NILE BASIN CAPACITY BUILDING NETWORK
RIVER ENGINEERING

RIVER STRUCTURE RESEARCH CLUSTER
-ETHIOPIA-

RESEARCH REPORT: MICRO-DAMS GROUP

Executive Summary

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Egypt,
Ethiopia,
Sudan and
Uganda

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Research objectives:

- To make an inventory of the existing micro-dam in Egypt, Ethiopia, Sudan and Uganda.
- To assess the performance of the inventoried micro – dams based on documentation available and limited field visit.
- To set the priorities for important research areas (significant problems encountered in the three countries) and recommend research topics to be further developed in a second phase of the project,
- To draft the guidelines for assessment of the performances of the micro-dam.

Table of contents

List of Tables

1. INTRODUCTION

During the launching eve vent of the regional research cluster of River Structures held in Addis Ababa, 4-6 March 2003, the participants decided to launch a research direction on micro-dams[1]. Four countries, namely Egypt, Ethiopia, Sudan and Uganda decided to actively participate to the development of a research plan on this topic.

The overall objective of the research is to assess and evaluate the river engineering problems that encountered at the design, construction, and implementation of the micro dams. For the first phase of the project March 2003 – June 2004, the following specific objectives were set out:

- To make an inventory of the existing micro-dam in Egypt, Ethiopia, Sudan and Uganda.
- To assess the performance of the inventoried micro – dams based on documentation available and limited field visit.
- To set the priorities for important research areas (significant problems encountered in the three countries) and recommend research topics to be further developed in a second phase of the project,
- To draft the guidelines for assessment of the performances of the micro-dam.

During the first phase of the project the following activities were accomplished:

- A partial inventory of existing micro-dam was done for Uganda and Sudan. Fifty-eight micro-dams in Sudan and twenty-two micro-dams in Uganda are identified and relevant data collected, Appendix 1 and Appendix 2, respectively. It should be mentioned that the data process of assessment of the existing small (micro) dams is not yet completed. Further work is therefore required. In the case of Ethiopia, making field visits should collect data about micro dams.

- The guidelines for performance assessment of the micro-dam in the Nile Basin region was drafted and proposed for discussion. The objectives of preparing this guidelines are:
    - To set up the requirements for initial investigations and subsequent analyses;
    - To set up funding for critical repairs, rehabilitation, or modifications;
    - To select and justify the optimal plan to protect human life, reduce property damage, and mitigate environmental damage;
    - To indicate the main measures to be taken to minimize the disruptions of service;
    - To maximize effectiveness of infrastructure investments and
    - To learn from the previous success / failure by having proper documentation of the existing local history.

Two significant areas were selected to analyse the performance of small dams. The first area is the safety performance and the second is the performance regarding its fulfilment in the expected yield / service.

1

Small dams being equivalent to micro-dam / small earth-fill dam is defined for use in this NBCBRE-project as a barrier constructed across a river or a natural stream to create a reservoir for impounding water, or facilitate diversion of water from the river or to retain sediment flowing in the river along the water with dam height measured from lowest point of natural ground level, including the depth of main stream channel, is less than *15 m* but can be considered as small up to 25 *m* if the storage is small (less than 2 million meter cube) and does not cause significant damage in life and properties to downstream environ in case of dam breach.

The dam safety performance assessment is made on the structure of the dam including its crest, u/s slope, downstream slope, drainage –seepage control, abutment contacts, inlet structure, spillway, stilling basin, and reservoir area.

The Service / Yield Performance, can be measured by comparing design reservoir yield versus observed reservoir yield and predicted loss of the reservoir volume due to sedimentation.

2 MICRO-DAMS: NEEDS AND CHALLENGES

In tropical unimodal or bimodal rainfall receiving areas of Nile basin, the need to develop irrigated agriculture through storage scheme (using micro-dam – large dams) as a supplement to the rain-fed agriculture (for example in Ethiopia, Sudan and Uganda) and to irrigated agriculture (in Egypt and partly Sudan) is justified by a number of factors. Among these important factors are:

- Significant drought periods and variable climate conditions

- Long dry spells occasionally disrupt the rainfall season. In areas where rainfall is unimodal, protracted dry spells sometimes interrupt the rainy season with serious repercussions on crop production. Even minor water deficits have had dramatic impacts on crop yields especially when these shortages take place during the flowering stage of the crop. Under such circumstances *supplementary irrigation* is crucial for the sustenance of crop growth and maturity. The unimodal nature of rainfall pattern places limitations on the varieties of crops that can be produced. Crops that need a lot of water during the dry season months require the use of irrigation systems. Irrigated agriculture therefore offers these countries an opportunity to achieve *crop diversification program*.

- The increase in population growth calls for improved agricultural production to match the demand for food. The rapid increase in population growth has led to declining amount of arable land. Under rain fed conditions crop production on such land is inadequate for food security. However, with the introduction of dry season farming through irrigation the productivity can be enhanced. Hence there is need for intensification of agriculture production through irrigation to keep pace with the population growth and job creation.

Finally, livestock productivity is highly constrained by lack of adequate feed and drinking water supply in the dry season. Where conditions of acute shortages of forage prevail severe reductions in livestock numbers occur. Irrigation could be used to produce livestock feed and also provide drinking water during the dry season.

These needs to conserve water resources for irrigation and water supply that can easily be managed by the rural community has resulted in the use of small earth dams, Figure 1, constructed by the local communities themselves, as sources of water supply for the development of irrigated agriculture.

However, it should be pointed out at the outset that the development of small dams for irrigation is being threatened by:

(1) Sedimentation problems arising from the degradation of catchment areas fuelled by four pressure indicators namely agricultural production, rapid population growth, poverty and wood energy demands,

(2) Inappropriate runoff estimation methods resulting in over sizing or under-sizing of dams,

(3) Unreliable spillway flood estimation methods.

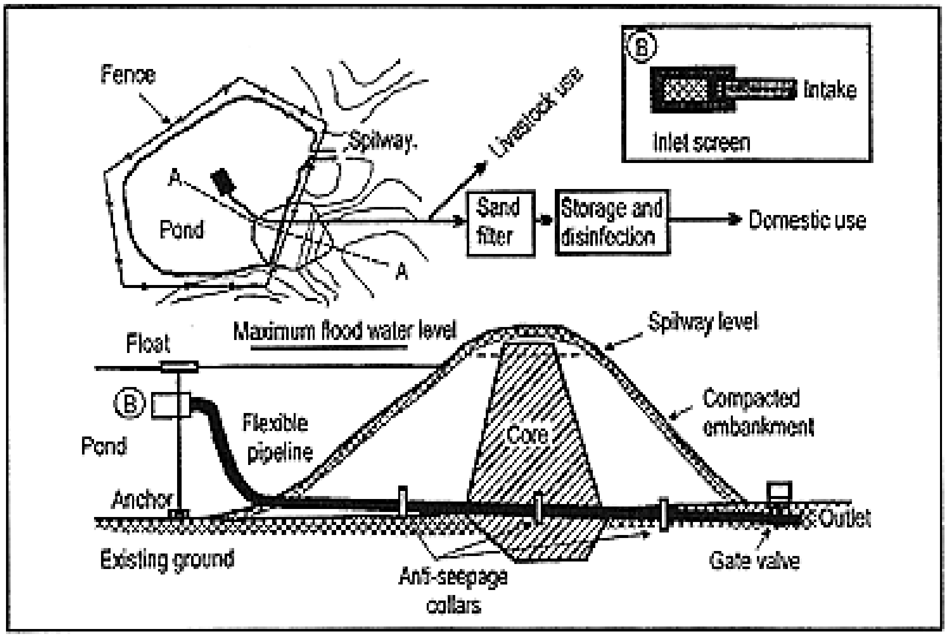


Figure 1. Micro-dam with its major structural components.

3 ASSESSMENT OF THE MICRO-DAMS IN UGANDA, SUDAN AND ETHIOPIA

In the last decade a number of micro-dam have been constructed in Ethiopia, Sudan and Uganda to be used for irrigation and water supply (domestic and cattle) purposes. It is known that most of them were designed under inadequate hydrological data condition - their stream flows / creek flows were not gauged. Some of the reservoirs failed to deliver the design yields. Some of them lost their useful storage for sediments in few years. Some failed due to overtopping. Some failed due dam failure- stability problems. Subsequently, a brief analyse of the small dams constructed in these countries and the main problems faced in operation is given

3.1 PARTICULARITIES OF THE MICRO-DAMS IN SUDAN

3.1.1 INTRODUCTION

Micro-dams in Sudan are important tool of water harvesting especially in the areas, which have limited rainfall, seasonal wadis and where groundwater is difficult to be utilized. In these areas the rainfall is collected during the rainy season, stored in small reservoirs and utilized during dry season. The importance of small dams in Sudan evolves from the fact that it can be the only source of domestic water supply in some areas.
The productivity of the rain fed sector becomes very low and unreliable over the last three decades due to erratic nature of the rainfall. On the other hand the domestic water supply in most parts of the Sudan (areas away from the Nile) relies on rainwater harvesting and ground water. In some parts tribal wars are initiated due to competition for water between pastoralists and farmers. Therefore, water harvesting is an important element of the development in rural parts of Sudan and hence it is worthy to study the design tools and recommend a proper design procedure so that an economic, stable and reliable micro-dam and its appurtenant were realized. Thus, it constitutes the backbone for economic and social development for rural areas. Up to season 1975/76 there were over 40 micro-dams in Sudan with a total capacity of more than 22 million m^3. In the past the Corporation for Rural Water Resources Development were the sole authority for the design and construction of the micro-dam.

Most of the micro-dams are constructed for domestic water supply purposes and in some occasions for domestic water supply and irrigation water supply. These dams differ in the construction material, capacity and the purpose of its construction. Due to the inadequate designs there are cases of failure, dam breaks and complete siltation of the working storage in few years. In some cases the dam appurtenance (spillways, gates, etc) were not properly designed due to the limited information and/or improper design/construction procedure.

3.1.2 RESULTS OF THE ASSESSMENT.

A number of fifty-eight micro dams constructed in Sudan were analysed for the scope of this study. Appendix 1 shows the main data about these structures. The most important conclusions after the assessment of their data and performances are summarised below:

General data

- Most of the micro-dam were constructed for the purpose of water supply.
- Small number of these micro-dams was constructed for the purpose of recharging groundwater.
- The operation and maintenance of these structures is under state responsibilities.
- There is no sufficient information on the operation rules available.

Siltation
Most of these micro-dam faced severe siltation problems e.g the Shawfogo and Golo Dams filled completely with silt (100%). The problem with these two dams is that they do not have gates to pass silts. Another example is Haloof Dam in Elfashir area silted completely (100%) though it has gates but because these gates are not operated for long time they become un-operational due to silt.

Clogging of the gates
In some cases the lower gates were designed as valves to be opened to pass the early floodwater and its contents of sediment. E.g. in Mallit dam the gates were clogged due to operation problems.

Spillway collapse
Spillway failure can be attributed to construction problems and/or design problems. An example is the dam in Kuma area where the spillway collapsed because it has very week supports.

Seepage below dams
Seepage of water beneath the dam or from the reservoir takes place when the geomorphologic characteristics of the dam side are overlooked.

Change of the wadi course (wrong intakes)
In Wadi Ira weirs are used to divert water to irrigate lowlands in Tulus area in Southern Darfur state. Due lack of knowledge about the geomorphology of the catchment and design mistakes the wadi changed its course.

In Golo dam one of the oldest dams, it has a number of spillways and channels to divert enough water to be stored and release the excess quantities outside the dam. Due one reason or the other these spillways are not operated properly in some years and due to the excessive sedimentation in the reservoir, the wadi started changing its course from one side to the other depending on the flood wave.

In summary Sudan has more than 100 micro-dam scattered all over the country with concentration in the western part. Most of these dams faces same problems which can be summarized in two broad categories namely design problems and construction problems. The construction problems appear be mainly quality control and specification problems. The following areas need be researched in the order of preference as relevant to Sudan Node: revisiting the design procedure, design floods for some of the wadi's, sediment yield estimation and control and watershed management. It is to be noted that the data inventory are not complete with respect to collecting all the existing micro-dam (operational or silted up) and listing up of the salient features of the identified micro-dam. Further work is therefore required along this line.

3.2 PARTICULARITIES OF THE MICRO-DAMS IN UGANDA

3.2.1 INTRODUCTION

Uganda is found within the Great Lakes region of Africa and shares common borders with: Kenya in the East, Tanzania and Rwanda in the South, DRC in the West and Sudan in the North. It occupies an area of 241,038 km^2 of which land area (excluding open water and swamps) constitutes 197,097 km^2 and open water and swamps constitute 43,941 km^2. The country's minimum altitude above sea level is 620 meters (Albert Nile) and the maximum altitude above sea level is 5,110 meters (Mt. Rwenzori peak). As a result of this high altitude, Uganda's would be tropical climate is modified considerably. The temperatures range from 15^{O}C to 30^{O}C with an average of about 21^{O}C.

Although landlocked, Uganda has fresh water lakes including Lake Victoria (which is shared with Kenya and Tanzania) and Lakes Edward and Albert (shared with DRC). There are other lakes, which are within its boundaries, and they include Lakes: George, Kyoga, Bunyonyi, Wamala and Bisina. The main rivers include Nile, Kagera, Semuliki, and Aswa.
The country's precipitation is fairly reliable and varies from 750mm per year in North – Eastern Uganda in the pastoral areas of Karamoja to 2000mm per year in the high rainfall areas on the shores of Lake Victoria, around the highlands of Mt. Elgon in the East and the Rwenzori Mountains in the West.

The Uganda population according to the 2002 census is 24.7 million growing at a rate of 3.3% while the gross national income per capita is estimated at US$ 250. Agriculture is the most important sector of the economy, employing over 80% of the work force. Coffee is the major export crop and accounts for the bulk of export revenues.

In Uganda, micro-dams are mainly used for storing water for livestock in the cattle belt. They are also referred to as valley dams because surface runoff and small tributaries collecting in a valley bottom are impounded to form the dams. They range in capacity from 46,000 m^3 to 1,000,000 m^3 while the head ranges from 3-7m. The dams are mainly constructed as earth-fill embankments and seepage and leakage are important factors in their design and operation. In fact most failure of the micro-dam in the past have been attributed to seepage and sedimentation.

The Uganda government is interested in increased water availability to the population with vast investments in under the Water for Production program. A total of 425 micro-dam have been constructed in semi arid areas of Nakasongola, Mbarara, Kotido and Moroto districts (Gibb,1989). A further 1000 dams are to be constructed over the next 5 years beginning 2003. On the other hand problems associated with loss of water are very common. Monitoring of the performance of existing dams is non-existent. However, reports of failed and failing dams are common in the press. Many of these failures are associated with water loss due to seepage and leakage. At one time a number of dams were constructed in Karamoja district but they were unable to retain water for any extended period of time, probably because of insufficient seepage and leakage assessment during the design process. There is, therefore need to investigate causes of these failures with the aim of designing better dams in future.

3.2.2 RESULTS OF THE ASSESSMENT

Inventory of micro-dam in Uganda was conducted with limitations on the reliability of the data set caused by the possibility of subjective responses of the field enumerators. Forms were prepared for the purpose of data collection and the responses were affected by the interpretation of the enumerator. However, limitations related to subjectivity of the enumerators were minimized with prior training of the enumerators before the exercise. The following sections give general results of the analysis.

Accessibility of the dams
Only 1% of the dams were considered to be inaccessible. 245 dams (68%) were found to be less than 5km from the nearest all weather road while a further 79 were found to be within a distance of 10km. In general dams in the south and southwest of the country were found to be more easily accessible than those in the north and northeast.

Maintenance
The local people were asked who maintains the dams and the responses are given in Table 1 In addition to the fact that it was reported that 32% of the dams are not maintained by anyone, a large number of the dams for which it was claimed that someone carries out maintenance, are in practice poorly maintained, if maintained at

all. The highest level of individual/community involvement in maintenance was noted in the southwest and central regions of the country at 44% and 50% respectively as opposed to the north and northeast with figures of less than 10%. This is in particular related to the people's perceptions of the ownership of the dams. Where more people feel they own the dams (southwest and central part), they are also ready to carry out maintenance on their own.

Table 1: Micro-dam maintenance responsibility

	Maintained by			
	Individual	Community	Government	No one
Percentage	6	18	44	32

The frequency of maintenance was assessed by gauging respondents' perceptions, Table 2

Table 2: Frequency of micro-dam maintenance

	Frequency of maintenance			
	As needed	Annually	Haphazard	None
Percentage	10	3	22	64

64% of the dams were reported to have no maintenance whatsoever, while attention for maintenance at another 20% is haphazard and dubious. Only 6% of the structures were reported to be maintained annually, while the definition of maintenance "as needed" is rather subjective and does not necessarily mean that it is adequate.

Table 3 gives a cross tabulation between maintenance responsibility and maintenance frequency.

Table 3: Relationship between maintenance responsibility and maintenance frequency.

Responsibility for maintenance	Frequency of maintenance			
	As needed	Annually	Haphazard	None
Individual	57%	19%	24%	0%
Community	23%	13%	60%	3%
Government	8%	5%	20%	67%

Land use of catchment area

Table 4 sows that the local population at most of the surveyed sites uses the catchment area for some sort of activity. It is only in a limited number of places (15%) that unused natural vegetation still exists. On the other hand regional analysis showed that unused natural vegetation still exists at 33% of the dams surveyed in the north while the figure drops 8%.

Table 4:Major land use of the catchment areas of the dams surveyed

	Catchment land use			
	Unused natural vegetation	Subsistence farming	Cash farming	Grazing
Percentage	15	42	0	43

Main source of water

An assessment of the main source of water showed that perennial and seasonal streams are the main source of water for the dams as compared to rainfall-runoff from the catchment, table 5

Table 5: Sources of water for micro-dams

	Sources of water		
	Rainfall Runoff	Perennial stream	Seasonal stream
Percentage	39	27	34

Spillway
Most of the spillways surveyed were made of earth, though some few were made of concrete and they were mainly of two types either side weir or crest weir (Table 6). The table below shows the results

Table 6: Spillway construction material

Number of dams	Material				
	Concrete	Earth	Buried	Not obvious	Total
Side weir as	6	210	37	33	286
Crest weir as	4	31	38	2	75
Total	10	241	75	35	361

Age of the dams
The ages of the surveyed dams are shown in the Table 8. The dams are generally old. Over 85% of the dams are more than 25 years old. The median age of the dams is around 52 years. This means a number of the dams have surpassed their design life (usually taken to be 50 years).

Note that the inventory does not include dams constructed since 1996. An assessment of the age distribution showed that on average dams in the north are older than those in the other regions, Table 8.

Table 7: Age of micro-dam

	Before 1950	1951-1960	1961-1970	1971-1980	1981-1996	Total
No. of Dams	109	107	38	20	13	287

Table 8. Age of micro-dam distribution by region

	Southwest	Central	Southeast	North
Median age (years)	43	31	51	55

The lower age of the dams in the central region is because most of the dams constructed in the 25years till 1996 were constructed in this region. It may be important to note that most dams constructed since 1996 were in the north particularly the northeast) and the southern part of the country.

Dam volumes
The survey also included an assessment of the maximum volume of the dams at construction, Table 9.

Table 9: Volume of construction material and number of micro-dam.

	Volume (m^3)				
	Under 10000	10000-30000	30000-100000	Over 100000	Total
No. of dams	37	49	96	79	261

The median volume of the dams was found to be around 50,000m^3 while there were quite a good number (79) with volumes over 100000m^3.

Siltation

Enumerators were required to estimate the degree of siltation of every structure they visited. This was intended to permit the estimation of the amount of storage capacity remaining for current use, use as a factor in future designs of dams as well as an input towards the rehabilitation cost estimate. On the other hand it was not possible to estimate the current available storage volume as other factors like breaching of the dam were involved. Though the figures were mainly estimates it was noted that the data set was big enough to make some useful deductions (Table 10).

Table 10. Rate of siltation

	Siltation (%)					
	<20%	21-40%	41-60%	61-70%	>80%	Total
No. of Dams	44	67	74	79	45	311

Overall estimates showed that the dams are suffering from a siltation rate of 53% i.e. the remaining storage of the dams is about half of the original volume. Further analysis showed that about 63% of the dams were reported to be 50% to 60% silted. A cross analysis of siltation level with age of the dams showed that the level of siltation increases with age. More recently constructed structures were less silted than older ones. However, it was noted that as age increases there are relatively limited differences in the level of siltation. This is probably due to the fact that other factors may become more important than siltation such as condition of the catchment area.

General condition assessment of micro-dams

The condition of the key components of the surveyed dams were investigated and the results summarised in Table 11 (a) and (b)

Table 11. General condition survey of micro-dam (a) crest and side slopes

Component	No. of dams that have				Total
	Well maintained	Silted	Breached/ buried	Not accessible	
Crest	11	76	244	10	341
Side slopes	5	26	235	10	276

Spillways

Component	Condition				Total
	Well maintained	Silted	Overgrown	Not accessible	
No. of spillways	4	24	273	19	320

It can be noted from above that the number of dams whose structures are well maintained is extremely low (only about 1%). About 70% and 85% of the dam crest and side slopes respectively have been breached or buried. Also 85% of the spillways are overgrown with vegetation. This means that they need urgent rehabilitation work if they are to continue serving the purpose for which they were constructed.

Conclusions and recommendations

The above assessment is based on an inventory that was done in 1996. There has been ongoing work in the country since then to rehabilitate old dams as well as construct new ones. There is therefore need to update the inventory so that a more current assessment can be carried out. On the other hand the above analysis gives a fairly good picture of the current state of micro-dams in the country. The assessment is mainly based on general observations by the enumerators. There is need to select a few case study dams and study them in detail so that we can make better inferences on their state.

3.3 PARTICULARITIES OF THE MICRO-DAM IN ETHIOPIA

3.3.1 INTRODUCTION

Traditional small-scale irrigation schemes have also existed centuries ago, notably in the Eastern, Central and North-western parts of the country. The diversion structures are constructed of wood, stones, and grass sods. They are often washed away during high river flows and have to be remade each year.

In Ethiopia modern small scale irrigation using micro-dam were given great emphasis after a major droughts have stricken the country in 1973/74 and 1984/85. It is believed that micro-dam help reduce family risks that are associated with crop failures resulting from droughts, although the coverage of the poor is very small.

Since 1992 the responsibility for the development of small-scale irrigation schemes has been transferred from the Federal Government to the regional governments. Sustainable Agricultural and Environment Rehabilitation Commissions (CO-SAER) have been established in Tigray, Amhara and Southern Nations, Nationalities and Peoples Regional States and Irrigation Development Authority in Oromia Regional State (OIDA). The current regional irrigation development services (CO-SAER and OIDA), provided design and construction assistance for permanent diversion structures and in most instances also for main and secondary canals.

During the previous 13 years more than fifty small dams have been constructed in Tigray and Amhara Regional States. Their storage capacity and dam height ranges from 0.1-3.10 Mm^3 and 9-24 m respectively. Since these storage dams are important to store rainwater and fill the gap between rainy and dry years similar projects are under implementation or planned to be implemented in the near future. Some of these micro-dams have multipurpose use such as for potable water supply, irrigation, groundwater recharge and livestock watering.

3.3.2 RESULTS OF THE ASSESSMENT.

Micro-dam in 1970's

Following a major drought of 1974/75 the construction of micro-dam by the Cuban engineering team had been carried out from 1978-1982 after the agreement made on the collaboration between the Ethiopian and the Cuban Governments, started just after the visit paid by the Cuban President Fidel Castro Ruz to Ethiopian in September 1978. The dams constructed by the team had been working together with the Ethiopian Water Resource Authority’s counter parts. During their stay in Ethiopia, they studied, designed and constructed 4 micro-dams. These are, Belbela, Wedecha, Tolly and Chichat dam. The first three are in the Awash River basin and the fourth one is in the Tekeze River basin. (Table 12)

Table 12. Micro-dam constructed in the late seventies in Ethiopia.

S.no	Site Name	River Basin	Cat,area (km^2)	Storage Capacity (Mm^3)	Dam height (m)	Command area (ha)
1	Wedecha	Awash	115	16	13	Regulation
2	Belbela	Awsh	88	12	21	2000
3	Chichat	Tekeze	43	4	15	100
4	Tolley-3	Awash	28	4	15	400
5	Diksis	Wabe s.	57	0.37	8	WS

The construction work started East of Debre Zeit town (abut 55km east of Addis Ababa). The Project is a classic, practical example of the works. It consists of two Micro-dams joined by a transverse canal, Wedecha Micro-dam, located at 2450 m.a.s.l. It has a catchments area of 115 km^2 and a storage volume of $16Mm^{3.}$ By means of small earth weir and a transverse canal this micro-dam can deliver by gravity its waters to Belebela micro-dam. The Diksis micro-dam was built to provide drinking water to the Diksis state farm and it was commissioned in 1979.

In 2003, a technical team from the Ministry of Water Resources had carried out a site visit on the Belbela and Wedecha dams. The team reported that,

- The spillway is inadequate to discharge the incoming flood
- High sediment load in the reservoirs
- Embankment cracks in the down stream face of both dams
- Lack of proper maintenance and rehabilitation work.

Dams in 1990's

Partial list of micro-dam constructed since 1990's are given in Table 13. Some detail description of selected micro-dam along with their benefits and problems they encountered are given below.

Mai-Serakit Micro dam

Mai- serakit, scheme is found in Tigray region. It is 30.6 kms far away from the town of Quiha to the northeastern direction. The watershed area of the scheme is found in Tekeze River basin. The topographic feature of the watershed area is composed of different land features, which are separated by the main intermittent river gullies, and other tributary gullies. The land slope of the area is dominated by undulating and rolling type land feature. There is also an area of hilly and mountainous land feature stretching from the left abutment to the south-eastern periphery of the watershed area.

The shape of the watershed is compact type in which it has an average length width ratio of 9:2. It has also medium drainage pattern in which the soil is mainly characterized by clay texture, and moderately to good permeability. The total length of the main stream is around 2.6 km

The area of Mai- serakit has remained to be drought-affected area for the last three decades. This is mainly attributed to climatic factors, the prominent element being erratic occurrence of rainfall. The implementation of small-scale irrigation using micro dams, which harness water of the rainy season, could easily be justified, considering the hydrological parameters that indicate sufficient rainfall to generate runoff for small-scale irrigation.

The supply of irrigation water leads to improved agricultural pattern, increased crop yield, and increased employment opportunity and thus bring about significant changes in the social and economic pattern of society.

Sewhimeda Micro-dam

Sewhimeda dam is found in Southern Tigray Zone about 10 Km west of Mekele town. It is a Zoned type of dam undergone through feasibility stage of investigation in 1996 and designed in the same year. Its construction was in 1997 with the aim to irrigate 30-40 ha of land. It is designed with 185m dam crest length, 14.5m maximum dam height and reservoir capacity about 700,000m^3. However, the dam encountered seepage problems during its operational period. The main reason is that very excessive seepage has been encountered through the reservoir and foundation materials. Therefore, in 2000, detail geological and engineering geological investigations had been carried out define the potential failure sources of the dam.

The site investigations were conducted in phases. Based on the geological mapping a detail engineering geological investigation the weak and pervious zones had been clearly identified on the reservoir area.

The water tightness problem of the site is vast. The alternating soil layers, shallow soil cover and exposed limestone units are the weak parts in terms of water tightness, since a large portion of them have contact with the reservoir water. In other words these weak formations are widely distributed within the reservoir area. So the solution would be disconnecting these weak formations with the reservoir water to bring a significant reduction in water loss. Therefore, to reduce the seepage problem blanketing of some portion of the reservoir area had been proposed.

Maylomy Micro dam

The micro-dam is located in the Tekeze River Basin at 12^{0}35$^’$ and 39^{0}22$^’$ in Amhara regional state. It was commissioned in 1998 to irrigate 55ha. Howe ever, before it serves its intended use seepage and cracking, problems occurred on the foundation and dam body.

Table 13. List of Micro-dam in Amhara and Tigray Regional states constructed since 1990's

	Site Name	Location		Catchment Area (km^2)	Capacity (Mm^3)	Dam Height (m)	Irrigation Area (ha)
		North	East				
1	Mejae			3.15	0.3	13.5	14
2	Mai-Gassa	13^{0}19'56	39^0 34'50	9.05	1.3	12.7	70
3	Mai-Delle	13^{0}13'30	39^{0}32'22	10.05	1.77	15	90
4	Mai-Haidi			1.96	0.24	9.2	9
5	Gra-Shito			4.46	0.3	10	16
6	Fledgling			6.12	0.28	14	20
7	Gereb-Segen			4.79	0.55	14.8	24
8	Felaga			8.16	0.9	11.9	75
9	Adi-Amharay			6	0.96	14.7	60
10	Sewhimeda	13^{0}32'11"	39^{0}24'38"	4.7	0.36	14.5	23
11	Gereb-Awso			0.97	0.11	10.5	9
12	Adi-Hilo			0.71	0.1	11.4	9
13	Adi-Shihu			9.4	1	10.8	40
14	Mai-Serakit	13^{0}31'20"	39^{0}41'30"	4.48	0.49	11	31
15	Gum-Sellase	13^{0}15'05"	39^{0}24'38"	18.55	1.9	11.5	110
16	Dana	11^{0}49'00"	39^{0}47'00"	7.3	1.67	20	
17	Tebi	11^{0}13'00"	39^{0}00'00"	9	1.15	17	
18	Maylomy	12^{0}35'00"	39^{0}22'00"	6.25	1.9	22	

The excessive seepage was observed at the mid section of the rock toe and the crack observed in the longitudinal direction of the dam body extending over 228m parallel to the dam axis. The minimum and maximum depth of crack was 20 and 90cm respectively (Girma G., 2001). It was finally recognized that, the cause of the problem was due to the combination of geological factors and inadequate experience in construction work.

Common problems encountered:
The design and construction of dams have not always been up to standard and a consequence, have caused partial or total failure of the work. Some of the above projects have problems related to:

- Overtopping due to inadequate spillway capacity – flood estimation problem
- Seepage through foundation, abutments and reservoir area – site selection problem
- Cracking or Structural failure – geotechnical problem
- Less inflow in the reservoir – hydrological analysis problem
- Sedimentation – design problem and lack of watershed management
- Lack of Proper maintenance and rehabilitation work

It is worth mentioning that, most of the above micro-dam projects had been designed and constructed in a situation where there were inadequate and poor quality hydro-meteorological data and insufficient geological instruments and laboratories. Problems identified in these micro-dams could be a good listens in building safe structure in the future

4 DRAFT GUIDELINES FOR PERFORMANCE ASSESSMENT OF THE MICRO-DAMS

Another important task accomplished by the research team was to draft theb guidelines for performance assessment of the micro-dam in the Nile Basin region. To assess performance of micro-dam requires accepted standards at least at country level. In USA many states have developed their own manual for assessing mainly the safety performance of dams, which are owned by public and private sectors.

Drafting a common guideline for assessing the performance of micro-dam in the Nile basin is useful in many respects. The manual will assist in:

- Required initial investigations and subsequent analyses;
- Needs for funding for critical repairs, rehabilitation, or modifications;
- Selecting and justifying optimal plan to protect human life, reduce property damage, and mitigate environmental damage for the case of failing dams;
- Minimizing the disruptions of service;
- Maximizing effectiveness of infrastructure investments and
- Learning from the previous success / failure by having proper documentation of the existing dam history.

4.1. DEFINITION OF MICRO-DAMS

Small dams being equivalent to micro-dam / small earth-fill dam is defined for use in this project as dams with height measured from lowest point of natural ground level, including for depth of main stream channel, is less than 10 m but can be considered as small up to 15 m if the storage is small (2 MMC). A short description of micro-dam design procedure is given in Annex III-I which gives some information during assessment of micro-dam performance. If dams are between 10 and 15 meters in height are treated as large dams if they present special design complexities—for example, an unusually large flood-handling requirement, location in a zone of high seismicity, foundations that are complex and difficult to prepare.

4.2 GUIDELINE FOR ASSESSMENT OF THE PERFORMANCE OF MICRO-DAMS

The objectives of preparing this guideline are to:

- To set up the requirements for initial investigations and subsequent analyses;
- To set up funding for critical repairs, rehabilitation, or modifications;
- To select and justify the optimal plan to protect human life, reduce property damage, and mitigate environmental damage;
- To indicate the main measures to be taken to minimize the disruptions of service;
- To maximize effectiveness of infrastructure investments and
- To learn from the previous success / failure by having proper documentation of the existing local history.

When considering performance of small dams, it is mainly divided into two areas. The first is safety performance and the second is the performance regarding its fulfilment in the expected yield / service.

The dam safety performance assessment is made on the structure of the dam including its crest, u/s slope, downstream slope, drainage –seepage control, abutment contacts, inlet structure, spillway, stilling basin, and reservoir area. In order to facilitate dam safety performance assessment, a checklist is given in Annex III-II which is adapted from the Maryland Dam Safety Manual.

Upon completion of the dam safety performance assessment, a decision is made by the inspector regarding the condition of the dam if it requires repair, monitoring or further investigation on the observed problem. Repair is required when obvious problems are observed. Monitoring is recommended if there is potential for a problem to occur in the future. Investigation is necessary if the reason for the observed problem is not obvious.

A brief description should be made of any noted irregularities, needed maintenance, or problems. Abbreviations and short descriptions are recommended supported by photographs.

Service / Yield Performance can be measured by comparing:

- Design reservoir yield and observed reservoir yield and
- Predicted loss of the reservoir for sedimentation and observed loss for sedimentation.

4.3 A SHORT DESIGN PROCEDURE FOR SMALL EARTH DAMS

4.3.1 INTRODUCTION

An earth-fill dam can provide a cost-effective method of storing larger volumes of water for livestock or irrigation. Compared to a dugout, the construction costs for a dam can be much lower per gallon of water stored.

The reason for this cost efficiency is that a dam can store water both behind the dam as well as in the excavated portion of the reservoir where earth-fill is obtained for its construction. With dugouts, all the water is stored in the excavation itself.

Most dams have a much larger surface area than dugouts and are shallower. As a result, dams have both higher evaporation losses than dugouts and poorer water quality.

Successful dams require planning, proper site assessment, design, construction and maintenance. Without this attention to detail, dams are in danger of washing out. Dam construction is not a "do-it-yourself" type of project. It is essential to obtain the assistance of experienced water specialists and construction contractors for a dam project.

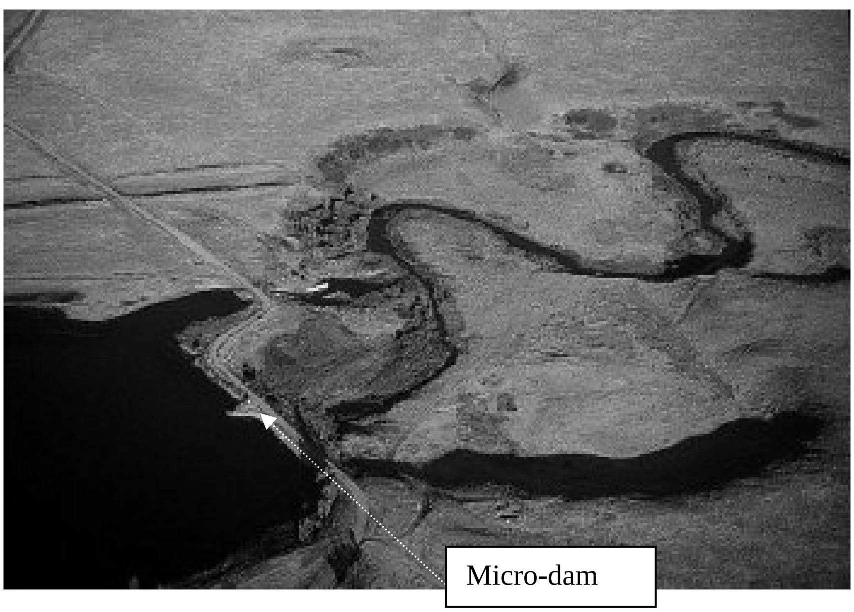


Figure 1. Small earth-fill dam – reservoir at left bottom.

4.3.2 PLANNING

Before you start construction, develop a long-term water management plan for the proposed dam. To do this plan, you will need to answer the following questions:

- What water sources do you currently have?
- How much water will they provide?
- How much additional water will be required from the dam itself on an annual basis?

Information for calculating an annual water supply inventory and the daily and annual water requirements can be found in the Dugout Sizing Worksheets that are part of Quality
Dams require an approval from Alberta Environment before construction. They also require a license under the Water Act legislation. A set of drawings similar to those shown in Figures 2, 3, and 4 in this fact sheet are also required.

Site selection is a critical component to the success or failure of an earth-fill dam. Consider the following points:

1 The dam must have the potential to fill with runoff (most years) or store sufficient water between runoff events that fill the reservoir. It is essential that the dam and reservoir have sufficient depth and volume to last through extended periods of drought.
2. Topographical features such as slope, width and height of dam, as well as reservoir capacity will influence construction costs. A topographical survey of the proposed dam site will be required to estimate costs, prepare necessary information for licensing and provide construction details for the contractor. Figure 2 shows a typical elevation view of a dam prepared from a survey.
3. Soil conditions must be suitable for both compaction and the prevention of seepage losses through the dam. It is highly recommended that some pre-construction soil testing be done at the proposed site or sites. This testing can be accomplished by digging five or six test holes or test pits where the dam and reservoir are to be located. Soils should be checked to depths three feet below that of any proposed excavation for the dam or reservoir.
4. An assessment of the hazard potential downstream should a dam failure occur.
5. A good location for a spillway that will effectively handle runoff and minimize erosion.
6. Watershed activities that can affect the water quality or quantity of runoff.

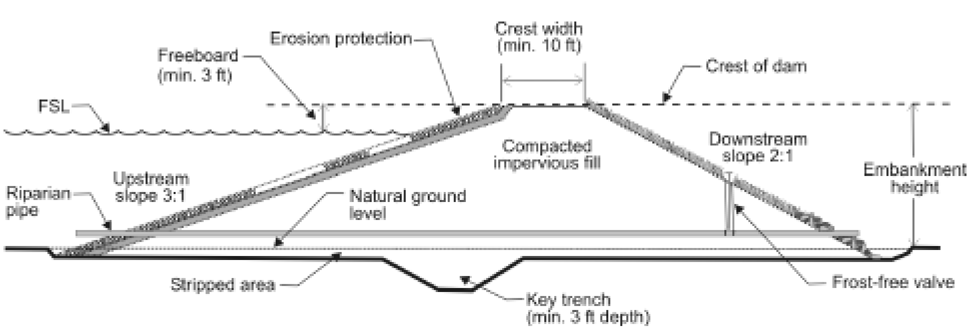


Figure 2. ***Elevation view of dam.***

4.3.3 DAM CAPACITY

The water storage capacity of a dam and reservoir (shown in Figure 3) can be estimated as follows:

Dam capacity = [Reservoir Length x Reservoir Width (at the dam) x Depth of the Water (maximum)] / 3. This calculation provides a close estimate on steep sided V-shaped water channels, but the accuracy of the estimate is poor on flatter, U-shaped water channels. The reservoir must store enough water between runoff events for a secure supply and have good storage characteristics to prevent excessive evaporation losses.

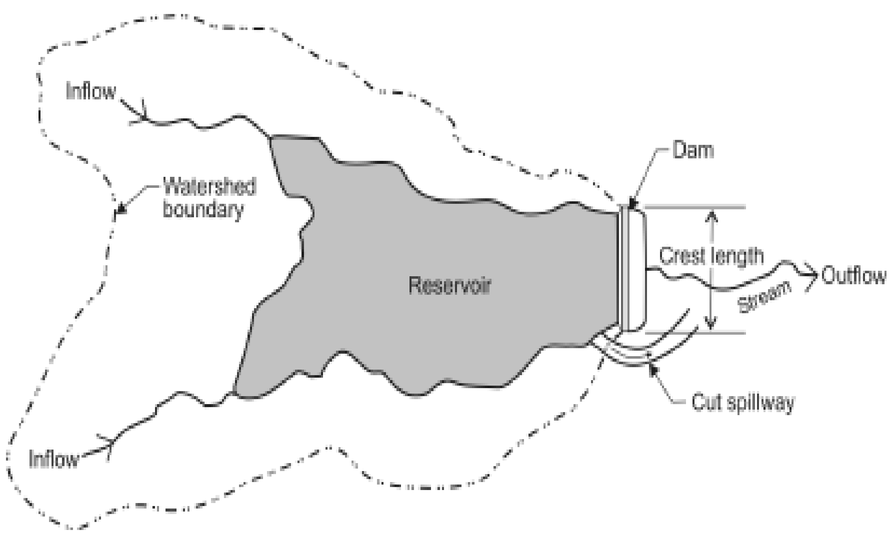


Figure 3*. Plan view of dam and reservoir.*

*Th*ese factors mean that an average reservoir requires a depth greater than 2 m. The storage capacity versus flooded area should exceed a six to one ratio.

4.3.3 EARTH FILL DAMS DESIGN CRITERIA

1 General

An earth dam is basically a trapezoidal embankment built in a valley to form a water reservoir. The design has to ensure:

1. It is impermeable enough to prevent excessive loss of water from the reservoir.
2. The design must ensure stable slopes.
3. Settlement of the dam must not be excessive so as to reduce the freeboard of the dam.
4. The upstream slope of the dam must be protected from the destructive action of waves, and the downstream slope must withstand rainfall erosion.

5. A sufficient bond between the embankment and its foundation must exist to prevent the development of seepage paths; excessive hydrostatic uplift must be controlled by proper drainage.

2 SLOPE STABILITY

Failure of an embankment dam can result from instability of either the upstream or downstream slopes. The failure surface may lie within the embankment or may pass through the embankment and the foundation soil. The critical stages in an upstream slope are at the end of construction and during rapid drawdown. The critical stages for the downstream slope are at the end of construction and during steady seepage when the reservoir is full.

It is common practice to install piezometers to measure pore water pressures and compare data with the predicted values used in design. Since pore water pressures are a dominant influence on the factor of safety of slopes, remedial action should be taken if the factor of safety, based on the measured values, is considered to be too low.

To ensure stability a number of conditions must be investigated:

- The slopes must be safe against surface slipping. To ensure this the slopes must be no steeper than the angle of repose
- The dam must be safe against sliding on the foundation
- The mass of the embankment must be safe against a circular arc failure or composite linear failure. This is likely to occur within an earth core or weak foundation

Reducing the gradient of the slopes can increase the safety against failure.

Figure 4 (a). Homogeneous Embankment

1. Slip within embankment
2. Slip circle through foundation

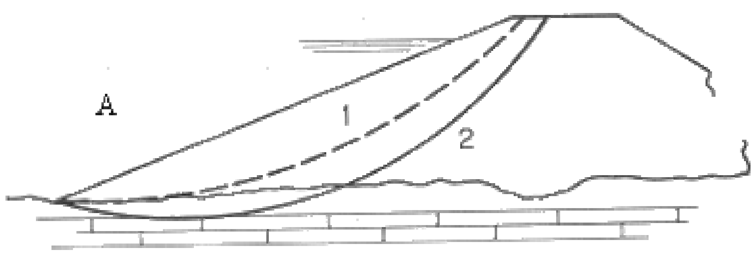
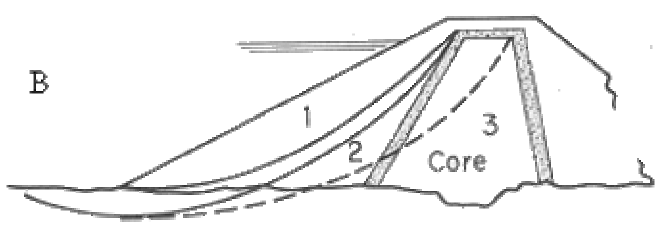


Figure 4(b) Zoned Embankment

1. Within rockfill
2. Through rockfill and foundation
3. Through core and foundation



3 END OF CONSTRUCTION

Most slope failures occur either during, or at the end of construction. Pore water pressures depend on the placement water content of the fill and on the rate of construction. A commitment to achieve rapid completion will result in high pore water pressures at the end of construction. However, the construction period of an embankment dam is likely to be long enough to allow partial dissipation of excess pore water pressure, especially for a dam with internal drainage. Installing horizontal drainage layers within the dam can accelerate dissipation of excess pore water pressures. However, a total stress analysis would result in an over conservative design. An effective stress analysis is therefore preferred. A factor of safety as low as 1.3 may be acceptable at the end of construction provided there is reasonable confidence in the design data.

4 STEADY SEEPAGE

When the reservoir has been full for some time, conditions of steady seepage become established through the dam with the soil below the top flow line in the fully saturated state. This condition must be analyzed in terms of effective stress with values of pore pressure being determined from the flow net. The factor of safety for this condition should be at least 1.5. Internal erosion is a particular danger when the reservoir is full because it can arise and develop within a relatively short time, seriously impairing the safety of the dam.

5 RAPID DRAW DOWN IN LOW PERMEABILITY SOILS

Rapid draw down of the reservoir after a condition of steady seepage will result in a change in the pore water pressure distribution. If the permeability of the soil is low, a draw down period measured in weeks may be 'rapid' in relation to the dissipation time and the change in pore water pressure.

6 RAPID DRAW DOWN IN HIGH PERMEABILITY SOILS

The pore water pressure distribution after draw down in soils of high permeability decreases as pore water drains out of the soil above the draw down level. The saturation line moves downwards at a rate dependant upon the permeability of the soil. A series of flow nets can be drawn for different positions of the saturation line and values of pore water pressure obtained. The factor of safety can then be determined, using an effective stress analysis, for any position of the saturation line.

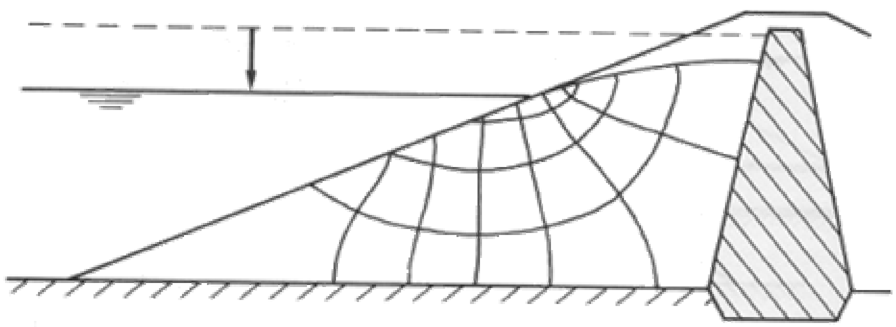


Figure 5. *Rapid draw down in high permeability soils*

7 SETTLEMENT

Settlement is a problem for embankment dams (Figure 6). It begins during construction and continues for many years after the dam is complete. The two main causes are:

1. The migration or working of fines from between the points of contact between the larger rock allows the particles to re-orient themselves into a more dense structure

2. The crushing of the contact points between the larger rocks under the extreme stress developed by the embankment weight causes the rocks to develop new points of contact which in turn crush again.

The problem can be avoided by proper compaction during construction. In earth fill dams it may be possible to overbuild the dam, to make a, say 50% higher dam that will settle to the correct height. Multi-stage construction also helps.

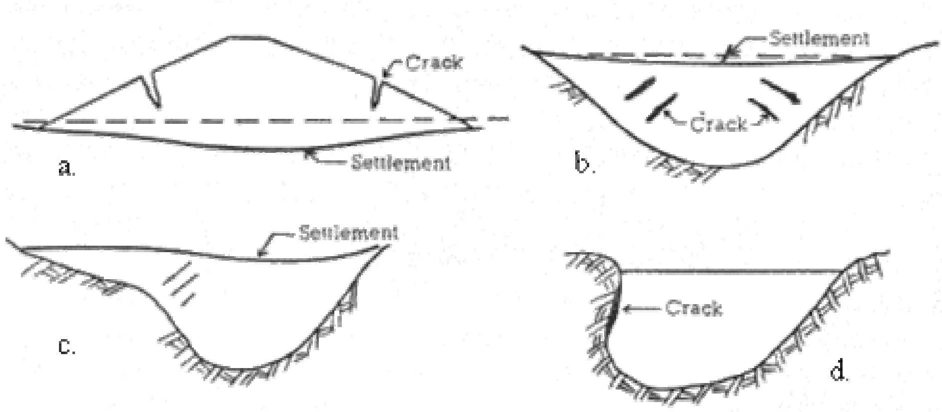


Figure 6: settlement pattern: a. Settlement in section b. Settlement - elevation
c. Irregular abutment, d. Overhanging abutment.

8 SLOPE PROTECTION

Both faces of an embankment dam must be protected against structural damage (Figure 7). In normal circumstances the downstream will only be subject to the forces of nature. The upstream face must be protected against erosion or disturbance by wave action, ice or by impact of floating debris. Various methods of protection include large rocks (rip-rap), precast concrete forms, soil cement or the waterproofing membrane of the dam. Protection must be well above and below the operating range of the reservoir.

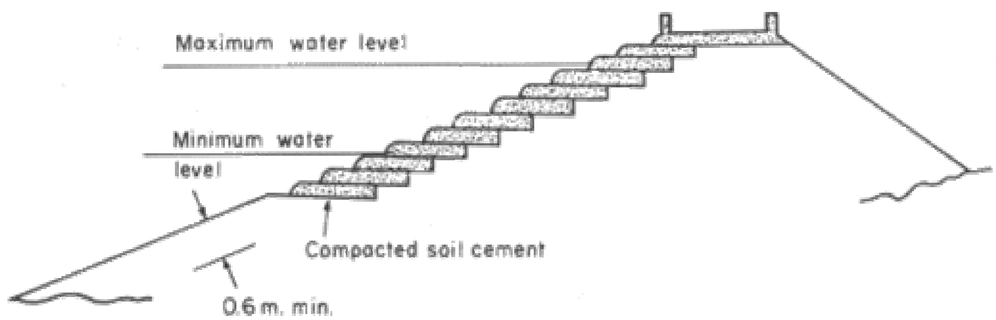


Figure 7*. **Soil Cement Slope Protection***

Rip-rap size : Mass of individual rock = 1000 x (Wave Height Hs)3 (kg)
The rip-rap must be durable, weatherproof and of good quality sound rock to enable it to withstand the changing harsh conditions.

9 IMPERMEABLE ZONE LOCATION

The location of the impermeable zone (upstream deck / central core) in an earth-fill dam involves the same factors as it does in the case of rock-fill dam.

The upstream deck has a number of advantages:

- It is more stable under the water load, because the downward force of the water produces frictional resistance to sliding
- The permeable rock embankment develops no uplift, since the embankment permits no movement of water upward from the foundation.
- The impermeable deck can easily be inspected and repaired if necessary.
- During construction dumping only on the downstream side and extending the membrane upward on the sloping surface can increase the height of the dam.

The disadvantages of an upstream deck are:
- The deck is vulnerable to weather and wave attack.
- If constructed of earth, sudden drawdown greatly reduces its stability and may cause it to slide.
- Settlement of the rock embankment tends to produce tensile cracks in the membrane.
- The central core location has a number of advantages:
- The core is equally supported and is more stable during a sudden drawdown (if constructed from earth).
- Settlement of the rockfill induces compressive stresses in the core, tending to make it more compact.
- There is less core volume and less cross sectional area for leakage for a given height of dam and thickness of core.

The choice for dams with impermeable zones depends largely on the stability of the core material. If it is strong, a near upstream location is often the most economical. However, if the core material is weak a central location is better.

10 SEEPAGE PATHS AND CONTROL MEASURES

PIPING

Internal erosion of the foundation or embankment caused by seepage is known as piping. Generally, erosion starts at the downstream toe and works back toward the reservoir, forming channels or pipes under the dam. The channels or pipes follow paths of maximum permeability and may not develop until many years after construction.

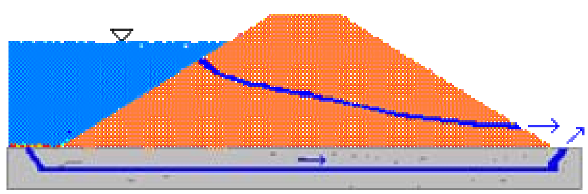


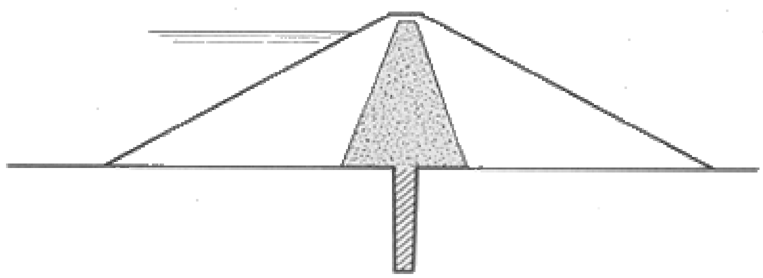
Figure 8. Piping

Resistance of the embankment or foundation to piping depends on:
- plasticity of the soil
- the gradation
- the degree of compactness

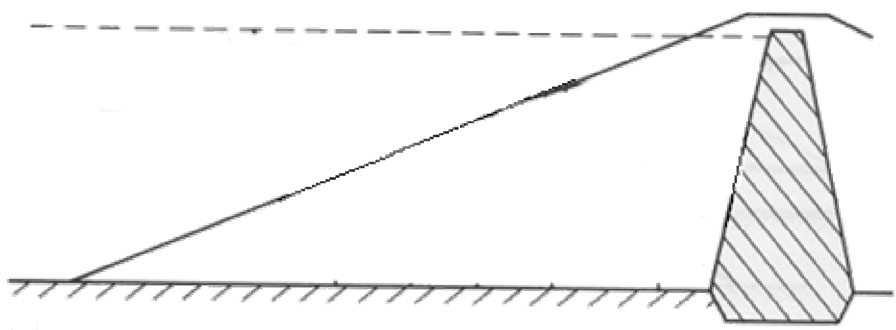
Plastic clays with a plasticity index >15, for both well and poorly compacted are the materials, which are most resistant to piping. Minimum piping resistance is found in poorly compacted, through to well-graded cohesion less soils with practically no binder. It is also found in uniform, fine, cohesion less sand, even when well compacted. Settlement cracks in resistant materials may also produce piping.

Piping can be avoided by lengthening the flow paths of water within the dam and its foundations (Figure 9). This decreases the hydraulic gradient of the water flow and hence its velocity. The flow paths can be increased by:

Cut off walls



Impermeable cores



Impermeable blankets extending upstream from the upstream face

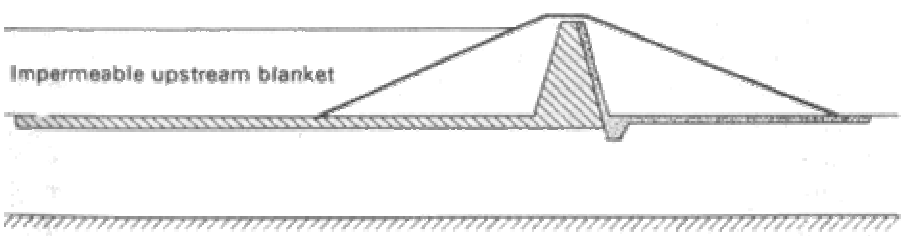


Figure 9: Seepage control

SEEPAGE CONTROL

Seepage is the continuous movement of water from the upstream face of the dam toward its downstream face. The upper surface of this stream of percolating water is known as the infiltration surface. The infiltration surface should be kept at or below the downstream toe (Figure 10).

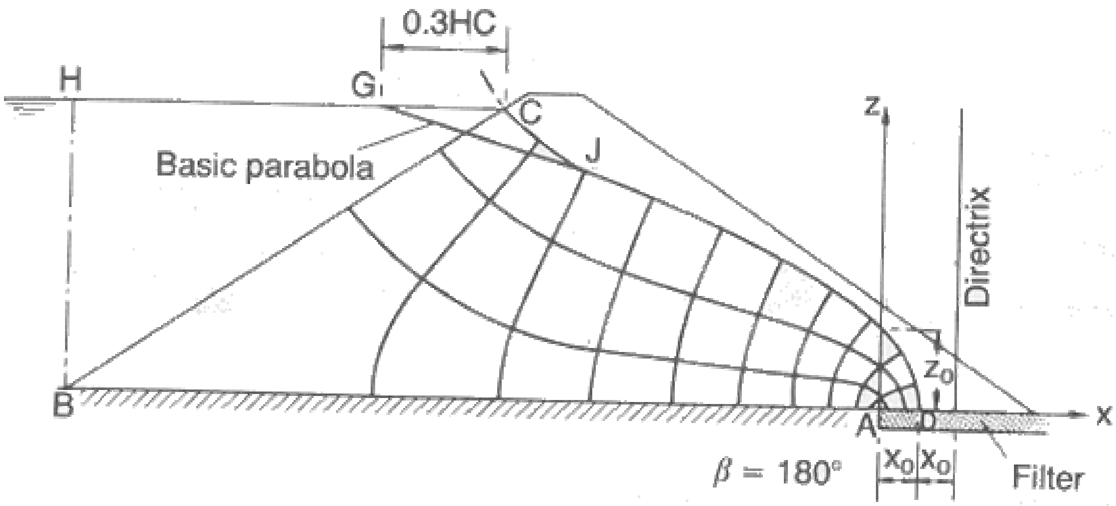


Figure 10: Flow net

The infiltration surface within a dam can be controlled by properly designed cores or walls.

11 INTERNAL DRAIN SYSTEMS

PURPOSE

A homogeneous dam with a height of more than about 6 m to 8 m should have some type of downstream drain (Figure 11). The purpose of a drain is:

- to reduce the pore water pressures in the downstream portion of the dam therefore increasing the stability of the downstream slope against sliding.
- to control any seepage that exits the downstream portion of the dam and prevent erosion of the downstream slope: i.e. to prevent 'piping'.

The effectiveness of the drain in reducing pore pressures depends on its location and extent. However, ensuring that the grading of the pervious material from which the drain is constructed meets the filter requirements for the embankment material controls piping.

TOE DRAINS

The design of a downstream drainage system is controlled by the height of the dam, the cost and availability of permeable material, and the permeability of the foundation. For low dams, a simple toe drain can be used successfully. Toe drains have been installed in some of the oldest homogeneous dams in an effort to prevent softening and erosion of the downstream toe.

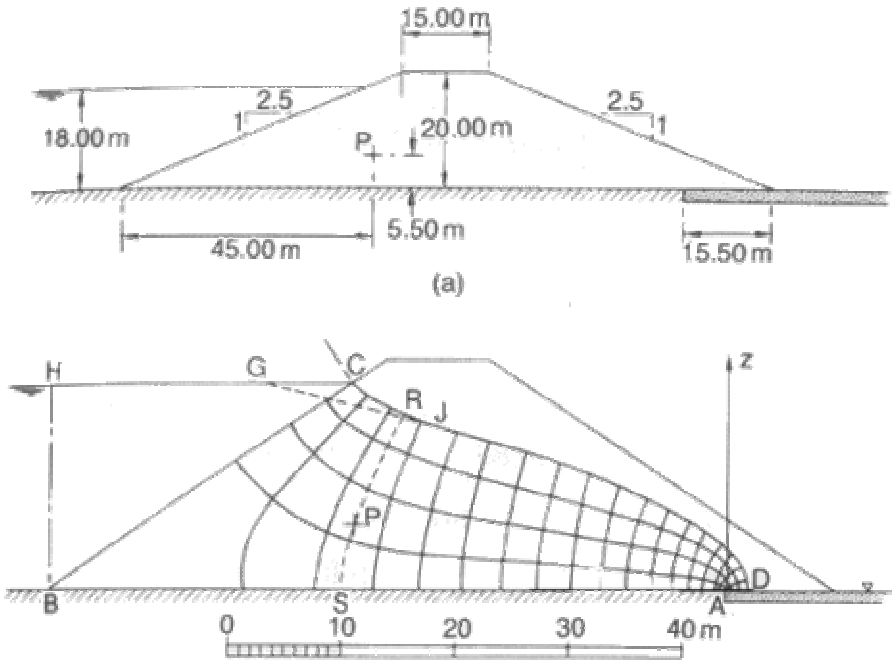


Figure 11. Toe drains.

For reservoir depths greater than 15 m, most engineers would place a drainage system further inside the embankment where it will be more effective in reducing pore pressures and controlling seepage.

HORIZONTAL DRAINAGE BLANKET

Horizontal drainage blankets are often used for dams of moderate height. Drainage blankets are frequently used over the downstream one-half or one-third of the foundation area. The Bureau of Reclamation's 45 m Vega Dam is a homogeneous dam which has been constructed with a horizontal downstream drain. Where pervious material is scarce, the internal strip drains can be placed instead since these give the same general effect.

DISADVANTAGES OF HORIZONTAL DRAINAGE BLANKETS

An earth dam embankment tends to be more pervious in the horizontal direction than in the vertical. Occasionally, horizontal layers tend to be much more impervious than the average material constructed into the embankment, so the water will flow horizontally on a relatively impervious layer and discharge on the downstream face despite the horizontal drain. Where this has occurred the downstream slope is prone to slipping and piping. Repairs can be made by installing pervious blankets on the downstream slopes or constructing vertical drains to connect with the horizontal blanket. Such vertical drains are normally composed of sand and gravel.

CHIMNEY DRAINS

Chimney drains are an attempt to prevent horizontal flow along relatively impervious stratified layers, and to intercept seepage water before it reaches the downstream slope. Chimney drains are often incorporated in high homogeneous dams which have been constructed with inclined or vertical chimney drains.

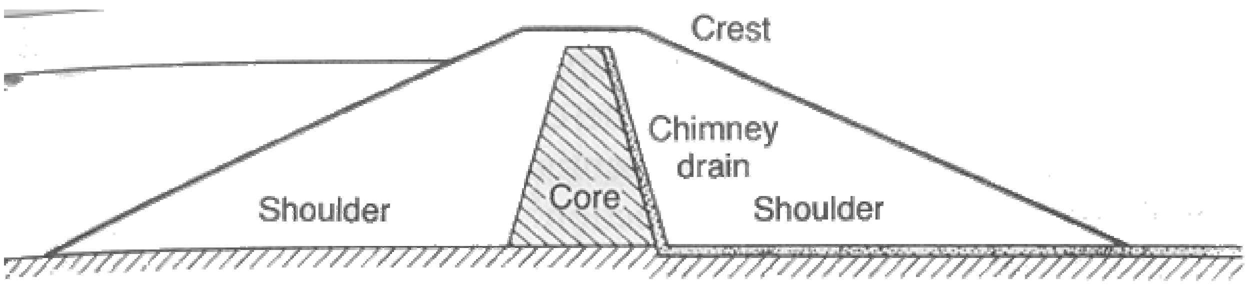


Figure 12: Chimney drain

In some major dam projects, chimney drains have been inclined at a considerable slope, both upstream and sometimes downstream. An upstream inclined drain can act as a relatively thin core. In addition to controlling seepage through the dam and increasing the stability of the downstream slope, the chimney drain is also useful in reducing pore water pressures both during construction and following rapid reservoir drawdown.

DIMENSIONS AND PERMEABILITY OF DRAINS

The dimensions and permeability of permeable drains must be adequate to carry away the anticipated flow with an ample margin of safety for unexpected leaks. If the dam and the foundations are relatively impermeable, then the expected leakage would be low. A drain should be constructed of material with a coefficient of permeability of at least 10 to 100 times greater than the average embankment material.

THIN UPSTREAM SLOPING CORE

In an earth dam with an upstream sloping core of low permeability, the foundation is assumed to be impermeable and in a steady state. Under steady state conditions the small amount of water that seeps through the core flows vertically downward in a partially saturated zone and then more or less horizontally in a thin saturated layer along the impermeable foundation. For this type of dam the downstream shell must be several hundred times more permeable than the core.

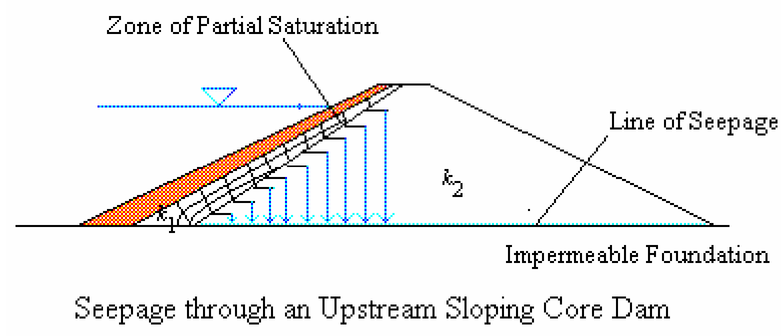


Figure 13 Upstream sloping-core

PARTIAL CUT-OFF

An earth dam constructed without a cutoff on permeable or semi-permeable foundations of earth or rock may lead to seepage beneath the dam creating unacceptable uplift pressures and causing instability. If an impermeable cutoff is installed to 60 % of the depth of the permeable foundation, the flow net and downstream slope gradient is only slightly modified to a lower level. A theoretical line of seepage for several depths is given here.

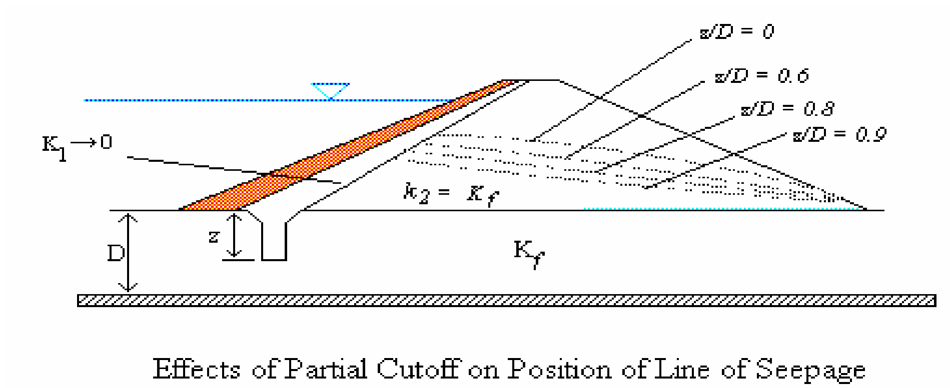


Figure 14. Partial cut-off

For an effective cutoff the positioning and depth of cutoff must be essentially 'perfect'. Since this is impossible to achieve, other methods of seepage control should be used in conjunction with cutoffs.

12 FILTER AND TRANSITION ZONES

Since the core is stabilised with rock or gravel zones, it is necessary to prevent the fine core material being sucked into the upstream shell material during rapid drawdown of the reservoir, or forced into the downstream shell by seepage water under reservoir head. Transition or filter zones must therefore be provided on each side of the core.

The upstream filter, if non-cohesive and of proper grading, can serve a valuable service by providing material for induced self-healing should a transverse crack appear in the core. Selection of the best material for this purpose is well justified. Although its prime function is to retain the core material against movement into the rockfill, the downstream transition material should be selected and placed so as to inhibit the propagation of a core crack into the compacted rockfill. It is good practice to widen the transition zones towards each abutment, i.e. where tension and oblique cracking may occur. To prevent migration of fines from the core:

- D15/D85 < 4-5
  (filter)/(zone being filtered)
- D50/D50 < 25
  (filter)/(zone being filtered)
- For sufficient permeability:
- D15/D15 > 4-5
  (filter)/(zone being filtered)
- To prevent segregation of the filter:
- D60/D10 < 20
  (filter)/(filter)

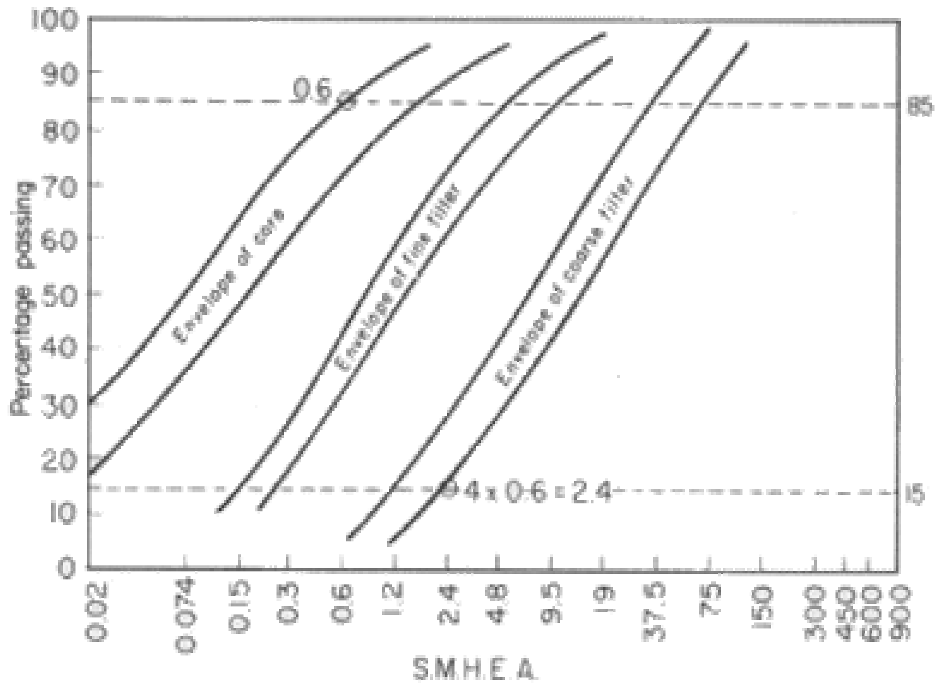


Figure 15. Single filter between core and rock fill

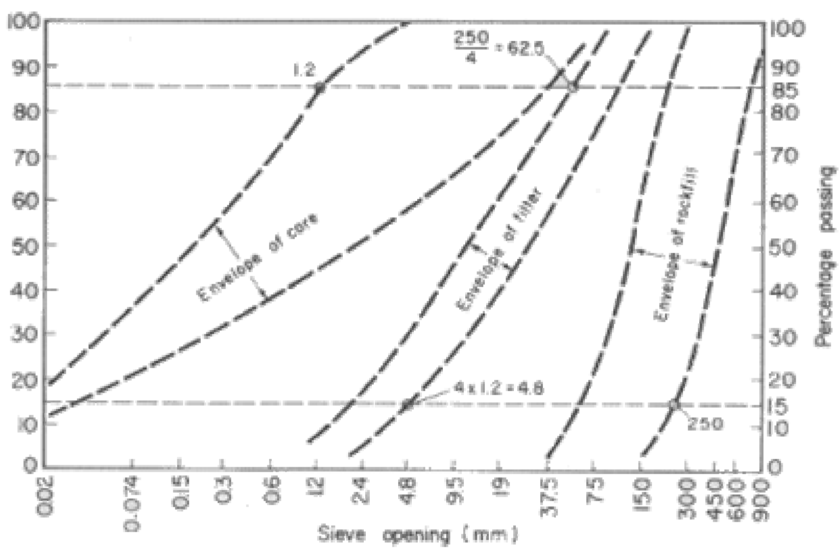


Figure 16: Double filter to core

13 CORES

The core may be defined as a membrane built within an embankment dam to form the impermeable barrier, the balance of the dam being provided to ensure stability. It may be of natural materials, clay, gravels etc. or prepared materials such as cement or asphalt concrete, or of metal, plastic, rubber, etc.

Figure 17: Foundation preparation

The thickness of the core will depend primarily on the material available, i.e. if good clay is available at low cost one would tend to be liberal with the core. The core width will often be related to the type of foundation (example Figure 17), the permissible hydraulic gradient along the contact zone.

A core of natural materials may be central, inclined and close under the upstream face or in some intermediate position. A general core thickness is one half of the height of the dam, depending on materials available. Permeability of the compacted core should not exceed 10-5 cm/s.

The hydraulic gradient relative to the core is the ratio of maximum head of water to the thickness of the core. Thin cores may be adequate for impermeability but it is essential to provide well designed filters on either side. The greatest danger with thin filters is the possibility that a 'blow through' may occur in a segregated zone.

The principal factors considered in determining core dimensions and embankment zoning are:

- The type and volume of core materials available;
- The relative economics of earthfill and rockfill;
- The plasticity of the available core material and its effect on the risk of core cracking;
- The extent and rate of reservoir draw-down;
- The nature of the foundation rock under the core.

Cracks frequently occur in earthfill dams and in cores of rockfill dams. Care must be taken to prevent such cracking and the Engineer must decide whether the cracks are likely to extend and become serious or whether they are stable and can be backfilled.

14 SPILLWAY DESIGN

The spillway is a critical part of dam construction. An under-designed spillway will result in the dam overtopping or serious spillway erosion during peak runoff. These situations can cause major water losses, potential flooding and damage downstream, in addition to the costs to repair the dam.

In small stock watering dams, a drop inlet spillway structure is cost prohibitive. Cut or natural spillways are most common.

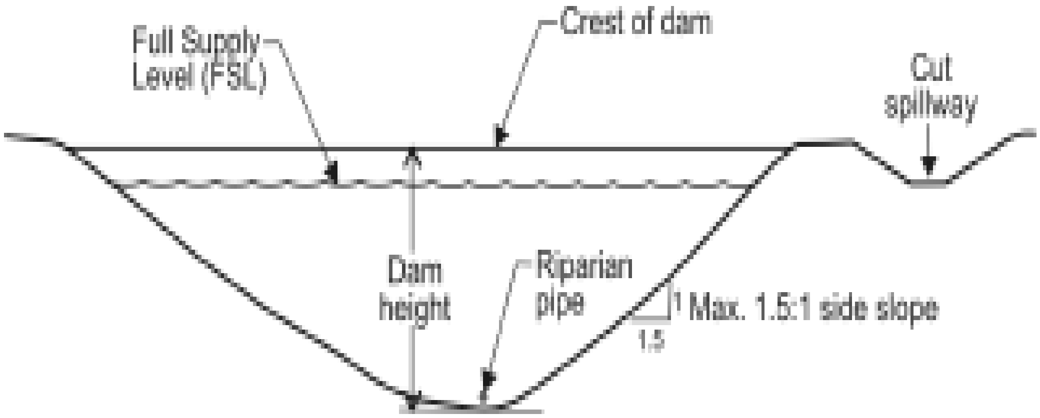


Figure 18. Cross-section of dam and spillway.

The spillway (Figure 18) should be designed with a wide base and a gentle slope, which will reduce water velocity and spillway soil erosion. The spillway base and sides should also be seeded to grass. To prevent spillway erosion, riprap (a collection of loose stones) alone or in combination with geotextile material may be required if the base slope of the spillway is steep. Side slopes of the cut spillway should be no less than 2:1 (4:1 slopes are preferred).

The spillway should be located away from the dam fill, not through or directly adjacent to the fill. This placement will reduce the risk of the dam washing out. Culverts are often used in spillway design, and if undersized, they can restrict spillway flow and result in project failure.

15 CONSTRUCTION ASPECTS

STRIPPING

The area covered by the base of the dam must be stripped of all vegetation and organic soil. The organic soil can be stockpiled and used on the downstream slope of the fill. All slopes steeper than 1.5:1 on sides of draw should be flattened to minimum of 2:1.

KEY TRENCH

A key trench (cutoff trench) is excavated below the base of the fill upstream of the centerline of the fill. The key trench is incorporated in the design for two reasons: to anchor the dam to the base material and to prevent piping (seepage under the fill).

The key trench should be a minimum of three feet deep for a dam the height of 10 to 12 feet. It should extend the full length of the dam and reach one third to one half of the way up the side slope of the draw.

FILL CONSTRUCTION

The dam must be constructed from an impervious (clay or clay-based) material. A simple field test to determine the suitability of the material for compaction requires adding a small amount of moisture to a handful of material and then mixing to the consistency of putty.

Next, try rolling the material between the palms of your hands. The material has good compaction characteristics if it can be rolled to the diameter of a pencil, approximately six inches long, then bent into a loop without separating the material. Several attempts may be required to obtain the proper moisture level to do the test.

Construction material taken from the surrounding hillsides or an excavation in the reservoir area must be placed close to horizontal in the fill in six inch layers and compacted. If the material is dry, moisture will have to be added, and suitable compaction equipment such as a sheepsfoot packer used to obtain the proper compaction.

A simple test to evaluate proper compaction is to place the edge of the heel of a hard-soled boot on the fill and push down hard with all your weight. If only a mark is left, compaction is satisfactory. If the heel sinks in, compaction is poor. No rocks over six inches in diameter should be placed in the fill.

Start construction by filling the key trench with well-compacted material, and continue adding six inch layers until the maximum height is obtained. The top of the dam at the center of the draw should be built 10 per cent higher than the design to allow for settlement of the fill.

A riparian pipe should be placed through the bottom of the fill during construction, along with a frost-free valve (curb stop) set well back in the fill to ensure frost protection. This pipe and valve system will allow water to be released downstream to a stock-watering trough, or to other water storage facilities during times of water shortages.

16 WATER QUALITY AND DROUGHT PROOFING CONSIDERATIONS

There are a number of ways to improve the water quality in a dam. At the planning stage, as far as possible try to avoid sites where watershed activities can allow poor quality or contaminated runoff to enter the reservoir of the dam. Examples of these sites include heavily cultivated fields or areas where a heavy concentration of livestock manure exists.

The design of the reservoir can also help improve water quality. The deeper the excavated reservoir, the better the water quality and the more drought proof it will be from evaporation losses.

Stripping the topsoil from the flooded area of the reservoir will reduce the amount of nutrients available for plant and algae growth. The more plant and algae growth generated, the more rot and decay are generated and cause the water quality to deteriorate. Regular treatments to help control plant growth will help maintain water quality.

ANNEX: Checklist for dam safety analysis (After Maryland Dam Safety Manual)

DAM ______________________ **DATE** ______________

OWNER ______________________ **WEATHER** ______________

INSPECTED BY ______________________ **POOL LEVEL** ______________

Item	Comments	Y/N	MONITOR	REPAIR	INVESTIGATE
1. CREST					
a. Visual settlement?					
b. Misalignment?					
c. Cracking?					
2. UPSTREAM SLOPE					
a. Erosion?					
b. Ground cover in good condition?					
c. Trees, shrubs, or other woody vegetation?					
d. Longitudinal/Vertical cracks?					
e. Adequate riprap protection?					
f. Stone deterioration?					
g. Settlements, depressions, or bulges?					
3. DOWNSTREAM SLOPE					
a. Erosion?					
b. Ground cover in good condition?					
c. Trees, shrubs, or other woody vegetation?					
d. Longitudinal/Vertical cracks?					
e. Riprap protection adequate?					
f. Settlements, depressions, or bulges?					
g. Soft spots or boggy areas?					
h. Movement at or beyond toe?					
i. Boils at toe?					
4. DRAINAGE-SEEPAGE CONTROL					
a. Internal drains flowing?	Est. Left _____ gpm Est. Right _____ gpm				
b. Seepage at toe?	Estimated _____ gpm				
c. Does seepage contain fines?					
b. Trees or shrubs in the channel?					
c. Seepage present?					
d. Soft spots or boggy areas?					
e. Channel slopes eroding or sloughing?					
10. RESERVOIR					
a. High water marks?					
b. Erosion/Slides into pool area?					
c. Sediment accumulation?					
d. Floating debris present?					
e. Adequate riprap protection for ditches?					

INSPECTION CHECKLIST - PAGE 2

INSPECTED BY _______________ **DATE** _______________

Item	Comments	Y/N	MONITOR	REPAIR	INVESTIGATE
5. ABUTMENT CONTACTS					
a. Erosion?					
b. Differential movement?					
c. Cracks?					
d. Seepage?	Estimated ______ gpm				
e. Adequate erosion protection for ditches?					
6. INLET STRUCTURE	Concrete or Metal Pipe (circle one)				
a. Seepage into structure?					
b. Debris or obstructions?					
c. If concrete, do surfaces show:					
1. Spalling?					
2. Cracking?					
3. Erosion?					
4. Scaling?					
5. Exposed reinforcement?					
6. Other?					
d. If metal, do surfaces show:					
1. Corrosion?					
2. Protective Coating deficient?					
3. Misalignment or split seams?					
e. Do the joints show:					
1. Displacement or offset?					
2. Loss of joint material?					
3. Leakage?					
f. Are the trash racks:					
1. Broken or bent?					
2. Corroded or rusted?					
3. Obstructed?					
4. Operational?					
g. Sluice/Drain gates:					
1. Broken or bent?					
2. Corroded or rusted?					
3. Leaking?					
4. Not seated correctly?					
4. Periodically maintained?					
5. Operational?					

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APPENDIX I

PRELIMINARY INVENTORY OF MICRO-DAMS IN SUDAN

Table (A): existing Micro-dam in Sudan up to season 75-76

No.	Name of the dam	Capacity	Year of construction
1	Arbaat	7 361 542	73-75
2	Hosheiry		67-70
3	Tobein	459 041	71-72
4	Adrous	953 358	72-73
5	Arab	4 612 505	72-73
6	Mukban 1	1 145 750	72-73
7	Mukban 2	1 698 120	72-73
8	Habel Katein		74-75
9	Hamashkoreb	280 000	76-77
10	Gisir Rashid	120 000	67-68
11	Dalasa	160 000	63-64
12	Qureisha	138 000	57-58
13	Abu Qulut	103 137	57-58
14	Jabel Adar	606 000	69-69
15	Matakaro	3 189 000	74-75
16	Wadi Halouf		75-76
17	Wadi golo	810 000	76-77
18	Abu Gidad	1 500 000	76-77
19	Wadi Basau	680 000	61-62
20	Wadi Eleigi		61-62
21	Wadi Tilfu	20 000	61-62
22	Wadi Anabagi	41 175	61-62
23	Karfu	1 955 000	67-68
24	Melleit	931 000	47-48
25	Tawila	300 000	56-57
26	Migabila	300 000	56-57
27	Bir Nahla	60 000	56-57
28	Azagarfa	300 000	56-57
29	J. Maalla	300 000	56-57
30	Traco Masonry	60 000	56-57
31	J. Darma	120 000	56-57
32	Matakero	1 200 000	56-57
33	Siriba Masonry	375 000	56-57
34	J. Utash	200 000	57-58
35	Hilalya	1 500 000	59-60
36	Hileilat	500 000	59-60
37	Wada'a	77 000	59-60
38	Miri Bara	4 221 500	67-68
39	Tilwadi	400 000	67-68
40	Es Sinut	250 000	68-69
41	Talodi	100 000	74-75
42	Rashad	302 500	76-77
43	Tina*	50 000	69-70
44	Khor Bagara	2 000 000	72-73
45	Ban Gadid*	60 000	72-73
46	Daw	650 000	73-74

Table B: Micro dams constructed after 1976

No.	Name	Capacity (M^3)	Status
1	J. Fula	500 000	Constructed 1979
2	Addiega	6 000 000	Constructed 1992
3	Abu Hadid	500 000	Constructed 1992
4	Barbara	500 000	Constructed 1992
5	ElFula Elzarga	100 000	Constructed 1996
6	Rashad Shamali	100 000	Constructed 1986
7	Kajma	200 000	
8	Taglibo	150 000	
9	Elain	3 750 000	
10	Banno	1 000 000	Constructed 1981
11	Ummbadr	80 000	
12	Turdat Elrahad	53 008 000	

Table C: Micro dams proposed for construction.

No	**Name of the dam**	Status of the dam	No.	**Name of the dam**	Status of the dam
1	Wadi Shakheeb	Under construction	35	Kaya	Proposed
2	Kajira	Under construction	36	Tulus	Studied
3	Assaisaban	At Design stage	37	Takolak	Proposed
4	Annugdab	Proposed	38	Sagady	Proposed
5	Alfula	Proposed	39	Twal	Proposed
6	Girwaya	Proposed	40	Baba	Construction
7	Abu Rajala	Proposed	41	Kidatir	Construction
8	Um Reihana	Proposed	42	Shattaya	Proposed
9	Tajir	Proposed	43	Sail Gassa	
10	Shilingo	Proposed	44	Mleibywa	
11	Um Breimbita	Studies	45	Abu Digais	Studies
12	Abu zabad	Studies	46	Omer	Proposed
13	Elkhuwei	Proposed	47	Marsheikh	Proposed
14	Um Urdah	Proposed	48	Darisa	Proposed
15	Rashad Elshargy	Proposed	49	Amiya	Proposed
16	Abu Oroog	Proposed	50	Abu Aradaib	Proposed
17	Elsikairan	Proposed	51	Bargo	Proposed
18	Abu Habil	Studies	52	J. Zina	Proposed
19	Elsinjikaya	Studies	53	Nyartatay	Proposed
20	Armal	Proposed	54	Margabig	Proposed
21	Shoshai	Proposed			
22	Elfiadh	Proposed			
23	Wad Mulah	Proposed			
24	Elbardab	Proposed			
25	Elbatha	Proposed			
26	Abu Gidad	Proposed			
27	Um Ramad	Proposed			
28	Abu Karshola	Proposed			
29	Shirkela	Proposed			
30	Elmarakh	Proposed			
31	Elreel	Proposed			
32	Umdafog	Construction			
33	Bout Elrayah	Proposed			
34	Abu Hamra	Studied			

Appendix 2

PRELIMINARY INVENTORY OF MICRO-DAMS IN ETHIOPIA

No	Dam Site	Location		Purpose	Elevation (m asl)	Full Water Level (m asl)	Catchment Area (km^2)	Dam Height (m)	Dam Length (m asl)	Met Data Available at	Annual Av Rainfall (mm)	Water Volume ('000 m^3)		Spillway Capacity (m3/s)	Soils	Bed Rock
		Lat (N)	Long (E)									Total	Usable			
1	Nabalachar (Planning stage)	2°34'55"	34°20'0"	Electricity production, Irrigation	1,150	1,160	314	16	4961	Moroto	478-1271	116,390	92,602	195	Black Clay Loam	Metamorphosed rock
2	Namalu (ready for implementation)	1°47'48"	34°37'21	Electricity production, Irrigation	1,180	1,205	28	29	330	Namalu	1234	11,900	9,480	-	Clay loams	Basalt of Mesozoic Era located 4-5m below river bed
3	Greek	1°34'56"	34°34'23"	Electricity production, Irrigation	1,092	1,104	1,096	17	840	Namalu	1541	13,680	10,844	91.6	Fluvial alluvium of earth and sandy clay	Basalt of Mesozoic Era located 8m below river bed
4	Kanyangareng Dam – planning stage	1°57'42"	34°55'58"	Electricity production, Irrigation	1,225	1,237	1,156	18	860	Namalu	635	12,090	9,532	95.2	red, brown or sandy clay	granite-gneiss of old-Proterozoic era located 3-4m below river bed
5	Omanimani	2°26'18"	34°28'46"	Irrigated farming and livestock	1,197	1,201	652	3	52	Moroto	699	63	40	63	red, brown or sandy clay	granite-gneiss of old-Proterozoic era
6	Napenenya	1°52'0"	34°35'2"	water for cattle	1,130	1,139	136	13	504	Namalu	1058	1,580	1,214	80.8	red, brown sandy clay	granite-gneiss of proterozoic era located 10m below river bed
7	Adukon (planned)	2°31'49"	34°40'27"	Water supply to Moroto Town	1,410	1,430	24	13	850	Moroto	679	17,700	-	87	red, brown sandy clay	granite-biotite schist of Proterozoic era

8	Kalere (Planned for a dyke)	-	-	Water supply to Kaabong Town	1,536	1,573	245.25	14	274	NA	600	-	-	31.2	Mainly sandy	granite-gneiss of proterozoic era located 1.5m below river bed
9	Nalakas (Planned)	3°43'45"	33°58'42"	Irrigated farming and livestock	1,478	1,500	128	26	559	Moroto	696	30,490	243,800	195	sandy clay	metamorphosed granite-gneiss rock 2m below riverbed
10	Longire	-	-	livestock watering	1,234	1,240	206	8	940	Moroto	652	217	158	28		metamorphosed granite-gneiss rock 5m below riverbed
11	Dopeth (planned)	3°05'0"	34o04'04"	livestock watering	1,254	1,260	722	10	1035	Moroto	681	-	-	-	sandy clay	metamorphosed granite-gneiss rock 10m below riverbed
12	Papa (Planned)	3°39'22"	34o04'26"	livestock watering	1,527	1,540	63	17	884	NA	678	2,700	2,140	117	Stone-sand or laterite-loam	metamorphosed granite-gneiss rock 7-8m below riverbed
13	Kapeta	3°46'42"	33o54'52"	livestock watering	1,513	1527	11.5	18	166	NA	750	947	741	3.4	Stone-sand or laterite-loam	metamorphosed granite-gneiss rock 4-5m below riverbed
No	Dam Site	Location		Purpose	Elevation (m asl)	Full Water Level (m asl)	Catchment Area (km^2)	Dam Height (m)	Dam Length (m asl)	Met Data Available at	Annual Av Rainfall (mm)	Water Volume ('000 m^3)		Spillway Capacity (m3/s)	Soils	Bed Rock
		Lat (N)	Long (E)									Total	Usable			
14	Kathil	3°33'34"	33°41'18"	Irrigated agriculture and livestock	1,396	1,414	17.4	22	572	NA	826	-	-	4.6	eroded laterite clay, laterite sand loam	metamorphosed granite-gneiss rock 5m below riverbed
15	Loyolo	3°35'29"	33°40'34"	Community water supply	1,430	1,440	5.4	13	214	Moroto	826	70,000	51,000	2	eroded laterite clay, sand loam	metamorphosed granite-gneiss rock 3m below riverbed

16	Lakapelepelot (Planned)	3°40'27"	34°12'05 "	livestock watering	1,626	1,634	45	12	633	Moroto	635	960	758	9	red clay, laterite sand	metamorphosed granite-gneiss rock 4-5m below riverbed
17	Nangen	3°20'31"	34°07'11 "	livestock watering	1,397	1,400	95	7	215	Moroto	628	60	48	16	red clay, laterite sand	metamorphosed granite-gneiss rock 1m below riverbed
18	Lotaliat	2°48'48"	35°45'13 "	livestock watering	1,175	1,180	10.6	9	154	NA	991	130	90	4	red clay, laterite sand	metamorphosed granite-gneiss rock 9m below riverbed
19	Naoyamuwe	3°20'0"	34°13'53 "	livestock watering	1,455	1,460	7	9	207	NA	572	-	-	-	red clay, laterite sand	severely metamorphosed granite-gneiss rock
20	Orabalo	2°43'02"	33°38'59 "	Irrigated farming and livestock	1,130	1,140	40.5	13	350	NA	1080	2,250	1,780	9	eroded laterite clay,	metamorphosed granite-gneiss rock 6m below riverbed

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