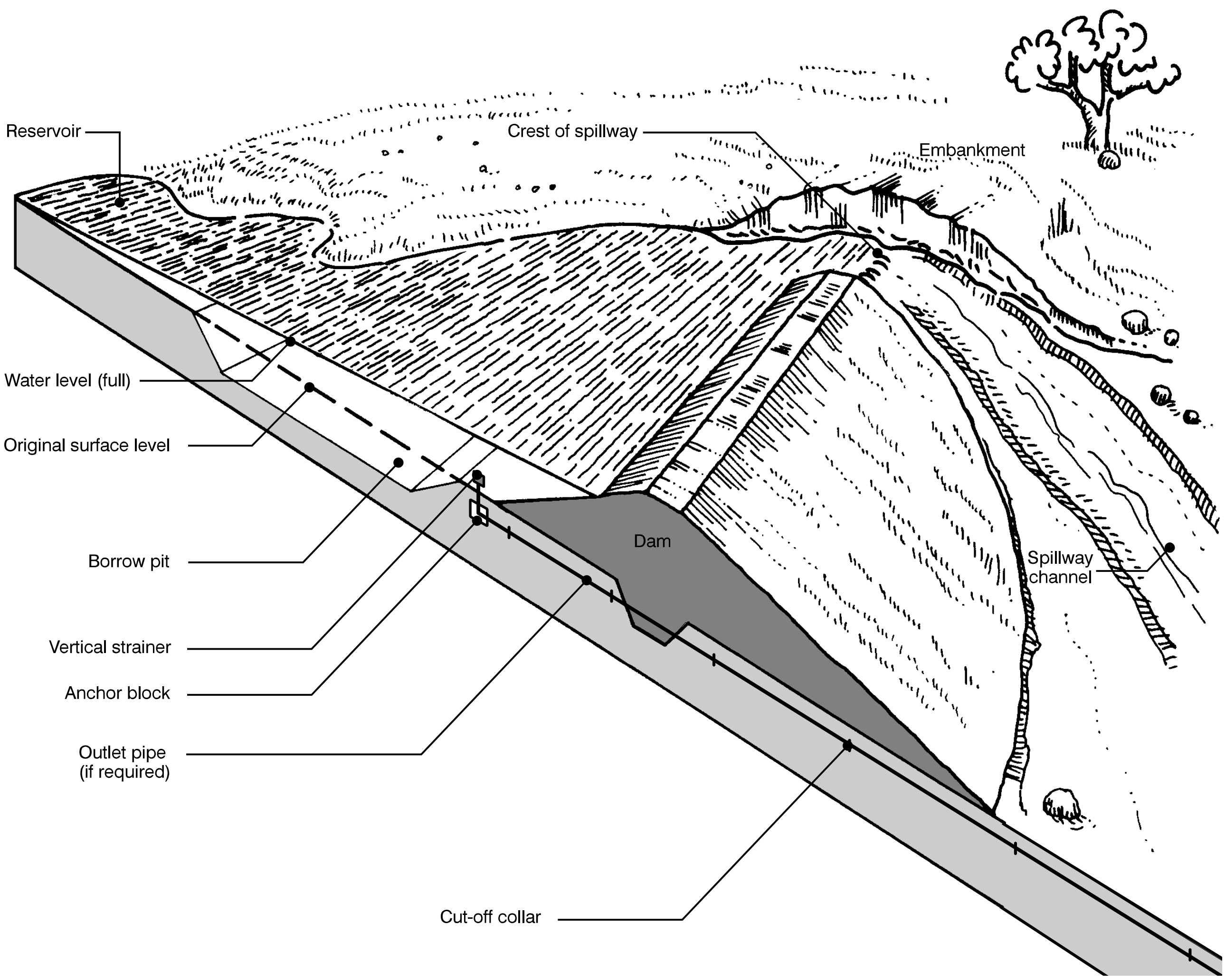

Figure 1. Section through a small earth dam and reservoir

Small earth dams

Design

The design below is suitable for dams up to 3m high. It is a uniform embankment of inorganic, clay loam soil, such as sandy clay loam, clay loam, silty clay loam, or soil with a higher clay content (sandy clay, clay, or silty clay). Any of these can be used provided cracks do not form. The dam must have a 'cut-off' which locks it into the subsoil foundation, ensuring that the dam is stable.

A 3m high dam would typically have a 2m maximum depth of water when full, increasing to 2.5m under flood conditions, with a 0.5m depth of flow over the spillway. The top 0.5m (minimum) is required to provide a safety margin (freeboard) which allows for water rising on the dam due to wind and waves, and wear and tear on the dam crest. The total design height of the dam must be increased for construction by at least 10 per cent, to take account of settlement.

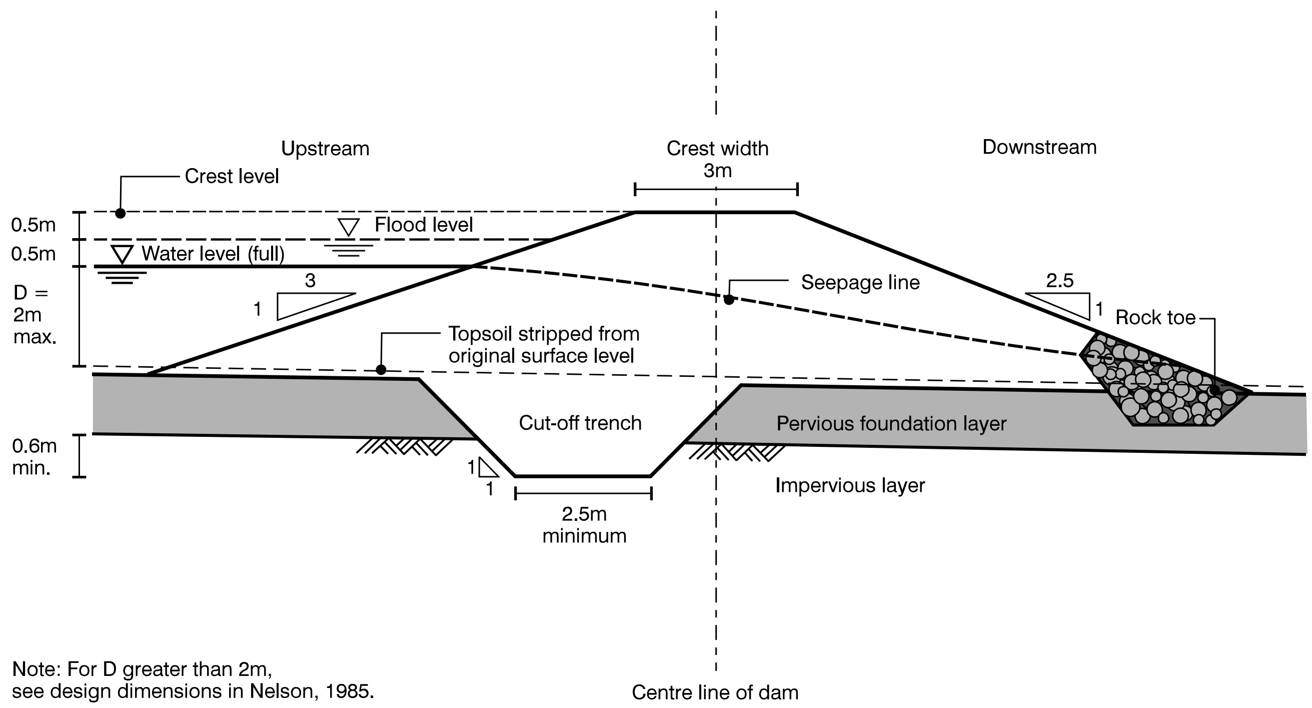

Figure 2. Section through a small earth dam (Source: Nelson, 1985)

Calculating the height of the dam

The height of the dam will depend on the storage required in the reservoir. To calculate this:

- determine the water requirement per day (R litres per day);
- estimate the area of the reservoir (A m^2), the evaporation and seepage losses per day (Emm per day) and, hence, the volume of losses per day (A x E litres per day);
- estimate the length of the critical period (T days), during which the stream flow is less than the water requirement and losses, when requirements would be met using the storage in the reservoir;
- estimate the average stream flow during the critical period (Q litres per day);
- the effective storage required (S litres) = (water requirement per day plus evaporation and seepage losses per day minus average inflow per day) multiplied by the length of critical period:

S = (R + AxE – Q) x T

The dam must be high enough to store this quantity of water. The storage capacity of the reservoir (C litres) is best determined from cross-section surveys across the valley, but can be estimated from the area of the reservoir (Am^2) and the maximum depth of water at the dam (Dm) when full:

C = 330 A x D

The site should then be surveyed to estimate the area (A) of the reservoir for different values of D, and a trial-and-error method will then give the reservoir capacity (C) which meets the storage required (S) and provides a safety margin. The resulting value of A should then be used in the calculation of S to obtain a consistent result. Height of dam = D + 1m.

Construction

The materials should preferably be taken from the reservoir area; different parts of the side of the valley should be examined so that the most suitable soils are located (soil textures will vary according to position in the valley). The following materials should be avoided: organic material — including topsoil — decomposing material, material with high mica content, calcitic clays, fine silts, schists and shales, cracking clays, and sodic soils. Avoid material with roots or stones.

Other construction points to consider:

- Construct during the dry season.
- Divert the stream; block it with a temporary low dam, or divert it through a culvert (which could become part of the outlet works or spillway later).
- Strip topsoil because it contains organic matter (such as roots) which prevents proper compaction and may provide seepage routes (piping) once the organic matter has decayed.
- Pay attention to people's safety — avoid hazardous practices and dangerous equipment.
- Place material in the dam:

  i) in layers 100 to 200mm deep;

  ii) at the optimum moisture content — when material can be rolled to pencil thickness without breaking, and is as wet as possible without clogging the roller; then

  iii) compact with a heavy roller, or by driving across vehicles or animals.
- Cover the whole dam with topsoil:

  i) plant strong grass (such as Kikuyu grass, star grass or Bermuda grass) to protect against erosion;

  ii) maintain the grass (water in the dry season if necessary), but prevent trees taking root, and keep out animals such as rats and termites.
- Protect the upstream slope:

  i) lay a stone or brush mattress (for example bundles of saplings between 25 and 50mm long) on the slope, and tie it down with wire anchored to posts;

  ii) secure a floating timber beam 2 m from the dam — these need replacing every 10 years or so.

Settlement

Even with compaction, earth dams settle as the weight forces air and water from voids (consolidation) — allow for this settlement in the design.

For small dams, well-compacted settlement should be between 5 to 10 per cent of the height of the dam.

Seepage/filter

Some water will seep through the dam, even if it is constructed of good materials, and well-compacted. This seepage reduces the strength of the dam. Nelson recommends the crest width and slopes shown in Figure 2 to provide a stable, 3m-high embankment making extra seepage protection unnecessary. A safer, but technically difficult, solution is to include a rock toe drain (as shown), to collect seepage water. This should extend up to a third of the height of the dam, and a graded sand and gravel filter must be placed between the dam fill material and the drain to prevent fine clay particles being washed out. The filter must be designed according to the particle size of the dam material and the drain, following, for example, recommendations in Schwab *et al,* p488-490.

Extraction of water from the reservoir

A gravity outlet can be constructed, as shown in Figure 1, using a screened inlet on the bed of the reservoir, and a pipe in a trench below the dam. Problems can arise with seepage through poorly compacted material beside the pipe (reduced by placing seepage collars along the pipe to increase the perimeter by at least 25 per cent), and difficulty repairing a damaged pipe. Alternatively, water can be extracted by lifting or pumping, using some of the methods described in Technical Briefs Nos. 22 and 47, for example:

- a sump (well reservoir) in natural ground at the side of the reservoir, supplied by gravity from a screened inlet and pipe through the bed and side of the reservoir;
- a bank-mounted motorized or human-powered pump; or
- a floating intake.

Safety and management

National and local regulations on small dams must be checked and followed in design, construction, and maintenance.

A technically competent person (an engineer or technician) should be responsible for designing and supervising the construction of the dam. The level of expertise required will depend on the potential for failure. Particular technical attention should be paid to the selection of materials and the design of the filter and spillway.

The sizeing of the spillway is important for protecting the dam during floods, but it is difficult to design. It depends on the rainfall intensity and the size and characteristics of the catchment area, and technical advice should be sought on local standards and practice.

A system needs to be set up for checking the condition of the dam and spillway, and for arranging any necessary repair work. This will usually involve training a local caretaker, who has access to a technician who inspects the dam at an appropriate interval (e.g. before each rainy season).

The dam should be regularly inspected for signs of deterioration, such as cracks, gullies, damage by rodents or insects, seepage, and damage to structures, especially the spillway.

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Spillways

A spillway is required to protect the dam from overtopping, for example during high flows. It passes surplus water downstream safely, preventing both the failure of the dam, and damage downstream.

Surplus water flows over a spillway crest at the top water level, and into an open channel around the side of the dam, discharging safely into the stream below the dam. It may be made from reinforced concrete, but a cheaper solution is a grassed spillway with a:

- vegetated earth channel
- protected crest at reservoir top-water level
- maximum velocity 2.5m/s

A grassed spillway requires regular inspection and maintenance, so that erosion can be repaired and a good grass cover is maintained. It is often used together with a trickle-pipe spillway so that small inflows into a full reservoir flow through the trickle pipe, and do not erode the grass spillway. Table 1 can be used to find the minimum inlet width for a given flood flow. These widths apply to well-grassed spillways. Poorly grassed spillways should be wider.

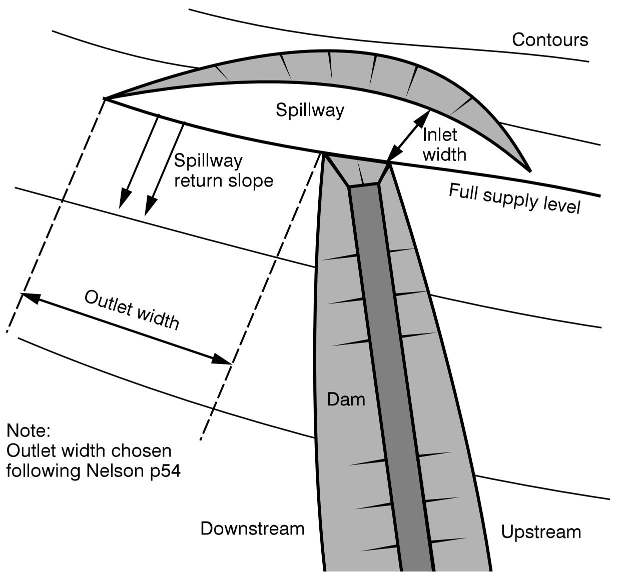

Figure 3. Plan of a spillway
(Source: Nelson, 1985)

Table 1. Minimum inlet width of the spillway

Flood flow (m^3/s)	Inlet width (m)
Up to 3	5.5
4	7.5
5	9.0
6	11.0
7	12.5
8	14.5
9	16.5
10	18.5
11	20.0
12	22.0
13	23.5
14	25.5
15	27.5

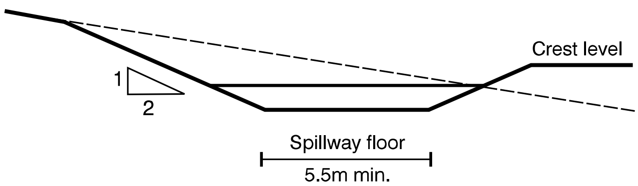

Figure 4. Cross-section of a spillway
(Source: Nelson, 1985)

Further reading

Fowler, John P., 'The design and construction of small earth dams', *Appropriate Technology,* Vol.3, No.4 (reprinted in *Community Water Development,* IT Publications, London, 1989).

Nelson, K. D., *Design and Construction of Small Earth Dams,* Inkata, Melbourne, 1985.

Pickford, John (ed.), *The Worth of Water: Technical Briefs on health, water and sanitation,* IT Publications, London, 1991.

Schwab, G.O., Fangmeier, D.D., Elliot, W.J. and Frevert, R.K., *Soil and Water Conservation Engineering,* Wiley, London, 1993.

Stephens, Tim, *Handbook on Small Earth Dams and Weirs,* Cranfield Press, Bedford, 1991.

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