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Manual on small earth dams

A guide to siting, design and construction

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by

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Contents

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This manual is based in parts on a publication by the author on the same subject and published by Cranfield Press (Stephens, 1991).

Acronyms, abbreviations and symbols

A	Area of the catchment (km^2)
A'	Area of the reservoir at full supply level (ha or m^2)
CAP	Crisis Action Plan
D	Maximum depth of spillway at the crest
DFID	UK Department for International Development
ESP	Exchangable sodium percentage
FSL	Full supply level
GPS	Global positioning system
L	Length of the dam at full supply level
H	Crest height of dam at full supply level (m)
H'	Maximum height of dam at full supply level (m)
H"	Freeboard height (m)
PMF	Probable maximum flood
Q	Dam capacity (m^3)
T	Throwback (m)
UNFPA	United Nations Population Fund
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
Y	Catchment yield (m^3)

Introduction 1

1 Introduction

This manual is designed specifically for engineers, technicians and extension workers involved in agriculture, commercial farmers and contractors – all with some understanding of engineering and some experience of dams, irrigation and water supply – involved in the siting, design and construction of small earth dams in the drier parts of the African continent. Such dams are suitable for supplying water to irrigation schemes, for rural and other water supplies (when properly treated) and for conservation measures.

The manual is derived from the author's many years of experience in dam design and construction in a number of countries in west, central and southern Africa and has been drafted with a view to providing, for the first time in this field, a collation of practical and useful guidelines for siting, designing and constructing small dams. Although derived from training and experience in Africa, the manual will be applicable to many other parts of the world and hence its publication by FAO. Thus, the manual essentially provides a comprehensive and pragmatic means for the practical understanding of the principles and procedures used in small earth dam construction and for the users to safely and competently construct small dams without recourse to the costly, complex and sophisticated design and construction techniques associated with dams on larger catchments.

The manual includes an introduction to community participation, social and gender issues in siting, constructing and operating dams, environmental issues and fish production as well as sections on costing dams, tendering for construction and awarding contracts.

Background 2

2 Background

2.1 INTRODUCTION

In many tropical, subtropical and Mediterranean climates, dry season agriculture and the pre-rainy season establishment of food and cash crops cannot be undertaken without large quantities of water. To rely upon streamflow at a time when temperatures and evaporation are often at a peak can be unrealistic and risky. It may become essential for a dam to be constructed on a river or stream to allow for off-season storage of vital water supplies. Although primarily for irrigation, such structures can be used, either separately or combined, for fish farming[1], stock and domestic water purposes, drainage sumps, groundwater recharge, flood amelioration and conservation storage.

2.2 SAFETY ASPECTS AND SCOPE OF THE MANUAL

In all dam construction, safety must be given priority and users of this manual should follow the guidelines below:

- ➔ Users should restrict themselves to the construction of earth dams no higher than 5 m from streambed to finished crest level.
- ➔ Dams on catchment areas exceeding 25 km^2 or with reservoir areas storing more than 50 000 m^3 may require the advice of a hydrologist to assist in the design of spillways and other outlets and for the estimation of freeboard.
- ➔ No spillway should be less than 10 m wide and 1 m deep for catchments up to 5 km^2 and should be at least 15 m wide and 1.5 m deep for catchments exceeding this area.
- ➔ Any dam that involves out of the ordinary topography (i.e. steep slopes upstream, risks of landslips), hydrology (i.e. flash floods, droughts, snowmelt) or soils (i.e. poor quality soils, sodic soils, permeable layers in the soil, bare earth surfaces in the catchment) should only be designed and constructed under the supervision of a qualified engineer.

Before any dam is constructed, an assessment of the hazard potential should be made. This section and Table 1 provides guidelines:

Table 1: Hazard potential

Loss of life	Economic loss	Hazard potential
Almost impossible	Negligible	None
Extremely unlikely	Minimal	Very low
Improbable	Marginal	Low
Possible	Appreciable	Moderate
Probable	Excessive	High

A dam that is assessed with a high hazard potential should not be built without guidance, for both the design and construction, from a qualified engineer. Dams assessed as having moderate[2] or low hazard potential may need design modifica-

1 Refer to Annex 3 for more information.

2 Sometimes an extra category ‘significant’ is added to this sort of table between high and moderate. Equally the word *hazard* can be changed to *risk*.

tions, including increasing the return period for the design flood, to mitigate the perceived risks, improve stability and reduce susceptibility to flood flows or overtopping.

Increasing freeboard or designing the spillway for the passage of larger flood flows (including having ‘emergency spillways’) can reduce risks to dams from extreme rainfall events. Other modifications that can be made to the embankment are designing for flatter, more stable slopes (especially on poorer foundations or when using poorer earth materials), the introduction of seepage relief measures such as drains and filters and additional mechanisms to permit the release of water from the dam to lower water levels at times of hazard. This is further discussed below.

For all dams, except those assessed with no hazard potential, a **Crisis Action Plan** (CAP) should always be prepared. At a minimum this will comprise:

- ➔ Contact names and telephone numbers (owner of the dam, authorities downstream, police and emergency services and others) to call if the dam is damaged, develops problems or is considered unstable.
- ➔ Information on possible areas likely to be affected downstream (estimated area of inundation) should the dam fail or significant amounts of water require immediate release from gates, drains or outlets. A map to illustrate various levels of inundation (with estimates of timings for any flood wave) should be prepared and be available.
- ➔ A list of names, addresses and telephone numbers (keep this up to date) of inhabitants living immediately downstream of the dam and within the estimated area of inundation.
- ➔ The CAP should be periodically updated to take into account changes in land use downstream and any changes to the catchment upstream.
- ➔ Plans for warning and emergency evacuation, including the provision of safe routes to follow in case of flooding/dam failure. Immediate evacuation should take priority over any other action should the stability of the dam be threatened.
- ➔ Information on resources to use and procedures to follow for emergency repairs. This should include a list of civil engineering contractors, equipment and materials’ suppliers and engineers available locally.

Finally, when a dam is no longer required, or is considered no longer viable, it should be made safe. This could include safely breaching the embankment and returning the river to (as far as possible) its natural state or converting the dam into a conservation structure with a programme of inspection and maintenance to ensure it does not become neglected and eventually a risk to downstream areas.

2.3 IRRIGATION DAMS

The financial benefits from the cultivation of land in many parts of the world are rarely large enough to allow for expensive, technologically advanced concrete structures to be built for impounding water, whether on- or off-stream, and the alternative is normally an earth dam or simple weir.

The actual usable storage capacity of such a reservoir must be greater than the net demand over a season for a crop and must take the following factors into account:

- ➔ The storage should be below the calculated yield of the catchment in a dry year or based on an acceptable average minimal yield over a period of years.
- ➔ Irrigation requirement, which will vary according to the time of year, crop and irrigation efficiency, evapotranspiration rates and other climatic factors. Consultation with local farmers, agriculturalists and climatologists will allow estimates to be made of the total amount of water required per hectare cultivated. For example, wheat grown in a sub-tropical dry season winter in southern Africa will require 5 000 to 6 000 m^3 of water per hectare per 100-120 day season.
- ➔ Evaporation losses can be high and will depend upon climate[3] and the surface area of the stored water. A narrow deep reservoir will have a much smaller evaporation loss than a broad shallow reservoir, and as evaporation can vary from 0.3 m to 2.5 m per annum from temperate to arid climates, this can be a very important design consideration.
- ➔ Seepage will always occur with an earth dam and will depend upon site soil conditions, the embankment itself and the depth of the water.
- ➔ Dead storage is the name given to that part of the reservoir that cannot be drained by an outlet or by pumping. The latter depends largely on the suction arrangements of the pumping set up – a 'flooded' suction through the dam wall will result in very little dead storage whereas pumps located on the side of the reservoir or the embankment will never bring the water level to zero. Note should be taken that it is not always wise to drain a dam completely, most especially if 'cracking clays' have been used in the embankment, core or reservoir floor.

Thus, the anticipated irrigation demand from a dam must be linked to the yield of the catchment in any one year. For semi-arid and arid areas it may be wise to estimate a *dry year* catchment yield and use this for calculating the amount of water available for irrigation or other uses.

Embankment dams have many advantages over equivalent concrete structures and are most appropriate for farm or other rural situations. Dams up to 15 m high, when built on suitable sites and correctly designed and constructed using good earthworks materials, can be built using relatively unsophisticated design procedures and equipment. Farm tractors (equipped with dam scoops, scrapers and rollers) are usually adequate for the construction of such an earth dam which, once completed, should generally have cost less than a concrete wall, with its attendant complex design and construction procedures.

Smaller earth dams require minimal maintenance (unless in difficult locations or in extraordinary climatic situations), and are better able to withstand foundation and abutment movements than the more rigid concrete and masonry structures.

Further advantage can be gained by constructing the embankment from material excavated from the reservoir area. This provides a small increase in storage capacity and reduces costs. Construction on a layer-by-layer basis will allow for good compaction and stability and, spillway parameters permitting, for a flexible timetable of construction to be introduced. Compaction is an essential part of the construction process whatever the size of the embankment and should not be ignored – always pay more for the equipment needed as this cost will be recouped

3 Evaporation from dams in South Africa is estimated at 25–30 percent of the water stored per annum.

by the construction of a better, safer and more stable structure. Construction can be scheduled to fit in with climatic factors and plant and equipment constraints. It is not uncommon for the part of the core below ground, and perhaps the spillway, to be constructed in one dry season and the remaining embankment, training banks and outlet works to be completed in the next. In such staged construction it is essential that, at whatever height the wall is stopped in the first season, a spillway, whether temporary or permanent, is built to divert flood flows safely away from the partially completed structures.

Where farm machinery is being used, the construction schedule can be tailored to fit in with other farm uses to avoid tying up machinery at the expense of agricultural production. It is extremely important that all equipment used in excavation and construction is in perfect condition. A breakdown during a tightly scheduled programme can disrupt staggered procedures, delay completion up to another season and introduce expenses that could have been avoided by simple maintenance procedures. Similarly, when farm machinery is used, it is wise to allow for a complete overhaul of all mechanical and hydraulic systems following completion of the dam when working out costs. For example, the process of scooping and moving heavy clays consistently over long periods is particularly wearing on tractor engines and gearboxes and, if maintenance is ignored, major problems may occur later in carrying out conventional farm activities.

An earth dam will be unique to an individual site; although special emphasis will have been given to local conditions, certain guidelines and generalities can be applied to all dams. When followed, such guidelines will allow for the safe and economic construction of embankments. It must be stressed that, although most of the procedures are simple, and more a matter of common sense than advanced engineering knowledge, if the safety of any design or construction element is in question, a competent civil engineer must be consulted. A failed dam, however small, is not only a matter of a lost structure but can result in loss of life and considerable expense for those downstream. All procedures therefore, in selecting, designing and building dams must be followed to the highest standards possible.

Far too many earth dams are built with a disregard to engineering practice and to local regulations. Water rights and abstraction licences exist in many countries and these should be applied for before construction starts. These not only regulate the amounts of water that can be stored within or abstracted from a river system but also allow inspection and control of dam building to maintain standards of safety and construction. Similarly, most countries in Africa and elsewhere, have environmental regulations to follow, either for applying for a water right or for the approval of the physical construction of a dam.

Guidelines also need to be followed if the dams are to be constructed by contractors and Annex 1 provides general advice on procurement, tender preparation, evaluation and award of contract.

2.4 COMMUNITY PARTICIPATION

For dams being sponsored by governments or other agencies for community operation and management, whether for agriculture or water supply, it is essential to consult local people. Try to obtain a representative view, not that of just landowners or important people in a community, but also those who will be most directly affected or benefit from any dam, to determine their needs and views. This is particularly important where the community is expected to contribute towards the siting and construction (i.e. with the provision of land, their labour and possibly local materials) operation and maintenance of the dam. Responsible ownership of the dam and its catchment by the community, even if the dam is to be built by an outside agency, is vital for future maintenance and longevity of the structure.

Social and gender issues should be considered at this time and throughout the design and construction process. Men and women differ in their preference and needs for water and will be affected differently when the dam is finished and is storing water. It is important not to constrain the participation of women or the poor in decision making, in membership of groups associated with the dam (and any irrigation scheme) and in evaluating changes that will occur in workloads for men and women following the introduction of the dam and its related infrastructure. Section 2.5 provides further guidelines on this.

The establishment of dam committees at an early stage is strongly recommended. The main users of the dam should be well represented on this committee – in Africa women are often responsible for drawing water and should therefore be consulted on the site to be selected and be included in the committee. The same committee should later be converted to the operation and maintenance committee once the dam has been completed.

Training local people in all aspects of dam repair and maintenance may need to be included in the construction programme. Where local participation is expected in the construction process any contracts awarded to private contractors should clearly define all contributions to be made by the community and the contractors asked to modify their work programmes and practices accordingly. This may lengthen the construction period and increase costs but may prove worthwhile in the long term in enhancing ownership responsibilities and skills amongst the beneficiaries.

2.5 SOCIAL AND GENDER ASPECTS

In most countries land and water rights are closely related, although water is often a public good, and therefore its use is associated with permits, concessions, and other tenure systems. Irrigated and rainfed land is the main source of livelihood for many rural populations. Women have much less access to this essential asset than men. The distribution of water and land is a major determinant of poverty.

Women and girls are typically responsible for collecting water for daily needs. This includes water for drinking, livestock, cooking, cleaning and overall health and hygiene within the household. According to the United Nations Population Fund (UNFPA), in 2002, women in many developing countries walked an average of 6 km a day to collect water. In southern Africa, migration of men from rural areas has led to an increase in women-headed households and an overburdening of women with tasks of maintaining households as well as farms. The availability of clean water close to home saves women's and girls' time, which can be spent on other productive and human development activities, such as crop production and education. Equally, it must be clear that the development of any irrigation scheme should not onerously increase the work load of both men and women.

Clear water rights lead to improved access to water, which is critical for maintaining good health and a sustainable livelihood. Studies from Africa show that both rural and urban women are engaged in small-scale enterprises and that improved access to water would help them to pursue these activities more effectively. Water quality is very important in this context for the health standards of the whole household. Planning projects for multipurpose use of water requires a thorough investigation of the non-agricultural uses and, in particular, an assessment of women's needs.

Designing for a safe and hygienic water supply from dams is thus important. Protected shallow wells or boreholes, fitted with hand pumps, downstream of the embankment, to benefit from any underground seepage, can be useful combined with restricting access to the reservoir (fencing). Alternatively, a pipe though the embankment (installed at the time of construction) with a simple sand filter and water outlets for domestic and livestock uses could be considered. All designs and installations must be completed with the full participation of the end users to ensure that they are appropriate and sustainable.

To identify key issues in social and gender aspects, and to assist in evaluating anticipated impacts that any project may bring about, FAO has guidelines for the social analysis of investment in agriculture and rural development. The Gender in agriculture sourcebook, (World Bank, *et al.*, 2009) is another useful reference on this.

2.6 THE USBR MANUAL ON SMALL DAMS

The reference text for dam construction is the United States Department of the Interior Bureau of Reclamation (USBR) Manual on the design of small dams (2006), and applicable to small dams constructed in the United States. 'Small' dams so defined are up to 90 m high. The technologies, procedures and methods of design and construction provided are tailored for such dams. Many of the design and construction procedures are not applicable to smaller 'farm' dams and cannot be downsized to become appropriate to the less sophisticated techniques and methodologies required. The USBR Manual is designed to be used by qualified, experienced engineers working on a range of dams and on large catchments in the United States. It is a useful reference but is not directly applicable to the small dams the present manual is targeting.