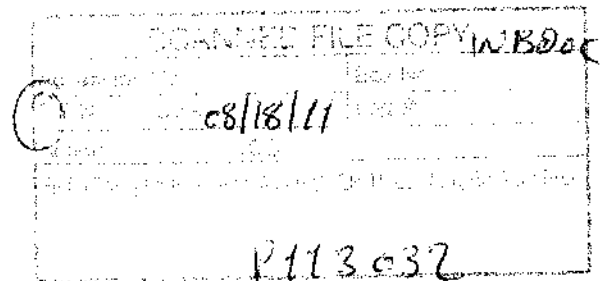


Federal Democratic Republic of Ethiopia

Ministry of Agriculture

Agricultural Growth Project (AGP)

Small Dams Safety Guidelines



Agricultural Growth Project (AGP)
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Preface

The purpose of these Guidelines is to provide owners of small dams with the requirements that they must meet to construct and operate a small dam. The emphasis throughout is on measures to achieve safe management of small dams. The general engineering requirements illustrated in this guideline apply specifically to small dams, and in areas where downstream hazards are minimal. The requirements illustrated apply to a hypothetical dam at a specific site. Since conditions and materials vary widely from site-to-site, it should be recognized that the guidelines may not directly apply.

Commonly, small dams are constructed of earth materials, but they may be made of concrete, boulders (rockfill), or other materials. For economic reasons and convenience most small dams are constructed of earth materials. Nearly all small dams in Ethiopia are constructed of earth materials. Even though this guideline will focus on earth dams, the principles and safety issues in design and construction of concrete gravity and rockfill dams are also covered.

The guideline is aimed at owners of dams, engineers/technical advisers, supervising bodies/authorities and contractors, and others owning responsibility and a duty of care for dam safety. Dam ownership carries with it significant legal responsibilities. Dam owners should be aware of the potential liabilities and how to effectively minimize their exposure to these liabilities.

It is important to appreciate that these guidelines focus on aspects which should be considered and procedures which should be followed to achieve a safe dam. They do not constitute a design guideline or operations manual for implementation. Design guidelines and other appropriate technical references must be used for detailed methods of investigations, analysis and design. The guidelines are not necessarily all embracing nor will cover every conceivable situation: ultimately the owner and technical advisers to the owner must decide what is appropriate.

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ABBREVIATIONS AND ACRONYMS

BoWR	Bureau of Water Resources
DFID	Department for International Development
EAP	Emergency Action Plan
EEPCO	Ethiopian Electric and Power Corporation
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
ESRDF	Ethiopian Social Rehabilitation and Development Fund
FAO	Food and Agricultural Organization
FEMA	Federal Emergency Management Agency (US)
GoE	Government of Ethiopia
ICOLD	International Commission on Large Dams
OP	Operation Policy
O&M	Operation and maintenance
Mm ³	Million cubic meters
MoWE	Ministry of Water Resources and Energy
SSI	Small Scale Irrigation
WUA	Water Users Associations

I Introduction

Dams provide benefit for a number of reasons. They commonly provide the following:

- Water supply,
- Irrigation water
- Generation of power,
- Storage of floodwaters to reduce downstream flooding potential,
- Provision of a fishery resource,
- Aesthetic benefits and others
- etc.

While dams do provide potential benefits they also have a risk associated with their design, construction and operation.

Clearly, as various dam failures and incidents around the world have shown, some with substantial loss of life and environmental damage, there is a need to exercise due care at all levels in achieving dam safety. There is a need to embody the level of advice necessary for full implementation of safety procedures by measures such as this guideline. Benefits which will accrue from the promotion and achievement of adequate dam safety practices include environmental protection, public confidence, and the commercial benefits to the owner of constructing and maintaining in a safe and insurable condition, what is usually a significant investment.

The owner of a dam is responsible for:

- safely operating and maintaining the dam;
- giving appropriate warnings if the operation or failure of the dam could cause damage;
- compensating damage caused by the operation or failure of the dam.

By having a regular inspection program, the owner benefits by:

- being able to recognize problems in their early stages and eliminating them before they become complex and expensive problems;
- minimizing risks and liability for downstream life or property

This guideline is designed to assist dam owners to understand their responsibilities and legal obligations. It includes guidance on good practice in planning, design, construction and safe operation and maintenance of small dams.

1.1 The Special Nature of Dams

Dams with their related structures and the storage reservoirs they form, have a special nature because of their scale, the water forces at work and the use of natural ground to form the major part of the reservoir containment. Most other man-made works are built of high strength manufactured materials, involve controlled geometry, do not involve large

storage of water, and generally do not use the foundation other than to support the works themselves. In the case of dams, however, account has to be taken of:

- dam site topography which usually cannot be altered significantly because of cost
- dam site and regional geology which greatly influences water retention and structural safety
- the most appropriate materials to build the dam from and the dam structure arrangements to assure a safe operable dam
- the earthquake forces which the dam with its stored contents may experience
- the potential floods which may pass through the reservoir and how these may be taken past the dam and returned to the river without risk of dam overtopping (unless specifically designed for overtopping), or erosion damage
- the surveillance, maintenance, and operational procedures (which may include the operation of flood gates) to ensure the dam works as intended
- the management of sediment passage down the river

It is the close interaction between the natural ground and manmade structures, together with water stored at a higher level, which most strongly characterize the special nature of dams. From the time it is first stored and for the whole life of the dam, the retained fluid has the potential to escape through any geological or manmade weakness. Dams age and deteriorate through ongoing geological and chemical processes and also may be found to be less safe than is desirable through technological advances which improve knowledge of dam and foundation behaviour, and earthquake and flood risk. Dam failures resulting in the uncontrolled escape of the stored contents can be catastrophic and preservation of safe conditions requires never ending vigilance.

As well as all dams constituting a special class of structure, each dam will have unique characteristics, particularly in terms of site geology and geometry. The variations in geology, building material types, geometry, earthquake and flood risk and the like, mean that it is not practicable to develop a standardized code-type design for dams. Each dam must be treated individually, taking all relevant factors into account.

1.2 Dam safety objective

The overarching dam safety objective is to protect people, property and the environment from the harmful effects of misoperation or failure of dams and reservoirs.

To ensure that dams and reservoirs are operated and that activities are conducted so as to achieve the highest standards of safety that can reasonably be achieved, measures have to be taken to achieve the following three fundamental safety objectives:

- to control the release of damaging discharges downstream of the dam,
- to restrict the likelihood of events that might lead to a loss of control over the stored volume and the spillway and other discharges,
- to mitigate through onsite accident management and/or emergency planning the consequences of such events if they were to occur.

These fundamental safety objectives apply to dam and activities in all stages over the lifetime of a dam, including planning, design, manufacturing, construction, commissioning and operation, as well as decommissioning and closure.

1.3 Dam safety principles

ICOLD principles form the basis from which safety requirements for dams can be developed and safety measures implemented in order to achieve the fundamental safety objective. Though the principles are meant for large dams, most of them are applicable to small dams as well. The safety principles form a set that is applicable in its entirety, although in practice different principles may be more or less important in relation to particular circumstances.

1. **Responsibility for dam safety** : the prime responsibility for dam safety should rest with the entity responsible for the dam and the activities that give rise to the risks. Responsibility for dam safety should be clearly defined. Government is ultimately responsible for assuring the safety of the public, property and the environment, around and downstream of dams. In order for the Responsible Entity to meet its obligations in relation to the safety of its dams, it is necessary to ensure that its dam safety management activities are approached in a systematic way.
2. **Role of government**: the legal and governmental framework for safety provides the overarching structures for dam safety assurance. Properly established legal and governmental framework provides for the regulation of dams and reservoirs, and related operational activities that can give rise to a dam breach and other inundation risks, and for the clear assignment of responsibilities. The government is responsible for the adoption within its national legal system of such legislation, regulations, directives and other standards and measures as may be necessary to effectively fulfill all of its national responsibilities and, where relevant, its international obligations. A modern view of safety governance includes the establishment of an independent regulatory body to assure the safety of dams.
3. **Leadership and management for safety**: effective leadership and management for safety should be established and sustained in organizations responsible for dam risks. Safety has to be achieved and maintained by means of an effective management system that integrates all elements of management. The management system also has to ensure the promotion of a safety culture, the regular assessment of safety performance, and the application of lessons learned from experience.
4. **Justification for dams and reservoirs**: dams, reservoirs and activities that give rise to dam safety risks should yield an overall benefit to society. For dam and reservoir activities to be considered justified, the benefits that they provide to society as a whole should outweigh their costs and the risks that they create. For the purposes of assessing benefits and risks, all significant positive and negative consequences of the operation of dams and reservoirs have to be taken into account.
5. **Optimization of protection**: it is recommended that protection should be optimized to provide the highest level of safety that can reasonably be achieved. The safety measures that are applied to dams, which give rise to societal risks, are considered to be optimized if they provide the highest level of safety that can reasonably be achieved throughout the lifetime of the dam, without placing an unreasonable burden on society and without unduly limiting its utilization.

6. **Limitation of risk to individuals:** measures for controlling dam safety risks should ensure that no individual bears an unacceptable risk of harm. Justification and optimization of protection do not in themselves guarantee that no individual, including employees and operators, bears an unacceptable risk of harm.
7. **Protection of present and future generations:** people, property and the environment, present and future, should be protected against the effects of dam failures and other reservoir risks. Due account must be taken of the fact that dam safety management decisions made in the present will affect future generations, and therefore have impacts that span many human generations.
8. **Prevention of accidents:** all reasonably practicable efforts should be made to prevent and mitigate dam failures and accidental releases. To ensure that the likelihood of an accident having harmful consequences is extremely low, measures have to be taken to achieve the following:
 - To prevent the occurrence of failures or abnormal conditions (including breaches of security) that could lead to uncontrolled release of all or part of the stored volume;
 - To prevent the escalation of any such incidents or abnormal conditions that do occur.
9. **Emergency preparedness and response:** appropriate arrangements should be made for emergency preparedness and response for dam failures and accidental releases. The primary goals of preparedness and response for a dam breach emergency are as follows:
 - To ensure that arrangements are in place for an effective response at the scene and, as appropriate, at the local, regional, national and international levels, to a dam breach emergency
 - To ensure that, for reasonably foreseeable incidents, inundation consequences would be minor
 - For any incidents or failures that do occur, to take practical measures to mitigate any consequences for human life and health, property and infrastructure, and the environment.

The dam owner/responsible entity, the employer, the regulatory body and appropriate branches of government have to establish, in advance, the arrangements for emergency preparedness and response for a dam breach emergency at the scene, at local, or regional level.

1.4 Dam Definition and classifications

'Dam' is not specifically defined in any of Ethiopia's regulations or directives. In this Guideline, the word dam refers to an artificial barrier, and its appurtenant structures, that is constructed to store, control, or divert water.

The term 'dam' includes the embankment and all other parts such as spillway, outlet and valves. Construction of a dam may be from earth or other suitable materials such as rock, concrete, etc.

There is no any guideline to classify dams in Ethiopia. The ESRDF's (Ethiopian Social Rehabilitation and Development Fund) small scale irrigation guideline has defined a "micro dam" as an embankment dam having heights not exceeding 15m above deepest river section

and gross storage of not more than 3 Mm³ and a "medium dam" as an embankment dam having heights between 15-50m above the deepest bed level and its storage capacity lies between 3-10 Mm³. These definitions have been applied to many small scale irrigation schemes that have been built in Tigray and Amhara Regional States.

There is no a universally accepted classification of dams as small, medium or large. A widely accepted definition of large dams is given by the International Commission on Large Dams (ICOLD). It defines large dams as those having a height of 15 meters from the foundation or, if the height is between 5 to 15 meters, having a reservoir capacity of more than 3 million cubic meters.

The World Bank distinguishes between small and large dams for application of its policy on safety of dams. OP 4.37, states:

- a) Small dams are normally less than 15 meters in height. This category includes, for example, farm ponds, local silt retention dams, and low embankment tanks.
- b) Large dams are 15 meters or more in height. Dams that 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, or retention of toxic materials. Dams under 10 meters in height are treated as large dams if they are expected to become large dams during the operation of the facility.

Information in this guide concerns small dams (dams less than 15 m in height and having a reservoir capacity less than 3 Mm³). It does not provide guidance for excavated ponds as they do not represent a safety concern and they generally do not have an embankment associated with them.

1.5 Dam Management in Ethiopia

In Ethiopia the Ministry of Water Resources and Energy (MoWE) is responsible for the planning and design of large dams. During the design phase, the Ministry usually adopts industry accepted standards of large dam design. No formal guideline/document has been prepared about how large dams are designed, operated and maintained.

Many small/micro dams were constructed for SSI mainly in Amhara and Tigray Regional states. Some of these dams are not functional due to sedimentation, seepage and/or low catchment yield.

The design and construction of small dams are carried out by Bureau of Water Resources (BoWR) in the Regions using partly the available design guidelines. Operations of SSI schemes and maintenance of irrigation infrastructures are handled by the farmers through Water Users Associations (WUA).

Minor maintenance works such as removal of silts and weeds from canals and rebuilding of temporary diversion structures are done by the users own initiatives annually at the

¹ The size of irrigable area categorized under Small scale irrigation (SSI) in Ethiopia is up to 200 ha with few exceptional ones having an area above the indicated size. The SSIs are managed by community during the operational periods.

beginning of the irrigation season. Major maintenance works that require input of experts and materials are handled to the respective BoWR of the Regions. However, operation and maintenance are mostly overlooked and are not a major activity of BoWR. There are no routine inspections. When a major problem arises, the BoWR will look for solutions. These days, Woreda Water and Agricultural Bureaus are established to carry out the operation and maintenance (O&M) of water and irrigation infrastructures among other duties. But the budget allocated to them is small and they don't have the required capacity to carry out this job.

1.6 Dam ownership

Dam owners are responsible for the safety and the liability of the dam and for financing its upkeep, upgrade, and repair. The common legal understanding is that the dam owner is the developer of the dam, and is therefore responsible for the potential impacts, which the impoundment of water may have on upstream or downstream life, property and environment.

As most infrastructure facilities, such as roads, bridges, and sewer systems, are owned by public entities, large dams are also owned and regulated by the Federal Government. However, the recent proclamation (Proclamation No. 197/2000) allows a person/legal person to construct waterworks including dams after obtaining a permit from the Supervising body. In some developed countries the majority of dams are privately owned.

The few existing large dams in the country are owned by the Ministry of Water and Energy. But it is a usual practice that dams are operated by various agencies depending on the primary purpose for which the dams were built. Thus dams constructed for hydropower are operated by Ethiopian Electric and Power Corporation (EEPCO) and those constructed for water supply are operated by Water Supply Authority. This has created a sense of "ownership" of the dams by these agencies. However, Ministry of Water Resources oversees dam operation during critical periods (i.e. droughts and floods).

Many small/micro dams were designed and developed for SSI by Regional Governments. The operation and maintenance of these small dams are carried out by Regional and Woreda Water Bureaus and the beneficiaries.

2 Parties Involved and Responsibilities

Those involved in the dam business fit into five main categories as follows:

- i. the dam owner or developer (ownership may change from time to time) who operate and maintain the dam
- ii. the supervising body/authorities who issue and administer legal permits
- iii. the technical advisers/engineers whose roles include investigation, design, evaluation and technical advice
- iv. the constructors or contractors who undertake construction and maintenance roles to specifications by others
- v. the public, who may be affected directly or indirectly by the dam and who have certain rights, particularly under environmental and licensing legislation.

The respective roles and relationships between the parties are introduced in the following sections.

2.1 Dam Owner

While the dam owner (who may also be the initial developer) may not be technically qualified and may play a relatively subordinate role in a new development or in appraisals of an existing dam, the owner nonetheless occupies the most important role. It is the owner who holds the various legal permits for the dam and is legally responsible for maintaining the dam in a safe condition and for operating it safely.

The owner usually relies on engineers for investigations, design, safety reviews and the like and on suitably qualified construction contractors for construction or rehabilitation. In these situations, the technical advisers and contractors act as agents for the owner and will carry an appropriate level of responsibility and liability for their actions under the terms of the contract for their services. However, it is important for the owner to recognize that in the event of a problem arising, the Authorities will look first to the owner and the owner must fully understand all owner liabilities, the limits of the liability which the owner's agents can accept, and the level of additional risk to be carried.

A responsible attitude towards safety by owners is essential to protect others and avoid negligence situations. It is also a prudent means of protecting the value of the investment. The owner holds the purse strings and initiates all of the activities associated with dam development and continued safe operation. By understanding and requiring guidelines such as these to be implemented, the owner will be taking positive initiatives to ensure that the dam is safely developed, maintained and operated.

2.2 The Supervising body/Authority

The Supervising body (MoWE or any organ delegated by MoWE) shall be responsible for the planning, management, utilization and protection of water resources. According to the Ethiopian Water Resources Management Proclamation (No.197/2000), the powers and duties of the Supervising body related to dams and dam safety issues include the following:

- issue permits and certificates of Professional Competence;
- require submission of plans and proposals from any person who apply for a permit to undertake any kind of water works and approve, rejects, or amend such plans and proposals;
- establish quality standards for surveys, design and specification of waterworks as well as standards for the construction of waterworks necessary for the development of water resources; it shall also supervise compliance of waterworks with the established standards;
- prepare directives, in consultation with public bodies concerned, in order to ensure that water resources are not polluted and hazardous to health and environment;
- issue directives pertaining to the safety of hydraulic structures for the prevention of damages caused by dam water to dams, persons, property and crops;
- give an order of rectification or suspension of waterworks which are incompatible or inconsistent with the Ethiopian water resources policy, relevant Basin Master Plan Studies and water resources legislative framework; and ensures its implementation

In considering environmental issues, the Federal and Regional Authorities will be concerned with dam safety in relation to potential environmental impact.

2.3 Engineers/ Technical Advisers and Contractors

Technical advisers and contractors cover a wide scope of activities in the dam industry. Various aspects of investigation, evaluation, design and construction demand a high level of specialist expertise, particularly in the case of large dams or technically complex dams. Typical skills and related roles include:

- engineering geology and geotechnical engineering skills for appraisal of foundation and dam constituent materials and their behaviour
- hydrological and hydraulic engineering skills for assessment of river flows and hydraulic design of spillways and other hydraulic structures
- seismological skills for appraisal of earthquake risk and selection of design criteria
- environmental assessment and engineering skills to identify issues and effects and achieve environmentally appropriate solutions
- dam and related structure engineering skills for design and detailing of the key structures and mechanical equipment, and establishment of maintenance and operating procedures
- skills in evaluating and managing construction risk, particularly floods during construction
- project management and quality assurance skills to ensure approved designs are translated into effective construction
- construction competence, experience, and integrity to ensure all works are built to the standards required - on larger or more complex projects, this will require selection of a range of specialist Construction Contractors for different parts of the works
- peer review and appraisal capability to overview technical advisers work or undertake periodic surveillance and safety reviews of existing dams

Technical advisers play a key part in achieving safe and effective dams and often carry heavy responsibility for their advice or services. It is vitally important that they and the owner understand the extent of their roles and the boundaries of their responsibilities. For example, it is not practical or reasonable to expect the designer of a dam to certify the adequacy of its construction if the designer has not had adequate representation during construction or control over decision making on site. It is therefore usual practice that continuity of key technical advisers be maintained through design, construction and commissioning.

Other technical roles include dam operation and routine surveillance. Generally these roles are fulfilled by the owner's permanent staff, or services may be contracted out.

2.4 Public

The public interest is cared for in the broader sense by legislations and its enforcement by the authorities. Members of the public particularly those directly affected by the dam and its operation have a direct interest to be involved in the planning and implementation processes of dams. Others may have interest in advancing a particularly environmental, social, cultural, or political perspective.

Public safety is of primary importance and one of the reasons behind these guidelines. The other participants in the dam industry must at all times recognize their duty of care to the public and act de facto as agents for the well being of the public.

3 Legal and Regulatory Framework

Ethiopia does not have specific dam and dam safety legislation or administration as some other developed countries do. Many countries have dam safety laws that require application to be made and subsequent approval obtained prior to the construction of new dams or the repair or removal of existing dams. In addition, legislations require that all dams be periodically inspected to ensure that their continued operation and use does not constitute a hazard to life and property downstream. Some low-hazard dams are exempt from the provisions of some dam safety laws. In most instances, these are dams less than 5 m in height or that impound a volume of water less than 20,000 m³. The height of a dam is measured from the highest point on the crest of the dam to the lowest point on the downstream toe. The volume impounded by a dam is measured at the highest point on the crest of the dam.

There are some broader legal obligations under Ethiopian law which owners need to appreciate. The policies and legislations which are somehow related to dams and dam safety issues are described below:

3.1 Ethiopian Water Resources Management Policy

The Ethiopian Water Resources Management Policy formulated in 1999 by the Ministry of Water Resources with the belief that an appropriate water resources management policy for the sector will enhance the development and management of the country's water resources to make optimum contribution to an accelerated socio-economic growth. The overall goal of the policy is to enhance and promote all national efforts towards the efficient, equitable and optimum utilization of the available Water Resources of Ethiopia for significant socioeconomic development on sustainable basis.

The policy aims to ensure access to water for everyone fairly and in a sustainable manner, protect water resources and sources, and promote cooperation for the management of river basins. The policy underline the fundamental principles that water is a natural endowment commonly owned by all the peoples of Ethiopia and that every Ethiopian citizen shall have access to sufficient water of acceptable quality, to satisfy basic human needs.

3.2 Ethiopian Water Resources Management Proclamation

The Parliament of the Government of Ethiopia (GoE) issued Ethiopian Water Resources Management Proclamation No. 197/2000 within the framework of the Water Resources Management Policy. The purpose of the Proclamation is to ensure that the water resources of the country are protected and utilized for the highest social and economic benefits for the people of Ethiopia, to follow up and supervise that they are duly conserved, ensure that harmful effects of water are prevented, and that the management of water resources is carried out properly.

The Proclamation provides that all the water resources of the country are the common property of the Ethiopian people and the state. The Ministry of Water Resources shall ensure and administers that the management of any water resource is put to the highest social and economic benefit of the Ethiopian people and the management of water resources of Ethiopia shall be in accordance with a permit systems. The Ministry is entrusted with

broad powers of planning, management, utilization administration and protection of water resources.

The basic thrust of this proclamation is that water resources management and administration in the country should be based on the national water Policy, the Integrated river basin master plan studies and the water resources laws of the country. MoWE is clearly identified as 'supervising body' in charge of enforcing the provisions of the proclamation.

The Proclamation recognizes principles such as: protecting water resources from pollution, requiring water users and water polluters to pay, encouraging the establishment of water user associations, and the requirement of professional competence to engage in water works design and construction activity.

The Articles pertinent to dam and dam safety in the Proclamation are the following :

Article 11 : Necessity of permits

(1) No person shall construct waterworks without having obtained a permit from the Supervising body. (2) Any person shall be required to discuss his/her proposal with the supervising body prior to applying for a permit.

"Water works" is defined by the proclamation as any man-made constructed or to be constructed for the purpose of putting water to beneficial use, and includes diversion, clearing, dam construction, drilling, investigation, regulation, purification, measurement, transportation, transmission, desalination, dike construction and other related and similar works.

Water works include dam construction.

Article 13: Application for permit

1. An application for water use, release or discharge of waste, and waterworks construction permits shall be submitted to the supervising body. The application shall include detailed information as may be specified in the regulations to be issued for the implementation of the Proclamation.
2. Any application for a permit to release or discharge any waste, which endangers human life, animals, plants and any living things, into water resources shall not be accepted. However, the Supervising body may accept the application requiring the applicant to release or discharge after having treated the pollutant.

Article 14: Issuance of permits

1. The Supervising body shall issue the permit applied for within sixty (60) days after receipt of the application, where the proposed use of water does not: (a) infringe, in any manner, any person's legitimate interests upon the water; (b) entail pollution or harmful effects on the water resource and the environment.
2. The Supervising body shall state the detail information, conditions and restrictions which should be mentioned in the permit form.

The Proclamation states that the details shall be determined by directives to be issued by the Ministry.

3.3 Water Resources Management Regulations

Ethiopian water Resources Management Regulations issued by Council of Ministers (Regulation No. 115/200) in 2005. A review of the regulations shows that it mainly contains a further elaboration of the Proclamation providing in detail the main requirements for the issuance of permits for a water use, water works and waste water discharge, the conditions for the issuance, as well as the level of water charge and requirements and classifications for profession licensing of consultants and contractors in water works, and provisions for fees and charges.

In this Regulation, the key points related to dam and dam safety is given in Article 7:

Article 7: Application and Manner of Dealing with them

- 1) An application for the construction, maintenance or alteration of water works shall be made to the Supervising Body.
- 2) The application to be submitted shall contain the design and safety measures along with the detailed study of the water works.

Specific directives need to be worked out with regard to dams and dam safety and issued by the MoWE.

3.4 Environmental Laws

Environmental issues are given more and more emphasis in Ethiopia, with the recent development of a set of laws, following the Policy (Environmental Policy of Ethiopia, 1997) and strategy (National Conservation Strategy). The Ethiopian Environmental Protection Authority (EPA) has drafted three major laws regarding Environmental Pollution Control (No.295/2002), Environmental Impact Assessment (No 299/2002) and Establishment of Environmental Protection Organs (No. 295/2002) and the Proclamations are issued by the Parliament.

The Environmental Impact Assessment (EIA) Proclamation has made it mandatory that development projects are required to be subjected to EIA scrutiny. It means that EIA is a legal requirement. This proclamation is a backbone to harmonizing and integrating environmental, economic, cultural, and social considerations into a decision making process in a manner that promotes sustainable development.

EPA has also developed EIA Assessment Guideline Document in 2002 and EIA Procedural Guideline in 2003. This guideline provides advice on how best to comply with the Environmental Impact Assessment Proclamation, Environmental Protections Organs Establishment Proclamation, Environmental Policy of Ethiopia and other relevant laws, and thereby ensure effective environmental assessment and management practices by all those who may be required to engage in EIA.

The EIA Guideline details the required procedures for conducting an EIA in Ethiopia and the requirements for environmental management as well as procedures for EIA in specific development sectors in the country (including: agriculture, industry, transport, mining and dams and reservoirs). Dam and reservoir projects, are identified as having adverse and significant environmental impacts, and may, therefore, require full EIA. The Guideline identifies issues for environmental assessment of dam and reservoir projects and their impacts and recommendations for environmental management.

A directive (directive No. 2/ 2008) to determine categories of projects subject to environmental impact assessment according to Proclamation No. 299/ 2002 was issued by Environmental Council in 2008. This Directive stated that EIA Proclamation shall be applied to dam and reservoir Construction project if:

- Dam height 15 meter or more, or
- Reservoir storage capacity 3 million m³ or more,

This directive implies that projects incorporating small dams (as defined in this guideline) are not subject to EIA of Proclamation No. 299/ 2002.

3.5 Health and Safety

A dam owner has liabilities to other people in civil law and/or under Occupational Health and Safety law (Proclamation No.42/1993), depending on the circumstances. Occupational Safety and Health Directive has been issued by GoE, Ministry of Labour and Social Affairs in 2003. The directive deals with the general safety and health provisions that need to be universally applied in all types of types of workplaces including the general duties and responsibilities of employers and workers. Part five of the Directive deals with safety and health in construction industry, which is a serious occupational hazard.

While the Directive applies for the greater part of activities not directly related to dam safety, the Owner (Employer) of a dam has to ensure that the dam as a workplace is safe for operational employees, as well as for other persons who enter the site.

All dams present a level of risk to persons, especially children wandering around the site (whether entry to the site is authorized or not) and any features that may present an unacceptable risk should be clearly identified and addressed. For example, the dam may have a narrow crest that is capable of being driven over, or it may have steep upstream or downstream slopes.

Warning: Any repairs to dams that are releasing or leaking water should be left to experts as there have been a number of incidents (including death) involving persons trying to 'save' the dam. Where an embankment is suffering unusual leakage or has suffered partial failure but has not completely failed, caution should be exercised and expert help sought. The nature of the dangers to persons trying to 'save' the dam may not be visible, and may not be recognized even by those who are used to owning dams.

Water quality in a dam can become contaminated or polluted if not replenished or flushed. Therefore there is a chance that it can become a danger to those who drink the water or to downstream users if passed downstream, even if the initial water quality was satisfactory.

Sometimes flushing is done during periods of high inflows, but this is only possible after the nature and level of the contamination has been determined to be safe. Maintaining a regular flow release from an outlet pipe can prevent the bottom water becoming anaerobic often identified as a 'rotten egg smell'.

4 Dam Failure and Dam Hazard classification

4.1 Failure of a dam

Dams are complex structures subject to several forces that can cause failure. These forces are active over the entire life of the dam, and the fact that a dam has stood safely for years is not necessarily an indication that it will not fail. One of the forces inducing failure is seepage through the dam or its foundation. All dams seep, but if the seepage is too high in the dam it can cause a structural failure ("landslide" of the materials in the dam). If the seepage comes to the ground surface on or below the dam and exits too fast, it can carry soil out of the dam or foundation, and cause internal erosion or "piping" failure. Another way a dam can fail is by being overtopped and washed out. Overtopping is the result of having inadequate emergency spillway capacity or a clogging of spillways. Causes and prevention of dam failure are discussed throughout this Guideline.

'Failure' of a dam does not necessarily mean the same as 'collapse' of the dam. More generally, it may mean failure to its design objectives. Hence, any damage to a dam short of collapse (such as development of cracks, localized slumps or erosion) or any failure to retain water as designed (such as excessive leakage through, under or around the dam) or any inability to pass incoming flood waters via the spillway, may be regarded as a failure of the dam, though some failures may be more serious than others.

Should a dam fail, its owner is likely to be held legally liable for all associated damage. To minimize the possibility of failure and the attached liability, an owner should:

- use the services of a suitably qualified engineer to design and construct the dam;
- make periodic visual inspections of the dam; monitor conditions that may affect the safety of the dam; perform regular maintenance; carry out repairs where and when required to meet current design and construction standards; and have an experienced dam engineer investigate any unusual conditions which could result in partial or total failure.

4.2 Likelihood of a Dam Failing

A dam may fail by water passing under, over, through or around it. To avoid failure it must be properly connected to the ground and constructed using best materials and methods to make it resistant to leakage and erosion.

Although small dam failures do not make their way into the news media very often, it is a fact that across the country some small dams fail.

The three major failures modes of small dams in Ethiopia are:

- Sedimentation behind dam : sediments deposited clog outlet and intake structures
- Seepage loss through foundation and embankment
- low catchment yield and low volume of stored water in dams

The most common causes for failure of small dams in Ethiopia would be as follows:

- a) Design is not adequate (hydrological, geotechnical, hydraulic).
- b) Very limited site investigations are undertaken and consequently understanding of site conditions is poor.
- c) Embankment placement methods are substandard eg. soil compaction methods.
- d) lack of watershed management practices
- e) Maintenance or inspection frequencies are inadequate.

Many failures result in total loss of the dam. In those cases where damage can be repaired, the costs of repairs can be very high, and possibly greater than the original cost of construction of the whole dam. Many dams, even of modest size, should be designed and their construction supervised by an experienced dam engineer. The advice of an experienced engineer should also be sought if any problems or uncertainties occur after the dam has been in service.

4.3 Dam Hazard classification

The destructive force unleashed by an uncontrolled escape of water stored behind a dam has the potential to harm people, property and the local environment. The consequential losses can include loss of life, socio-economic, financial and environmental losses.

The risk that a dam poses is related to both the consequences of failure and the likelihood that a failure could occur. Measures can be taken to reduce the risk to an acceptable level and that is what dam safety is about.

The height of the dam, its maximum impoundment capacity, physical characteristics of the dam site and the location of downstream facilities should be assessed to determine the appropriate hazard classification.

When considering hazard in terms of dam classification, it is important to realize that the term "Hazard" is not the same as "Risk". For example, a large dam may be rated a high hazard structure because its location is such that a catastrophic failure and sudden release of water could adversely threaten downstream life and property. However, the same dam also could be at low risk for failure because it is conservatively engineered, receives regular inspections, and is exceptionally well maintained. Thus, its probability for failure is very low. In other words, risk is the product of hazard multiplied by the probability that a failure will occur.

Another example to illustrate this concept would be a smaller sized irrigation reservoir located miles from human habitation. In this situation, the dam is rated a low hazard structure because of its location, but it could be at high risk for failure because it was not properly designed by an engineer, it has never been inspected, and it is poorly maintained.

It is important to realize that a dam's hazard rating does not define the physical condition of the structure. Instead, "Hazard" is the definition that is used to estimate the amount of damage that could occur in the event the dam was to suddenly fail and release the contents of its reservoir. For that reason, any dam that is rated a high hazard structure must be properly designed, regularly inspected, and maintained in the best condition at all times

because the consequences of a failure are just too great to ignore. All reasonable methods must be implemented to reduce the risk of failure for high hazard dams.

Many countries which operate dam safety programs have established a classification system between 3 and 5 categories that relate to the consequences of dam failure. Most classifications divide dam hazards into three ratings: low, significant and high. Each rating is an estimate of the potential consequences to downstream life, property and environment that would result from a catastrophic dam failure.

For the purpose of this Guideline, FEMA's (US Federal Emergency Management Agency) three classification levels are adopted as follows: low, significant, and high, listed in order of increasing adverse incremental consequences. The classification levels build on each other, i.e., the higher order classification levels add to the list of consequences for the lower classification levels, as noted in the Table 4.1.

4.3.1 Low Hazard Potential

Dams assigned the low hazard potential classification are those where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

4.3.2 Significant Hazard Potential

Dams assigned the significant hazard potential classification are those dams where failure or mis-operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.

4.3.3 High Hazard Potential

Dams assigned the high hazard potential classification are those where failure or mis-operation will probably cause loss of human life.

Table 4.1 Dam hazard classifications

Hazard Potential Classification	Loss of Human Life	Economic, Environmental, Lifeline losses
Low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable. One or more expected	Yes

A primary purpose of any classification system is to select appropriate design criteria. In other words, design criteria will become more conservative as the potential for loss of life and/or property damage increases. This guide is intended for the owners of dams with hazard potential classification of Low.

5 Planning of small Dams

5.1 General

The following chapters relating to new dams outline recommended principles and procedures to achieve a safe dam. The key components and principal safety issues which can arise in a dam development are outlined and then the recommended procedures are described. Procedures are covered in general terms and are to be applied for small dams with low hazard categories.

Small dams are commonly constructed of earth materials because of economic reasons and convenience. Even though this guideline will focus on earth dams, the principles and safety issues in design and construction of concrete gravity and rockfill dams are also covered.

5.2 Dam types

Small dams are usually built using suitable materials found locally where the dam is to be located. Various materials are used for dam construction including earth, timber, rock, concrete and steel. If local materials are not suitable then they may have to be brought in from other areas. The embankment types of dams (earthfill and rockfill) and concrete gravity dams are discussed briefly below.

5.2.1 Embankment dams

ICOLD defines an embankment dam as, "any dam constructed of excavated materials placed without addition of binding materials other than those inherent in the natural material. The materials are usually obtained at or near the dam site"

Dams constructed of soil, of rock, or of a combination of soil and rock are called embankment dams. Embankment dams are most economical where the materials at the dam site can be used to construct the embankment with little or no processing.

The materials available locally control the size and configuration of the dam. Small embankment dams can be built of a single type of soil, which must hold back the water and provide enough strength for stability of the embankment. Large dams are usually "zoned," with fine soils (silts or clays) at the center of the dam (the "core") to hold back the water, and sand, gravel or rockfill in the upstream and downstream parts of the dam (the "shells") to provide the strength needed for stability of the embankment.

An important element in a zoned dam is an impermeable blanket or core which usually consists of clayey materials obtained locally. In locations where naturally impermeable materials are unavailable the dams are built of rock or earth-rock aggregates, and the impermeable layers of reinforced concrete, asphaltic concrete, or riveted sheet steel are placed on the upstream face of the dam.

Embankment dams have been built on a variety of foundations, ranging from weak deposits to strong rock. An advantage compared with concrete dams is that the bearing strength requirements of the foundation are much less. Minor settlement during and after construction is generally not serious because of the adjustability of the material.

5.2.1.1 Earthfill dams

An earthfill dam is an embankment dam, constructed primarily of compacted earth, either homogeneous or zoned, and containing more than 50% of earth. An earth dam is basically a trapezoidal embankment built in a valley to form a water reservoir.

Earthfill 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.

The sloping water face is called the upstream slope (face) and the downstream called the downstream slope. More generally, the main features of a dam are shown in Figure 5.1.

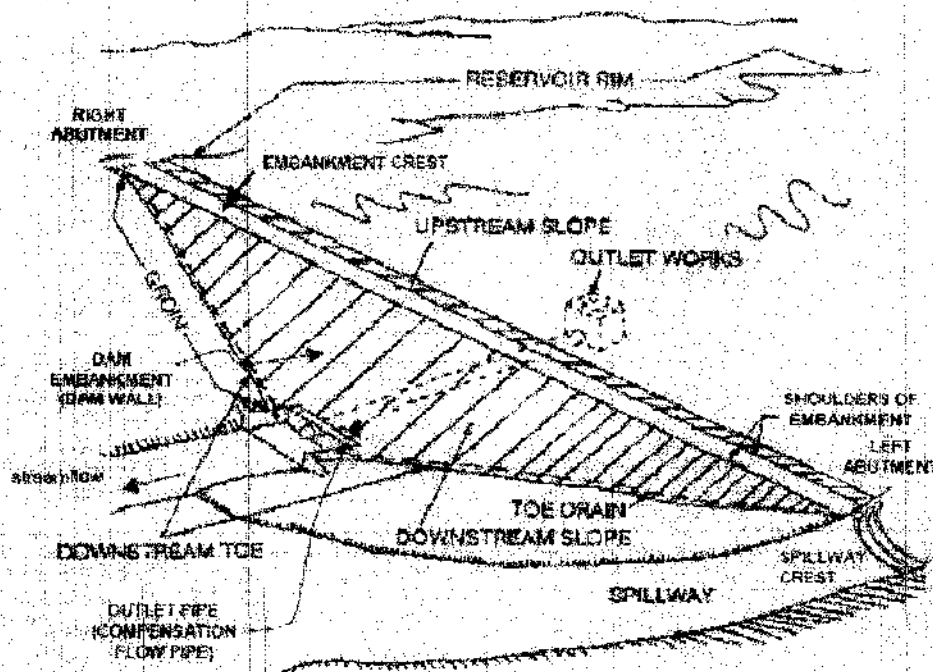


Figure 5.1 Main features of a small Earth dam

5.2.1.2 Rockfill dams

ICOLD defines a rockfill dam as, "an embankment type of dam, dependent for its stability primarily on rock". As rockfill dams must contain an impervious zone - now usually selected earth with filter zones, comprising a substantial volume of the dam - the term Rockfill dam usually represents a dam that contains more than 50% of compacted or dumped pervious fill. The dam is dependent for water tightness on an impervious upstream blanket or an impervious core. A section of a typical rockfill dam is shown on Figure 5.2.

Like an earth dam it is composed of fragmental materials, with each particle independent of the others. The mass stability is developed by the friction and inter-reaction of one particle on another rather than by any cementing agent that binds the particles together.

The main rockfill provides the structural support for the dam by its weight and internal stability. The impervious zone holds back the water. It is made up of the membrane which holds the water and transition zone which transfers the water load to the rockfill. The

membrane may be a thick blanket or core of earth or a thin diaphragm or deck of wood, concrete, steel, asphalt, dry rubble masonry or stone masonry. The auxiliary support members help to sustain the membrane or parts of the main rockfill. These components are similar to the shell, core, and appurtenances of the earth-fill dam and are analyzed in a similar way.

Rockfill is particularly suitable when there is no satisfactory earth available and when a plentiful supply of sound rock is at hand. They require design by professional dam engineers.

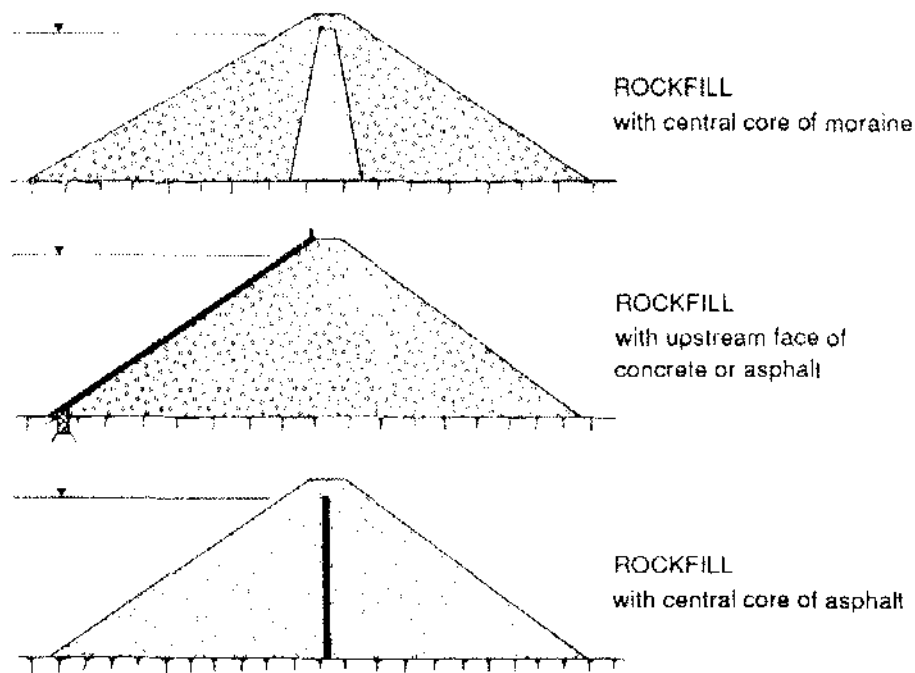


Figure 5. 2 Sections of rockfill dam

5.2.2 Concrete dams

Dams constructed out of concrete and which rely solely on its self weight for stability fall under the nomenclature of gravity dams. Concrete gravity dams gain their strength from their mass providing resistance to sliding and overturning. It has a cross section such that with a flat bottom, the dam is free standing. The dam has a center of gravity low enough that the dam will not topple if unsupported at the abutments. Because of their lack of flexibility they are generally founded on rock. A favorable site usually is one in a constriction in a valley where the sound bedrock is reasonably close to the surface both in the floor and abutments of the dam. A section of a conventional concrete gravity dam is shown on Figure 5.3. Small concrete dams generally may have no internal galleries.

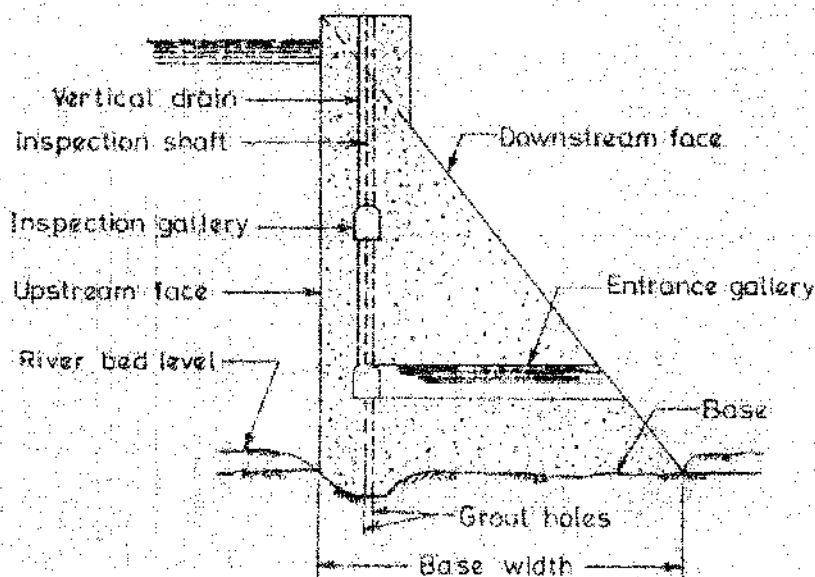


Figure 5.3 A section of a concrete gravity dam

The demands of producing a significant quantity of concrete and the formwork involved often mean concrete dams are not economic on a small scale. Concrete dams also require design by professional dam engineers.

5.3 Principal Dam Components and Related Safety Issues

The complete dam comprises several parts, the number and type depending on the particular dam and its function. In the context of dam safety, the dam also includes the reservoir and its margins.

The main components of a dam are:

- Reservoir
- Embankment (dam body)
- foundation
- spillway;
- outlet works;

The principal components, their functional requirements, and typical areas where risk or safety issues occur, are summarized as follows:

(i) **The Reservoir:** the reservoir behind the dam will generally have a fluctuating water level which temporarily increases as floods pass through it and falls in cases where the stored water is drawn off for use. Initial reservoir filling and water level changes can make reservoir margins unstable where they are steep and/or have unfavorable geology. If the reservoir is full and there is a major reservoir landslide, the displaced water may cause major damage downstream and also cause the dam to fail.

(ii) **Embankment:** the Embankment is the main dam structure that creates a barrier which holds the stored water. The embankment cannot be treated in isolation from its foundations or the adjacent natural ground (or abutments) with which it acts in an integrated

manner. Similarly the dam and spillway design need to be integrated to ensure that flood flows do not overtop the dam.

The embankments (and its foundations) must have adequate strength to withstand the applied forces and be sufficiently water tight to maintain the storage and prevent seepage from eroding the materials of the dam (it is unlikely there will be no seepage).

Areas of risk affecting safety can be extensive and include:

- not correctly assessing material properties or not correctly placing materials during construction, thereby leading to lower strength than required
- material types, thickness and disposition being inadequate to control seepages, leading to internal erosion
- overtopping and erosion of the embankment

(iii) **Foundations including abutments:** the areas of ground on which the dam is located and the areas of ground adjacent, form part of the total water barrier. If the foundations do not adequately support the basic dam structure, or are themselves weak or prone to high seepage flows and forces, then they can create an area of high risk. As for the dam structure, areas of risk can be extensive and include aspects such as:

- geological defects in rock structures which are points of weakness and/or of high seepage flow potential, leading to poor structural performance and potential instability due to seepage
- weaknesses in the abutments making them vulnerable to slope failures
- lack of information, inadequate identification or provision for seismic forces and movements

(iv) **Spillways:** the spillway has to carry the flood flows safely past the dam and can take several forms. These include the use of a separate auxiliary spillway which operates only in floods which are very large, or have very low frequency. In some situations, particularly where the reservoir is not permitted to rise significantly during a flood, flood gates are installed and opened progressively to bypass the incoming flood flow.

Spillways and flood gates constitute a high risk part of the dam, with failure of the spillway system putting the dam or abutments at risk of severe erosion damage possibly leading to collapse. Areas of spillway risk include:

- flood sizes being underestimated with consequential undersizing of components
- Secondary effects such as debris blocking the intakes. This is often important for smaller structures with less spillway capacity.
- energy control arrangements at the end of the spillway being inadequate, causing erosion and structural collapse by undermining
- spillway chute details allowing high energy flow to create destabilizing uplift pressures at structural joints
- flood gates not operating as intended and auxiliary spill paths for this eventuality not being adequate

(v) **Outlets** : outlets or conduits may be required for drawing off water from the dam for its ultimate use. Conduits, particularly those taken through the dam structure or foundations, create safety risks if the conduit openings can admit high leakage into the surrounding fill or foundation. If seepage can track along the conduit in an uncontrolled manner, it can lead to erosion and a "piping" type failure. Many small dams have failed through inadequate protection against seepage associated with conduits.

(vi) **Other Structures**: other structures include, intakes on the upstream side of the dam, construction diversion comprising coffer dams, energy dissipation, tailrace of the dam. In certain cases, damage to the structures can lead to consequential damage to the dam or endanger spillway capacity. The risks will depend on each situation but must be evaluated and protected against.

5.4 Services of an Engineer

Because of the size and nature of many small dams, and because construction of most small dams looks deceptively simple and uses familiar technology, it is tempting to think that the services of a professional engineer are not required. This is often a mistake. Not only is it true that a significant proportion of small dams fail, but did you know that a high percentage of dams fail during their first filling? This generally means the design, construction or filling rate of the dam was an aspect that was not understood.

An experienced dam engineer carrying out the dam design and supervising the construction is beneficial because the structure will be properly designed and built to current industry standards. The cost of engineering services should be a minor percentage of the total cost of the work. More importantly, that cost should be a very small percentage of the greater cost of reconstructing the dam if it fails, not to mention the additional cost of compensation for the damage caused by the failure. Note also that relatively few engineers are experienced in dam design and/or construction supervision. Make sure that the professional engineer whom you select has a suitable track record of experience in dams of a size and type which is relevant to you, including experience with earth materials found in Ethiopia.

The Engineer should hold a certificate of competence permit issued by the Supervising body for consultancy service relating to water resources study, design and supervision activity. In addition to professional engineering qualifications, the engineer needs to have:

- i. A sound knowledge of relevant dam design principles and methods to ensure safety, economy and durability;
- ii. An appreciation of local meteorological, hydrological and geological conditions;
- iii. A knowledge and understanding of current industry practices and standards with respect to dams; and
- iv. A broad knowledge of other factors which might be relevant in particular situations, including knowledge of legal obligations and awareness of such potential problems as siltation, seepage, erosion, and pollution.

There are some fundamental principles which should be applied through the investigation, design, construction and commissioning stages to achieve an adequate level of safety. The principles are:

- i. the competence and experience of the owner's agents relative to the nature and dam hazard category of the dam, must be appropriate in all areas.
- ii. there must be a cooperative and trusting relationship between the owner and technical advisers, and the designers must be given full control over decision making in critical areas.
- iii. the owner must agree to apply the appropriate level of funding for investigations, design and construction to reduce the chances of critically important issues (particularly related to foundations) being not sufficiently well assessed or under protected.
- iv. the designer/technical adviser has a duty not to compromise unduly due to financial pressures from the owner, developer or contractor.
- v. continuity of key technical advice should be maintained throughout all stages of the dam from development, through design, construction and commissioning, to reduce chances of critical points of design philosophy and intent being misinterpreted during construction or commissioning.

5.5 Site Investigations

Most failures are due to lack of appreciation of how the particular dam site would react to the superposition of the dam and reservoir. It is therefore essential that a detailed site investigation takes place and the results are appropriately used by engineers.

In the planning stage possible dam sites will have been chosen from contour maps and aerial photography, selected primarily on topography. A narrow gorge is best, hoping for minimum quantities in the dam and a valley opening upstream to provide the required storage. There may be alternative sites along the length of a river and hence further investigation has to be done to ascertain the best possible position.

A wide range of issues needs to be considered. To overlook one or more of them may, in particular circumstances prove crucial to the operation and safety of the dam. A checklist for site investigation is provided in Appendix B.

Pre-design and design investigations, depending on the situation, will encompass:

- defining topography
- defining hydrology, particularly flood characteristics
- defining geology and site specific foundation conditions and properties
- determining the properties of construction materials
- determining seismic and volcanic hazards and earthquake forces
- determining the potential impact and environmental effects
- local knowledge of previous designs in the vicinity

The degree to which each area of investigation is taken depends on the potential impact, scale of project and value of the investment to the owner. However, the importance is stressed of undertaking an adequate level of geological and foundation investigation by suitably qualified Specialists, working closely with appropriately qualified dam designers. Many dam safety issues and incidents and also dam failures, are attributable to inadequate investigation and/or application of sufficiently well qualified personnel. Even small or low hazard dams can have high likelihood of foundation related problems.

5.5.1 Selecting the Dam Site

Locating a dam depends on a number of factors including:

- suitable valley that will catch the most water;
- location that will maximize the available catchment area and minimize the cost of the dam;
- suitability of the foundations and materials available at the site; and
- location of the dam relative to where the water is to be used

Each of the above points will require some degree of compromise to get the most cost-effective result. There may also be a need to give thought to the visual impact of a proposed dam to your neighbour, as they have a right to object to the structure if it affects their residential amenity.

From an economic viewpoint, a dam should be located where the largest storage volume can be captured with the least amount of dam body. This is generally possible if the valley is narrow with a steep side-slope and the slope of the valley floor will permit a deep basin. These sites also tend to minimize evaporation losses from the dam. You should avoid locating the dam where run-off from houses, dairies or septic systems can pollute the water.

When choosing the location and size, you should also take into account what would happen if the dam failed suddenly and whether it would result in loss of life, injury to persons or livestock, damage to houses, buildings, roads, highways or railroads.

5.5.2 Considerations at Investigation Stage

5.5.2.1 Some Technical Consideration

Site selection and site investigations are critical components to the success or failure of a dam. Consider the following important technical aspects in this regard:

(a) The catchment is the area of land from which run-off is to be collected. If it is the main source of water supply, make sure that it is capable of yielding enough water to maintain both the supply in the dam and the required releases over all periods of intended use. The catchment area however should not be too large, as it will then require a big and expensive overflow system (or spillway) to safely pass excess run-off from heavy rainfall without overtopping the dam.

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.

(b) Topographical features such as slope, width and height of dam, as well as reservoir capacity will influence construction costs. Site survey will provide the levels and distances to allow proper calculation of the dam size and material quantities needed for the construction and ultimately the cost of the dam.

(c) Site tests are conducted to establish the material properties for the embankment and foundation and include:

- A good understanding of local geology - whether the investment ground in the vicinity of the reservoir is suitable for the storage of large volumes of water;
- Knowledge of the properties of the foundation material beneath the dam. Whether it will support the load without excessive deformation, and control seepage within acceptable levels;
- Understanding of the materials from which the dam will be built. Whether they have adequate strength, durability and impermeability, and from where they may most economically be obtained.

(d) A good location for a spillway that will effectively handle runoff and minimize erosion.

(e) Watershed activities that can affect the water quality or quantity of runoff.

The storage basin must also be impermeable to hold water and where this is not so, expensive clay lining may be required.

5.5.2.2 Environmental Considerations

Dams with their associated reservoirs can have substantial environmental effects and any existing dam or new project must comply with environmental legislation and associated licensing or permit requirements. The Ethiopian EIA guideline has identified issues for environmental assessment of dam and reservoir projects. It should be recognized at the outset that dam developments have effects extending beyond the immediate confines of the dam and inundated areas. For example;

- Reservoir slope stability, may become a dam safety issue due to the risk of overtopping caused by large volumes of reservoir water being displaced by slope failures.
- Siting of the dam/reservoir must take into consideration the local earthquake and faulting activity which may cause breaching of the dam
- Groundwater level changes may affect stability and land use around the reservoir margins and possibly adjacent to the downstream river, as a result of changed water levels.
- Trapping of sediments in the reservoir can result in upstream shoaling and loss of reservoir storage.
- Flora/fauna effects may occur in storage basin, downstream, and in passage around and through the dam.
- Minimum flow maintenance downstream of the dam to ensure the survival of flora and fauna, and to reduce causes of stream bed deterioration.
- Social development/changes to downstream use given the changed flood situation.

Flora and fauna

Waterways provide habitat and water to support a wide range of native plants and animals. When a dam is built in such areas, these habitats can be lost through inundation and the physical barrier the dam poses.

There are also changes to the flow patterns resulting from dam construction and operation. Existing native in stream and riparian (streamside) vegetation can be lost through permanent

inundation or removal as a result of dam construction. The dam site may be a creek, marsh, soak, and drainage-line and may not flow for many months of the year. However, these habitats often support fish, invertebrates, frogs and birds that are adapted to these particular conditions. The effect of dams in changing flowing water to standing water will change the local habitat such that it is no longer suitable for most flora or fauna found at the original site. The major changes can include reduced flows downstream, a reduction in water quality, and an increase in water temperature. The combination of these factors often leads to local extinctions of such flora and fauna. Dams constructed on waterways can also act as a physical barrier to migratory and localized movements of aquatic biota, particularly fish. Some species of native fish need to migrate in order to spawn and recolonize. Many species will also move upstream into intermittent streams when there is sufficient flow to access spawning habitat and food. If fish passage is blocked by dams on waterways, they may eventually become extinct from sections upstream of the barrier. This will also have negative impacts for the species as a whole due to reduced access to critical spawning sites and habitat. The impact of dam as a barrier will obviously vary depending on the type of waterway it is built on. A dam that blocks the passage of a permanently flowing stream will be of greater concern than a dam on a depression in the middle of a paddock, as there are greater intrinsic values associated with permanently flowing streams. The introduction of barriers to migration is a potentially threatening process to flora and fauna, and thus must be managed to prevent such impacts on flora or fauna.

Sediment transport

Dams on waterways will capture almost all of the sediment carried by water flow. Silt, sand, gravel, and organic matter are trapped behind the dam instead of being carried down the waterway. This starves the waterway of the material needed to replenish gravel bars, rebuild the streambed, and renew floodplain and estuary soils. In addition, the maintenance of dams may require the periodic flushing of accumulated sediments to improve water quality in the dam. Excess sediment input and deposited silt can be lethal to fish, fish eggs and invertebrates, and will have effects of smothering critical habitat such as spawning sites, nursery grounds and food sources. For invertebrates, sediment input will directly impact on the areas of the streambed where they live. Many invertebrates live amongst the rocks on streambeds, and sediment deposition fills spaces between rocks leaving them with no available habitat.

Compensation Flow Requirements

As a condition, there may be a requirement for the storage dam to make provision for a by-pass channel around the dam or an outlet by means of pipe through the structure. This will allow predetermined water flows to be passed down the waterway. Your dam may only be permitted to harvest a certain amount of water depending on the flow patterns of the waterway.

The by-pass channel or outlet pipe and valve comprising the outlet works will need to be sized to suit the compensation flow requirements. This requirement is to provide security to downstream users and the environment.

The outlet pipe has benefits in that it is a means for releasing water from the storage in the event of a problem with the dam wall. When the dam is full, a spillway is used to pass excess flows.

5.6 Dam Design

Many dam designers in Ethiopia make reference to dam design guidelines for small dams developed by Continental Consultants under ESRDF. The guideline can serve as a baseline for further update and revision.

A manual for small dams' design is recently prepared by Investment Centre of Food and Agricultural Organization (FAO) and is available at FAO's web site. The manual can be used for small earth dams no higher than 5 m from streambed to finished crest level.

Dams have to be designed by professional engineers. There are only a relatively small proportion of professional engineers (even among civil engineers) who have experience in dam design or construction. It may be tempting to select a 'general practitioner' consulting engineer because of their proximity or cost, but you are aiming here to guard against possible costs far greater than the consultant's fees.

Dams which are larger in size and potentially hazardous require a range of specialist disciplines, applying industry accepted state of the art analysis and design procedures, and involve considerable effort in identifying the most cost effective design. It is important to translate designs into clearly understood construction specifications and drawings, backed by an appropriately extensive design report which records all design data, philosophy and assumptions, and defines areas requiring re-evaluation or confirmation during construction. The design must be buildable. A check sheet is provided in Appendix C to guide review of a dam design.

5.6.1 Embankment dams Design

When considering embankment design, there are several variables and elements that have to be specified.

- Crest width
- Side slopes
- Earth cuts
- Impervious core
- Seepage control
- Wave protection
- Freeboard
- Embankment vegetation, and
- Allowance for settlement

The design has to ensure:

- a) It is impermeable enough to prevent excessive loss of water from the reservoir.
- b) The design must ensure stable slopes.

- c) Settlement of the dam must not be excessive so as to reduce the freeboard of the dam.
- d) The upstream slope of the dam must be protected from the destructive action of waves, and the downstream slope must withstand rainfall erosion.
- e) 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.

The single most common cause of earthen dam failures is overtopping of the embankment. An undersized spillway will lead to overtopping; therefore spillway design is critical to reservoirs. The spillway must be located such that discharge will not erode or undermine the toe of the dam. If the banks of the spillway are made of erosive material, provision must be made for their protection. Consideration must be given to the hazard to human life and potential property damage that may result from the failure of the dam or excessive flow rates through the spillway. Further consideration must be given to the likelihood of downstream development that may result in an elevation of the hazard classification.

5.6.2 Concrete Gravity Dam Design

The major concepts and criteria in designing a concrete gravity dam are that it has to be:

- Safe against overturning at any horizontal plane within the dam.
- Safe against sliding at any horizontal place within the dam.
- So proportioned that the allowable stresses in both the concrete and the foundation shall not be exceeded.

Two other factors directly affect the design of a dam, the intensity of hydrostatic pressure at various points within or under the dam and the area upon which pressure acts. The dam has to be checked for stability under this hydrostatic pressure distribution on the base if no drainage is provided (or all drainage is blocked). It is important to expend effort and money on a drainage system to ensure satisfactory function over the entire life of the dam.

5.6.3 Extreme Events

Large earthquakes, storm/flood activity and failure of upstream dams can be considered extreme events. The risk of failure from these events is minimized by using engineering design standards and relevant guidelines incorporating adequate margins of safety.

Emergency preparedness set up well in advance is the only available measure of reducing the impact when a dam failure is about to happen.

5.6.4 Sedimentation

The effective life of many of small dams is reduced by excessive siltation – some small dams silt up after only a few years. This issue is poorly covered in the many small dam design manuals that are available, as they mostly focus on the civil engineering design and construction aspects.

The hydrological calculations needed to support the design of small dams and to predict future siltation are often either too simplistic, or on the other hand too complex and too

dependent on data to be of use to small dam designers. The guideline developed by DFID and HR Wallingford can be used in the absence of local references. The guideline contains appropriate methods for predicting, and where possible reducing, siltation rates in small dams in semi-arid zones in Eastern and Southern Africa.

6 Construction of a Dam

The quality of construction is all-important to dam safety. The dam components will not have the level of safety targeted or adopted by the designer if construction materials or workmanship do not equal or exceed the design specifications.

As far as construction is concerned, the following requirements are necessary from the dam safety viewpoint:

- the contractors must be suitably experienced and committed to achieving the standards of work specified
- the level of supervision of the works, quality assurance procedures and designer continuity, must be appropriate to the scale and complexity of the dam.
- the owner must recognize that inherent uncertainties may remain after design investigations and only be revealed during construction, and have funding in place to deal with costs arising from additional requirements identified during construction
- any area identified in the design process as requiring confirmation by the designer during construction, must be totally under the designer's control, and no design change, however small, shall be made without the designer's review and formal approval
- a suitably detailed design report and drawings showing the as-built structure of all components of the dam and foundation shall be developed as an on-going and integral part of the construction supervision process, and be prepared after completion of each component so that there is a reliable record to refer to at all times in the future

6.1 Selecting a Contractor

Beware of the 'bargain price' in dam construction!

The use of inexperienced contractors and/or inadequate supervision can develop into an expensive liability. Nothing can take the place of a reputable contractor, using appropriate equipment and experienced machine operators and working under supervision of an experienced engineer.

Check the standard of previous work and ask if they have done any work under the supervision of an engineer experienced in dams. Check out any references given!

6.2 Construction Supervision

Construction supervision is an important phase of dam construction. Supervision is meant to ensure that the design factors and specification requirements have actually been included in

the final product. Note that the expertise's of the designer and the constructor are quite different; there are many subtle but important design issues, even with small dams, which can easily be undermined by the construction process but which are not apparent to the untrained observer, yet have potential to cause costly failure.

If foundation preparation, material selection, outlet/spillway installation and embankment compaction are not properly carried out then the safety of the dam will be compromised. It is totally unwise to attempt to construct a dam without having an appropriate specification and plan in the contract. Not only do the specifications and plans form a coherent set of instructions for the contractor to follow, but in the event of things going wrong, either during construction or afterwards, there will be no record as to what the standard of construction should have been, thus making it exceedingly difficult for the owner to point to the person responsible for his loss in the event of a legal argument.

Remember even the best contractor might be tempted to take an occasional short-cut in the absence of good supervision, without recognizing the potential technical consequences for the performance and/or safety of the dam.

6.3 Construction of Embankment dams

6.3.1 Dam Foundation

All topsoil (the upper layer containing any organic matter such as grass or roots, however fine) and vegetation must be stripped from the area where the embankment is to be placed and put to one side. This material should not be mixed with the clayey material to be used for the bank.

Mixing topsoil with the bank material to save costs or because of convenience is asking for trouble! The organic matter in the topsoil will decay in due course, causing leakage paths to develop later, and may even lead to difficulty in obtaining adequate impermeability in the embankment in the short term.

A core (cut-off) trench should be excavated along the centerline of the bank to provide good protection against under-bank leakage. The cut-off trench should extend the full length of the bank including up the abutments. It must be wide enough to allow the construction equipment to achieve the required standard of compaction; its depth will depend on site soil conditions.

In most cases, it is not difficult to find suitable foundation materials relatively close to the surface, if unsuitable upper soils (including topsoil) are first removed. The founding material must be sufficiently stiff and impermeable, and must extend to sufficient depth to allow the storage behind the dam to be retained without significant leakage, but also to avoid any appreciable settlement of the constructed embankment. In some locations, upper soils below topsoil are soft, weak or contain gravel or other inclusions (such as calcareous materials) which can form a leakage path. This is one of the reasons for recommending the inclusion of a cut-off trench below the embankment, no matter how low, so that the content of the next layers below the embankment can be checked out before construction of the embankment begins.

6.3.2 Embankment Materials and Construction

6.3.2.1 Selection of Materials

Most dam walls are constructed of earth materials. While construction of dams has to be practical, and is limited by available materials within economical distance, selection of appropriate materials is vital for dam safety and performance.

This applies not only to the materials used in the embankment, but also materials on which it is founded as noted above.



Figure 6.1 Typical embankment slips resulting from construction or material defects

The embankment must be capable of securely retaining water. This is generally done by (a) ensuring that the materials for the embankment contain sufficient clay, and (b) ensuring that the materials are adequately compacted.

Small dams tend to be built from a whole range of soil types from sand to the stickiest of black clays. Each general soil type has its own characteristics and problems, which must be considered when designing the dam.

Soils most susceptible to problems are:

- Dispersive clays which are those that will disintegrate spontaneously in the presence of water. They are very common in arid climates and their presence can be suspected if water in local dams and streams normally has a muddy appearance. They may be free of problems during construction of an embankment, but problematical when the dam is filled or filling.
- High plasticity clays suffer from swelling and shrinkage causing cracking problems. Water can escape through the cracks and erode the embankment. These soils are also difficult to compact without leaving voids internally.
- Low clay content material that does not have sufficient clay to provide strength and impermeability.

Use of any of these materials can result in leakage that may lead to piping or tunnel erosion (ie. the removal of soil unseen within the dam embankment while surface soils remain intact). If such erosion is unchecked, this will lead to rapid failure; it usually becomes apparent as surface leakage only when the internal erosion has already well progressed.

6.3.2.2 Placement of Earth Materials

Embankment material placement should be done in horizontal layers of uniform thickness. Good compaction requires that each new layer is bonded onto the previous layer. To achieve the best results the material must be placed with sufficient moisture to make it pliable just before becoming crumbly and not so wet that it stains the hands or flows under compaction. The optimum moisture content for compaction is normally determined by laboratory testing.

6.3.2.3 Compaction of Earth Materials

The materials in the embankment must not only contain sufficient clay, they must also be adequately compacted with each compacted layer bonded to the one underneath.

Inadequate compaction can result from:

- The use of material which is too wet or too dry (the acceptable margins are quite small). Note that it is generally easier to compact and handle material which is a little below its standard optimum moisture content, and that is commonly done with embankments for other purposes such as roads, but the consequence of doing so is a marked increase in the leakage potential of the finished product, hence it is not appropriate for dams; or
- The use of tracked plant rather than compaction rollers designed for compacting and kneading the soil layers into each other is asking for trouble. Even one layer of inadequately compacted material in a bank can result in seepage leading to failure. It is very tempting, and very common, to use tracked plant for small dams because it is available and is much less costly, but again, this is inviting trouble! Remember that tracked plant has tracks in order to keep the contact pressure low (for example, to cross soft ground), whereas what is required for good compaction is a combination of much higher contact pressures and ability to penetrate layers and knead them to ensure good bonding and eliminate leakage paths. Proper compaction plant is designed to do these things.

6.3.2.4 Rockfill materials

The quality of the rock is a major factor in the choice of a rockfill dam and in the design of the structure. Extensive testing is necessary to judge whether the rock is suitable for construction.

Quarrying - The cost of drilling and blasting constitutes a large part of the unit price of rockfill.

Rock Durability - There is no entirely satisfactory test to determine durability of rock over centuries, and hence good judgments has to be used. Examining old structures such as walls and bridge piers built of the same material is helpful.

6.3.2.5 Placement of rocks

Dumped Rockfill - the main body of fill is placed by dumping. The initial part of the fill is dumped from clamshell cranes, cableways, or from ramps on the abutments to form a mound or bank. The remainder of the fill is dumped from the top of this mound, allowing the rock to fall down the sloping surface. The combined effect of sliding, tumbling and impact

cause the pieces to become tightly wedged together. Not more than 15% fines should be in the dumped rockfill, since they prevent good compaction and make drainage of water difficult.

Rolled Rockfill - if the rock is soft and breaks readily into pieces less than a third of a cubic metre, a rolled rockfill can be used. It is placed in layers and then rolled by heavy rubber tyred rollers and heavy vibrating rollers. Four to eight passes are required for compaction.

Reshaping the Fill - the dumped rockfill assumes side slopes of the angle of repose. If a flatter slope is required it can be formed by introducing horizontal berms as required.

6.3.2.6 Decked rockfills

The membrane used to deck the rockfill may be a thick blanket or core of earth or a thin diaphragm or deck of wood, concrete, steel, asphalt, dry rubble masonry or stone masonry.

Cement concrete face has a very long life, it is an obvious watertight membrane on rockfill dams. The facing can be tied to the dam in two ways, either poured directly onto the rubble transition zone. A mortar bed is initially placed which penetrates into the rubble a few centimeters. This is immediately covered with the concrete to form a monolithic mass which extends into the rubble and is thus bonded to the dam. Or, ribs are placed in the bottom of the slab by forcing grooves in the facing. The ribbed support, however, is unnecessary if the bonding with the backing is effective.

6.3.3 Outlet Pipes or Structures in Embankment

Outlet pipes under the dam wall are used for the controlled release of water from the dam. If not properly installed, they can readily provide a path for leakage from the dam, resulting in failure of the embankment and uncontrolled release of water.

Proper installation requires the backfilling and compaction to be carried out with extreme care. Using cut-off 'collars' at intervals along pipes passing under a bank can reduce the possibility of leakage. However, special care is required to ensure adequate compaction in these areas, and this may require the use of special small equipment.

Outlet pipes or other works should be placed in original ground rather than in the embankment. As far as possible, the location of such structures in the embankment itself should be avoided. It is likely that they will be damaged during construction of the embankment and/or when any settlement occurs, but such damage will be unseen. Because of difficulties with compacting backfill properly around an outlet pipe it is better to backfill with concrete. Never use sand or other granular material as pipe backfill or bedding.

Ideally, steel pipe with cement mortar lining and backfilled with concrete should be used. Unlined steel pipe can corrode and perforate within 20 years and lead to internal erosion of the embankment or abutment and result in dam failure. The use of concrete cut-off collars and an upstream guard valve is considered to be highly desirable, but such features themselves create an additional need for special care and attention to detail in both design and implementation.

6.3.4 Spillways

When selecting a site for the construction of a spillway, care should be taken to choose an area where there has been no previous disturbance of the natural ground. The usual site is near one of the dam's abutments. However, spillways should be confined to locations clear of the embankment so that no flow is likely to go onto and damage the dam wall.

There are many problems that can develop depending on the type of spillway and the materials it is constructed from. If the spillway develops problems which go unnoticed the embankment may be endangered.

Note: you should regularly inspect and maintain the spillway. If uncertain about a particular problem, an engineer should be consulted.

6.4 Concrete dam construction

6.4.1 Foundation

A concrete gravity dam intended to be constructed across a river valley would usually be laid on the hard rock foundation below the normal river overburden which consists of sand, loose rocks and boulders. However at any foundation level the hard rock foundation, again, may not always be completely satisfactory all along the proposed foundation and abutment area, since locally there may be cracks and joints, some of these (called seams) being filled with poor quality crushed rock. Hence before the concreting takes place the entire foundation area is checked and in most cases strengthened artificially such that it is able to sustain the loads that would be imposed by the dam and the reservoir water, and the effect of water seeping into the foundations under pressure from the reservoir.

Improvement of the foundation for a dam may be effected by the following major ways:

- Excavation of seams of decayed or weak rock and backfilling with concrete.
- Excavation of weak rock zones backfilling the entire excavated region with concrete.
- Excavation for and making a subterranean concrete cutoff walls across leakage channels in the dam foundation where the where the water channels are too large or too wet for mining or grouting
- Grouting the foundation to increase its strength and to render it impervious.

6.4.2 Temperature control of mass concrete for dams

When a concrete gravity dam is constructed of mass concrete, it undergoes volumetric changes with time due to the release of heat of hydration by the concrete. A rapid rise in the temperature of mass concrete takes place during the phase when the concrete mass is in plastic stage and undergoes hardening. After hardening, the concrete gradually cools due to effect of atmospheric temperature, which tends to subject the concrete to high tensile stresses. Cracking occurs in the concrete when these tensile stresses exceed the tensile strength of the concrete. This cracking is undesirable as it affects the water tightness, durability and appearance of hydraulic structures. Hence, methods to control the temperature rise during dam construction are absolutely essential.

Most commonly used methods are pre cooling, post cooling and reducing heat of hydration by proper mix design. The ideal condition would be simply to place the concrete at stable temperature of dam and heat of hydration removed, as it is generated, so that temperature of concrete is not allowed to rise above stable temperature. However this is not possible to achieve practically. Therefore, the most practical method is to pre cool concrete so as to restrain the net temperature rise to acceptable levels.

6.4.3 Aggregate production

Huge quantities of aggregate would be required for the construction of a massive structure like a concrete gravity dam. The acceptability of the natural aggregate is to be judged upon the physical and the chemical properties of the material and the accessibility, proximity to site and economic workability of the deposit. A suitable quarry has to be identified in the neighbourhood that can supply continuous source of aggregates.

6.4.4 Concrete production and handling

Standard practice is for materials to be batched by weight. The procedure to be adopted for moving concrete from the mixers on to the dam will be governed by site conditions. Having produced a good placable concrete, the problem is to transport it to the dam site with the least possible segregation or change in consistency, so that it may be compacted uniformly into the dam without reasonable effort. Nowadays a cableway laid across the dam valley is often used with buckets of large capacity. At many construction sites concrete is placed using chutes or even a belt conveyor. It is recommended that concrete shall have to be placed in position within 30 minutes of its removal from the mixer.

6.4.5 Concrete placing, consolidation and curing

For laying concrete over the rock foundations, it has to be ensured that the surface is clean and free from mud, dirt, oil, organic deposits, or other foreign material which may prevent a tight bond between rock and concrete. In case of earth or shale foundations all soft or loose mud and surface debris shall have to be scrapped and removed. A layer of concrete (lift) that is laid is generally kept as 1.5 m, in a view to ease construction and limit excessive temperature rise. The concrete of subsequent lifts has to be placed after allowing sufficient time for the previously laid concrete to cool and attain its initial set and become hard. Once a lift is cast it is thoroughly compacted with vibrators.

Curing of concrete is important but a difficult task for the construction engineer. Primarily it is necessary to maintain satisfactory moisture content in the hardening concrete. This may be achieved either by the application of water (usually from sprinklers or perforated hoses) or by prevention of loss of water (by application of some membrane to the surface).

6.5 Commissioning

Commissioning the dam provides the first test of the design and construction and may not be fully completed for some time due to the time required to fill the reservoir, establish stable seepage conditions and provide a flood which realistically tests spillway performance.

Experience has shown that inherent safety problems are often disclosed during commissioning and the initial year or so of full operation. Strategies which maximize the opportunity to monitor performance against expectations are therefore critically important from the dam safety viewpoint.

Carrying out the commissioning of the dam and respective components is important until the responsible Designer is able to certify to the owner that the dam can be considered fully operational.

7 Safety Surveillance

7.1 Purpose of Regular Inspection

The purpose of a dam safety surveillance program is to avoid failure of the dam, by giving early warning of any kind of symptom of trouble as early as possible. The main causes of failure, which can often be avoided by effective surveillance and maintenance programs, are:

- seepage/leakage
- slips/slides
- erosion
- cracking
- movement/deformation of embankment
- structural defects (outlet pipes, spillway)
- spillway or outlet blockage.

Safety surveillance of a dam is a program of regular visual inspection using simple equipment and techniques. It is the most economical and effective means an owner has of maximizing the long-term safety and survival of the dam. Its primary purpose is to monitor the condition and performance of the dam and its surroundings, particularly any changes that may be occurring. Potentially problematic trends can thereby be spotted early and provide adequate warning of their development so that timely maintenance can be carried out. You should always check the water level and spillway flow performance for any unusual changes. Sometimes it is an advantage to use an engineer experienced with dams. They are more familiar with problems and can provide better security against legal action in the event of a dam problem impacting on others.

7.2 Inspection Procedures and Methods

The procedure for dam safety surveillance is unique to each dam but consists essentially of regular, close and systematic examination of the entire surface of the dam and its immediate surroundings. Such procedures are already normal practice in the case of large dams.

In the case of small dams, however, especially those dams where owners have not sought appropriate advice, there may be a perception that above procedures are unnecessary, or an unproductive use of time. There may also be a lack of knowledge of what needs to be done. However, for small dams, surveillance programs can usually be devised which are simple yet systematic and effective.

A safety surveillance inspection includes taking appropriate measurements and keeping concise accurate records of observations made. Particular techniques and equipment that might be used are outlined in Appendix E. For small dams it is prudent to obtain professional engineering advice to set up the program first, using a simple set of check sheets to record observations. They are just as sensible - in fact much more so, given the potential for costs to you if it fails- as having your car checked and serviced regularly, even though you do not think the car is about to give up on you yet! These procedures form part of a dam safety management program and are intended to catch problems early and enable action to be taken to prevent them developing further once detected.

7.3 Frequency of Inspections

The frequency of inspection required for an effective program of surveillance depends on a variety of factors including:

- Size or capacity of the dam;
- Condition of the dam; and
- Potential for damage resulting from failure of the dam (represented by the hazard category).

Adoption of the inspection frequency for a particular dam is the responsibility of the owner, though professional advice should be sought for large dams or those categorized under significant and high hazard dams. As a guide, Table 7.1 gives suggested frequencies for a two-level surveillance program adopted from guidelines for managing small dams in Rwanda. The higher level would comprise a full inspection using the relevant equipment and techniques outlined in Appendix E. The second level is envisaged as a more frequent quick visual inspection aimed at detection of unusual changes during the period between thorough examinations.

Table 7.1 Suggested inspection frequencies quick visual inspection and comprehensive examination

Quick Visual Inspection				
Dam Potential classification	Hazard	Dams equal to or higher than 15 meters	Dams smaller than 15 meters	Small dams less than 1 megaliter
High		daily	twice weekly	weekly
Significant		twice weekly	weekly	fortnightly
Low		weekly	fortnightly	monthly
Comprehensive Examination				
Dam Potential classification	Hazard	Dams equal to or higher than 15 meters	Dams smaller than 15 meters	Small dams less than 1 megaliter
High		weekly	monthly	3-monthly
Significant		monthly	3-monthly	twice-yearly

Low	3-monthly	twice-yearly	yearly
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7.4 Special Inspections

Special inspections will be required after unusual events such as earthquakes, major floods, rapid drawdown or volcanic activity. Special inspections should enable the dam owner to become aware of faults before partial or total failure occurs. Times when inspections additional to those above are recommended are:

- before a predicted major rainstorm (check embankment, spillway and outlet pipe);
- during and after severe rainstorms (check embankment, spillway and outlet pipe);
- after any earthquake, whether directly felt on the owner's property or reported by local news media (check all aspects of the dam).

Inspections should be made during and after construction and also during and immediately after the first filling of the storage.

7.5 Dealing with Problems

A systematic program of safety surveillance should maximize the likelihood that any developing conditions likely to cause failure would be found before it is too late. Surveillance will also help early detection of problems before they become major repair bills. As identified earlier typical problems (many of which are treatable if found early enough) are most likely to fall into one of the following categories: seepage/leakage; erosion; cracking; deformation/movement; concrete structure defects; and spillway blockage.

The following chapter outlines some of the simple maintenance activities, which can be carried out to prevent or remedy potentially dangerous conditions in embankment dams. Appendix D lists in more detail the problems that might be revealed by a safety surveillance program. It also outlines their possible causes, consequences and possible remedial action.

When a significant concern exists it is strongly recommended that the Supervising body/ authorities and emergency services be informed at the earliest opportunity so that appropriate response can be implemented. Seeking help with a developing problem needs to be done quickly before the problem develops into something serious. When seeking help from a dams engineer make sure that you note down enough details to be able to explain the size of the problem, its location, how quickly it is changing and the current status of inflows and water level.

If the engineer is not familiar with the dam it is useful to have drawings ready which can be sent by fax or by e-mail if available. Remember that it will take time for someone to come onto the site for a detailed inspection. Depending on the rate of development it may be too late! A key thing to remember is that the impact of a failing dam will be significantly reduced if there is less water in the dam. So be prepared to drain the dam if a serious problem develops or is developing.

Warning: If a leakage problem is occurring, do not place anyone in danger by trying to plug the upstream side of the leak. There is a real danger of people being drawn or sucked into

outlet pipes or erosion holes. Seek experienced help. Lives can be put at risk trying to save dams using inexperienced persons.

7.6 Inspection of Rockfill dams

An inspection of a rockfill dam should follow the same principles as that for an earth dam, particularly if the impermeable barrier is located within the body of the dam. The upstream slope, crest, and downstream slope should be examined for evidence of erosion, slumping, seepage, and large vegetation. An upstream lining for a rockfill dam should be inspected for conditions that could result in leakage. These could be cracking in a concrete facing or tearing and crimping in a flexible lining. Any significant cracking in a concrete facing or tearing/crimping in a flexible lining should be repaired. The protective layer over a flexible lining should also be maintained to ensure its continued performance.

7.7 Inspection of Concrete dams

Concrete dams are more rigid than earth or rockfill dams and are thus less tolerant of movement. A small displacement of one section of the dam could affect the stability of the structure or result in significant leakage through or under the dam. Any movement of the structure could also compromise its contact with an abutment. In addition, any concentrated seepages at the downstream toe or the abutment contacts should be examined to ensure that piping is not occurring through the foundation or abutment areas.

Concrete surfaces should be examined for spalling and deterioration due to weathering, unusual or extreme stresses, alkali or other chemical action, erosion, cavitation, vandalism, and other destructive forces. Tapping the surface with a hammer or some device will locate "drummy," unsound concrete.

Structural problems are indicated by cracking, exposed reinforcing bars, large areas of broken-out concrete, misalignment at joints, undermining and settlement. Rust stains may indicate internal rusting and deterioration of reinforcement steel. Spillway floor slabs and upstream slope protection slabs should be checked for undermining (erosion of base material).

7.8 Inspection Checklists

The most thorough method and best way to keep records is to use a checklist to record the findings of regular inspections. It will remind you of what to look for and become a record of the condition of the dam when you last inspected it. Of course, such records must be systematically stored so that the information on them can be readily retrieved. This can be useful in the event of a problem developing, as you will thereby be able to show that you have exercised due diligence with respect to the dam. It is a similar activity to doing a routine roadworthy check on your motor car. It is not only good pro-active management of your asset, but may also help to protect you against liability in the event of your dam causing loss or damage. Appendix E provides a sample dam Inspection checklist for your information. It may need to be modified to suit your particular dam.

7.9 Instrumentation and Monitoring

Instrumentation at a dam furnishes data to determine if the completed structure is functioning as intended, provides a continuing surveillance of the structure, and is an indicator of developments which may endanger its safety. The extent and complexity of instrumentation at a dam depends on the size of the structure, its intended purpose, and the potential for loss of life and property damage downstream of the facility.

The recorded data, when evaluated on an ongoing basis, enables behavioral trends to be tracked and give early warning of adverse behaviour. Typical items instrumented or monitored include:

- profiles and condition, deformations, seepages or damp areas (visual)
- reservoir water levels which relate to dam loads and flood behaviour
- local rainfall which relates to background seepages
- drainage and distinguishable seepages which relate to control of leakage water flow
- Clarity of seepage flow which relates to potential erosion of embankment or foundation material.
- water pressures within the dam and foundations which relate to structural behaviour
- movement or deformation of the dam surface and internal structure which relates to structural behavior
- stresses within the dam which relate to structural behaviour
- seismic acceleration which relates to structural behaviour

The instruments needed at a dam could range from simple bucket and stopwatch to measure seepage flow at a small dam with low hazard, to all of the above instrumentation at a large dam with high hazard.

The O&M Manual should contain clear instructions on how to use monitoring equipment and how to take measurements at monitoring point. A map identifying each instrument and monitoring point, and forms for recording the data should be provided. The monitoring points themselves, as well as any seepage or other areas needing attention should be kept clear of obscuring growth and be permanently marked. All data should be recorded on an appropriate form. Monitoring can only be beneficial if the observations are recorded in an orderly way and form a clear performance record.

Routine monitoring must be accompanied by an effective system of evaluating results and taking action where necessary. The operations, maintenance and surveillance manual should contain maximum values for critical items (e.g. seepage values, water pressures, and deformations) set by the technical advisers. If critical values are reached, the matter is referred immediately to the appropriate technical advisers for review and action.

8 Operation and Maintenance of Dams

Effective and ongoing operation, maintenance and surveillance procedures are essential to ensure the continued viability and safety of a dam and its appurtenant structures. Poor operation, maintenance and surveillance will invariably result in abnormal deterioration, reduced life expectancy and possibility of failure. The proper operation, maintenance and surveillance of a dam provide protection for the Owner and the general public. Furthermore, the cost of good operation, maintenance and surveillance procedures is small compared with the cost and consequences of a dam failure which could include major repairs, loss of life, property damage and litigation.

The term 'operation' when applied to a dam may at first be regarded as applicable only to larger dams. Typically, such dams have a variety of control equipment in use as part of the structure (such as valves, flood gates and electrical control panels). However, when we define it as any activity or practice which allows the owner to keep inflows and outflows under control, or which safeguards the integrity of the dam, it can be seen that even small dams without elaborate equipment can be, and should be, operated.

This is because the nature of the responsibility carried by a dam owner is the same for a small dam as for a large one. The only difference is in the scale of the responsibility and that is then reflected in the smaller scale and sophistication of activities which usually applies for a small dam compared with a large one.

The definition of operation given above also implies that monitoring of performance, and maintenance, are inherently part of the duty of care which attaches to the responsibility of ownership of a dam, regardless of its size.

The following sections deal only with some very basic aspects of operation and maintenance.

8.1 Control of Flows

Operation of a dam includes the control of flow of water from or around a dam via by-pass channels, outlet works or spillway structures. 'Control' refers to activities or design features aimed at ensuring that :

- inflows do not overtop or endanger the dam structure;
- outflows achieve the required environmental (compensation) flow rate where this is applicable;
- and outflows are delivered in such a way as not to endanger the dam or to cause damage downstream (in larger dams this may include flood regulation; in small dams it will include avoiding erosion of the toe of the dam, the spillway channel or the area downstream).

8.2 Routine Surveillance

Routine surveillance or inspections can also be called operation activities because they are not specifically maintenance. Surveillance/inspections involve observing the behaviour of the dam and recording flows into or out of the dam or water level gauges. It is geared to securing both safety of the dam and satisfactory technical performance.

8.3 Filling and Emptying

Be aware that the rate of filling or emptying a dam should be controlled. If done too quickly problems can occur in an earth embankment.

If filled too fast, especially for the first time or after a long dry period, the material within the bank does not have enough time to get sufficiently wet, expand and seal. Therefore leakage may occur. In the case of embankments constructed from dispersive clayey soils, this problem is more severe and can lead to rapid and complete failure of the embankment.

Emptying too quickly prevents the moisture in the embankment from draining fast enough, and with the water load reduced on the upstream side, the internal pressure in the embankment can cause slumps or slides. How quickly is 'too quickly' will depend on the type of soil in the embankment, but as a first rule of thumb, emptying faster than 0.2m in level per day should be avoided.

8.4 Maintenance

Because many small dams fail through lack of maintenance, it is prudent to have a definite and systematic maintenance plan.

The maintenance plan should be decided upon when the construction work on the dam is completed. It will affect the life of the storage if you do not maintain it properly.

A good plan should include the practices to be used, as well as the approximate time of the year when they are applicable.

An engineer can give you advice and prepare a simple program to be followed. The plan should also include steps to be taken if particular problems are encountered. All records of maintenance activities should include details of observations made, repairs carried out (including details of location), no matter how minor.

8.5 Maintenance Problems of Embankment dams

The most common problem areas or causes requiring maintenance of embankment dams are described briefly below. Appendix D includes a more comprehensive summary of their causes, consequences and remedies.

1. Seepage and Leakage

Water escaping from the reservoir might appear locally ('leakage') or over a wide area ('seepage'). It might be visible on the embankment, at the downstream toe area or at the abutments. The rate of flow might be small or large, steady or increasing, clear or muddy.



Figure 8.1 Seepage from the reservoir in one of the small/micro dams in Tigray

Unless the flow is clear and the rate only small and not increasing, most forms of leakage represent the first warning. Seepage indicated by green patch of potentially serious problems and indicate the need for dry grass early repair work.

It is important that the embankment is well maintained and grass kept relatively short (70 mm is good) so that seepage is readily identified if it occurs.

Appendix D lists the most commonly encountered forms of seepage and leakage, and the means by which repairs might be made. The only common factor is that, unless the cause is readily apparent and the repairs immediately effective, expert professional advice should be sought.

2. Cracking and Movement

(a) Cracks

During dry periods, there will always be minor cracking as the embankment dries out but good topsoil and grass cover will help prevent this. However, some soil types are more prone to cracking than others and, where these types of soil are common; cracking is often a serious problem.

Transverse cracks running across an embankment can allow water to start seeping through. Longitudinal cracks running along the embankment can fill with water during a storm and, as a result, saturate lower layers which may cause part of the embankment to slump. Ideally, large cracks should be filled as soon as possible with compacted clay, but, in practice, this can be difficult and it may be necessary to trench out the cracks before filling them so the clay can be compacted. Waterproof layers such as a compacted gravel surface on the crest help prevent drying and cracking.

(b) Embankment Settlement

On large dams, it is usual to have special level markers to monitor embankment settlement. On small dams, embankment settlement can be checked approximately by monitoring the freeboard (the difference between full water level and the top of the bank, measured at the highest point). Hard and fast rules cannot be laid down but, as an indication, it should not normally be less than about one fifth the height of the embankment, but the important point is to examine the records to see if settlement is still occurring or if it has settled down. Checks should also be made to see whether there is any development of transverse cracks in the crest, and if so, professional advice should be sought.

(c) Surface Slips on Embankment

Slides are major structural defects. They normally require major remedial works such as flattening of batter slopes, improved drainage or addition of rockfill as a stabilizing weight at the toe of a slope. Selection of an economical and effective remedy normally requires expert professional advice.

3. Erosion

Erosion is also a problem with many causes. The following are among the most common forms of erosion.

(a) Rilling of the Bank (small erosion gutters down the bank)

This usually happens where there is no topsoil and grass embankment rilling and erosion cover on the bank. To rectify the problem, pack rills with grass sods or cover the bank with topsoil and sow down. Maintain a good grass cover on the embankment but keep it short to make surveillance easier.

(b) Damage from Wave Action

To reduce wave action damage, protect the bank with rocks, hay mulch and netting, or grasses. For larger dams more substantial rock protection is warranted and the use of windbreaks around the shoreline should be considered. Wave erosion can occur even when rock is placed on the upstream slope for protection. Constant vigilance is necessary to ensure the upstream slope remains in good condition.

(c) Spillway Erosion

Heavy flows over spillways can lead to erosion. Where this occurs, fill in minor erosion with grass sods, cover with hay mulch and pin down with netting.

Ensure that the spillway remains as level as possible across its entire width to avoid flow concentration. Consider installing a low flow concrete gutter/trench to control erosion and protect the vegetation cover on the spillway from prolonged saturation following a storm. This is not an alternative to the outlet pipe. If erosion persists, more substantial protection is probably required.

(d) Sinkholes

Sinkholes are holes or depressions at the surface resulting from internal erosion, which has caused underground cavities into which the surface material eventually subsides. Sinkholes are often a sign of severe and widespread hidden damage, and rectifying this problem is difficult. It is necessary to determine the nature and trace the extent of such damage, and to backfill all eroded areas with well compacted clay before dealing with the visible surface holes or depressions in a similar manner. This is tedious, and it is difficult to ensure that the whole extent of the problem has been addressed. Unless the defect is found to be superficial and associated with flows from rainfall run-off rather than leakage from the dam, professional advice should be sought.

(e) Wind Erosion

Erosion due to wind action can occur when the embankment material has high sand or silt content, and vegetation cover is poor. It is often associated with the passage of stock. Re-establishment of good grass cover is the best remedy.

4. Stock Damage

Keep stock off the embankment. A fence to exclude stock should be constructed around the perimeter of the embankment, storage area, spillway and spillway downstream slope as soon as possible after the dam is completed. Apart from damaging the grass cover and creating 'stock paths' which can lead to serious erosion, the water in the storage can become turbid and polluted by continued stock access. The best alternative is to provide stock water from a trough, or install a fenced walkway to a restricted area of the stored water.

5. Dispersive Clays

The presence of dispersive clays on the ground is often the cause of severe discoloration of reservoirs and streams, but that is not the main issue here. The issue is that their presence in a dam embankment can result in the loss of material from the embankment by internal erosion and consequent major leakage problems and failure. The failure may appear to develop gradually but the final stage often occurs very rapidly, and with little or no warning.

As far as possible the use of dispersive clays in construction of a new dam should be avoided but, where unavoidable, the design of embankment and filters has to take account the nature of these material into account. Application of chemicals can help to stabilize these kinds of soils. Compaction of dispersive clays must be carried out to very high standards in accordance with specifications prepared by an experienced engineer. The moisture content for compaction must be carefully controlled, which can only be determined by laboratory testing of the material.

6. Defects in appurtenant structures

(a) Spillway Blockage

Debris, bushes, trees, shrubs, fences and tall grass should be regularly cleaned from all parts of the spillway, including the approach area. These will tend to obstruct flow and also catch

any floating debris that would normally pass through the spillway. These obstructions can lead to overtopping the embankment.

(b) Outlet Pipe Blockage

The cleaning of an outlet pipe is a problem if the gate valve has been closed after the rainy season because trash and siltation can clog the inlet on the upstream side of the embankment. This type of blockage could place a dam owner in conflict with the Supervising body/authorities and with the downstream users because a dam on a waterway requires the gate valve to be operated so as not to diminish flows during the drier months. It is recommended that regular flushing be carried out to minimize the risk of outlet blockages.

In the event of a blockage there are different techniques and types of equipment available to dislodge an obstruction (ie. cleaning rods, flexible sewer pipe cleaner). Most techniques can only be employed when the storage is empty or close to it. Persons should not be in the water if flow is passing through the outlet. Seek professional advice.

7. Outlets and Valves

All valves used for releasing water from a dam must be properly maintained. It is important to remember that if you have a developing problem with your dam you may need to empty it as quickly as possible. It is therefore important to service/exercise the valve regularly to make sure it is operational at all times. If it starts to get difficult to operate you have a developing problem that requires attention.

Provision should be made at the outlet pipe point of discharge to reduce the velocity of exiting water. Rock placed on a layer of crushed rock to minimize erosion, or an effective concrete outlet structure should be constructed to dissipate the energy of the discharging flow. The type of protection will be dependent on the size and the pressure head of the water.

Another problem at an outlet valve is the potential for neglect if not in regular use. Remember that if you have an emergency problem with your dam and need to empty it quickly to save it from total failure you will need this valve to work. It is recommended that this valve be operated few times per year to make sure it is operating properly.

8. Vegetation

(a) Trees

Self-sown plants, trees or other deep-rooted plants should not be permitted within 5 metres (or the anticipated height of the mature growth) of the embankment or spillway. The roots of this type of vegetation could provide a path for leakage through the dam and, ultimately, result in its failure. Planting trees and shrubs can provide windbreaks, which prevent wave action and, therefore, soil erosion, and also give shelter for wildlife. If trees are required, they should be planted around the foreshore of the water storage, well away from the dam embankment and spillway. The dominant wind direction needs to be considered.

(b) Weed Control

Aquatic weeds in dams can block pump and pipe inlets, deter stock from drinking and, in some cases, taint the water. If weeds are treated when they first appear, dams can be kept relatively free of some of the more troublesome species. All plants can become a problem and each may require a different control method. However, in all situations the same factors should be considered in deciding what control methods, if any, should be used.

In each case: determine whether there is a problem and, if so, what it is; identify the specific plant causing the problem; find out what control methods are available and which of them could be used; investigate whether these control measures could cause any other problems (eg. toxicity to fish and livestock) and, if so, whether they can be avoided; and decide whether or not all factors considered, control is practical, desirable and worthwhile.

9. Sedimentation and watershed management

Sedimentation occurs in every reservoir of a dam. Sedimentation rates vary widely and depend on many factors of the watershed areas. In Ethiopia, most of the sediment enters reservoirs with floods occurring during the rainy seasons of the year.

The best way to avoid sediment problems is to reduce erosion in the watershed area. "Watershed management" – including afforestation and the promotion of farming conservation practices (such as contour tillage, strip-cropping, conservation cropping systems, and other land improvement practices) which reduce soil erosion – is frequently advocated as the best way of cutting sediment deposition in reservoirs..While these schemes may be recommended in project plans, they are rarely implemented: dam-building agencies are usually more interested in putting their funds toward building dams than planting trees and digging field terraces.

As most dam owners do not control the watershed land, other means must be found to minimize the effects of sedimentation. One way is by dredging. However, this is expensive and will eventually have to be repeated because the sedimentation process never stops. Disposal of the dredged material is often a problem. Periodically opening the drain valve will help keep sediment from obstructing or burying the drain inlet.

For ponds with smaller drainage areas, vegetated strips around the pond will act as filters and trap much of the sediment. These are especially effective for ponds where much of the runoff enters as sheet flow rather than in small streams.

The control sedimentation needs to be based on the correct identification of source areas of sediment, a knowledge of the processes by which water and sediment are moved over the land surface, and an understanding of how these processes are affected by the physical environment and socio-economic factors. Soil conservation can be achieved through watershed management by targeting erosion control measures at critical locations in the

landscape, producing appropriate designs and gaining the support of interested groups and organizations for their implementation.

8.6 Maintenance of Concrete Dams

Concrete is an inexpensive, durable, strong and basic building material often used in dams for core walls, spillways, stilling basins, control towers, and slope protection. However, poor workmanship, construction procedures, and construction materials may cause imperfections that later require repair. Long-term deterioration or damage caused by flowing water, ice, or other natural forces must be corrected.

8.6.1 General Concrete Repair

Floor or wall movement, extensive cracking, improper alignments, settlement, joint displacement, and extensive undermining are signs of major structural problems. Drainage systems may be needed to relieve excessive water pressures under floors and behind walls. Because of their complex nature, major structural repairs require professional advice.

Before attempting repair of a concrete surface, all unsound concrete should be removed by sawing or chipping, and the patch area thoroughly cleaned. A sawed edge is superior in every way to a chipped edge, and sawing is generally less costly than mechanical chipping.

There are different methods and techniques of repair. Most of these techniques require expert and experienced assistance for the best results; therefore, the services of a professional engineer must be obtained to prepare a plan before repairs are made. The particular method of repair will depend on the size of the job and the type of repair required.

8.7 Modifications

(a) Spillways

Experience has shown that some landowners or lessees try to modify the spillway on a dam to achieve an increase in storage capacity.

This practice is fraught with danger. If you fill in or obstruct a spillway then the chances of overtopping the dam are greatly increased. Water pressure loading on the dam wall will also increase due to the added height of water and this may cause instability in the bank and embankment slips.

(b) Crest Modification

Even the addition of topsoil to the top of an existing dam has been tried as a means of gaining an increase in storage capacity. This can create problems because it is not easy to get a good bond between the top of the dam and the new material and topsoil is very permeable. Because of the shape of the dam a simple rising will also result in a narrower crest width making maintenance difficult.

Modifications are best left to an engineer to assess and design a safe structure to meet your needs. Otherwise it may be the most expensive water you ever collected.

8.8 Personnel and Training

Safe management of dams is a frame of mind and involves all the people concerned from the owner to operations Staff. Education and training must therefore be conceived along the lines of developing awareness of the need for ongoing vigilance, surveillance and maintenance in addition to giving instruction in the 'nuts and bolts' mechanics of the relevant and desirable procedures. The training and awareness raising must be related to the specific characteristics and potential hazard classification of the dam.

Clearly, the personnel involved must understand and fulfill their respective roles and be suitably trained in their areas of responsibility. This is particularly the case for caretakers and operational staff who may be recruited into their positions without prior specific experience.

8.9 Community Participation

For dams being financed by governments or other agencies for community operation and management, it is essential to consult local people. Try to obtain a representative view, not that of just important or elderly 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 construction (i.e. with the provision of labor and possibly local materials) operation and maintenance of the dam. It is very vital for future maintenance and longevity of the dam.

Training local people in all aspects of dam repair and maintenance may need to be included in the construction program. 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 programs and practices accordingly. This may lengthen the construction period and increase costs but may prove worthwhile in the long term in enhancing responsibilities and skills amongst the beneficiaries.

9 Emergency Action Planning

Dams should be designed, constructed, operated and maintained to minimize the risk of dam failure. Nevertheless, incidents can occur either naturally or precipitated by phenomena such as floods, earthquakes, sabotage or mal-operation which could create an emergency situation with respect to dam safety. For this reason emergency action planning should be undertaken for high and significant potential hazard Classification dams to minimize the adverse effects of such incidents. Emergency action planning is likely to have less importance for small dams with low hazards.

The plan should list actions that the owner, operators and relevant government and local authorities should take if an incident or emergency develops. The process of developing an emergency action plan (EAP) may involve some or all of the following actions:

- identify safe access routes to the dam for the conditions anticipated
- determine the inundated area from assessments of the possible effects of a dam failure

- determine and identify those conditions that may initiate an emergency and specify the actions to be taken and by whom
- identify all agencies and individuals who would be involved in the emergency action plan, and co-ordinate the development of the plan with those parties
- identify communications systems between parties and individuals
- identify all special equipment and resources required and their location
- test and revise the plan at regular intervals

9.1 Extreme Events

Extreme events such as earthquakes flood or storm activity present a situation where preventative action may be difficult. Whilst there is little that a dam owner can do to prevent them occurring, the risk of dam failure from flood and earthquake can reasonably be expected to be minimized by proper design and construction. A proper dam design looks at the engineering aspects and applies margins of safety that have been developed from industry experience.

Pre planning for an emergency is an important means by which to minimize the impact from dam failure. Failure of another dam upstream can also impact on your dam. Dam owners carry the responsibility for the safety of their dam under the law. This risk can be minimized by the proper upkeep of the dam. If you are concerned about the condition of any dam, you should contact your local regulating authority which can direct work to be done to make the dam safe.

9.2 Emergency Preparedness

Emergency preparedness is about having a plan of what to do in the event that failure of your dam appears imminent. Owners can play an important role in ensuring the safety of dams by having proper operating procedures, adequate inspection, and maintenance and safety surveillance. However, there should also be a plan of action in case the dam fails or is threatening to do so.

The EAP should be directly related to the specific dam's structure and its immediate environment. It will depend on the owner's knowledge of the dam and its operation. It should be reviewed and, if necessary, updated annually. This is especially true for dams with a history of leakage, cracking, settlement, misalignment or erosion from wave action.

Since dam owners may be liable for damages associated with the failure of their dam, it is imperative to issue an effective and timely warning to downstream residents if a dam is about to fail. The better and earlier the warning the less likely injury will occur and some damage may be avoidable. In rural areas telephone or direct contact will usually be used to warn the nearest downstream residents. When telephone conversation is not possible, the person observing the dangerous condition may have to personally warn the nearest downstream residents, campers, etc. The dam owner should therefore keep a listing of the nearest downstream residents and their phone numbers along with the police, emergency services and other emergency numbers.

9.3 How to Deal with a Dam Failure Concern

Immediate action is required on recognition of a threatening condition developing:

1. If failure is imminent (eg. water is rising and approaching the top of the embankment, or heavily colored water is leaking from the embankment or foundation) then you should immediately contact:

- An engineer, to seek advice
- Police, and local government bodies
- Your neighbours downstream, to inform them that you have concerns but are working on the problem.

2. If failure appears imminent or is actually in progress (eg. water is spilling over the embankment, or erosion of the embankment, spillway or foundation is occurring). If there is no chance to save the dam, inform the following at once:

- Downstream neighbours,
- Police;
- Local government bodies

Advise that you cannot do anything and need help.

3. Where major flooding is expected or in progress upstream of the dam site, then inform the following:

- Downstream neighbours
- Local government bodies;
- Police;

9.4 Emergency Checklist

Addressing an emergency situation could require many people and organizations to be informed at the earliest opportunity. Keep in mind that preservation of human life must always have first priority. A contact list should be prepared and kept accessible and up to date.

A 'Dam Safety Emergency Plan' that may be useful and can be hung on the wall near the telephone. It provides procedures to follow in the event of certain circumstances occurring and therefore allows response by persons not fully familiar with dam safety procedures.

Contact Organizations for Advice

There are a number of potential problems that may threaten the safety of a small dam. These can be expensive to remedy. Consequently, it is imperative that dam owners seek advice from an expert when in doubt. In the event of a problem on a dam, Regional and Woreda Water Bureaus and non government organizations may be able to provide advice or a service.

In any particular area the best advice can usually be obtained from a consulting engineer with local experience in design, construction, maintenance and repair of dams. Many consulting

engineers in general practice will not have an appropriate background in dams and local knowledge is usually the best guide to firms or individuals with good track records in such areas.

10 Removal or Decommissioning of a Dam

Removal of a dam, or decommissioning which has the same effect as removal, may occur because the dam has outlived its usefulness, or it requires safety works which the owner cannot afford or which render uneconomic the operation associated with the dam.

An owner cannot simply walk away from a dam because it is of no further use or is too costly to manage or rehabilitate. Instead, the dam must be either removed or decommissioned. In either case, it should be made incapable of storing any water either temporarily or permanently. Decommissioning other than by removal is normally done by breaching one or more sections of the dam wall or embankment.

The dam owner is still responsible for ensuring the safety of residents and development downstream, and of the dam itself while it is in the process of being removed or decommissioned, and indefinitely afterwards if it is not removed but decommissioned. Removal or decommissioning of a dam is not without its problems, and thought should be given to the following:

- Has an assessment been made of the costs associated with the removal?
- Will the proposed works eliminate any future operation, maintenance, surveillance or remedial work?
- Can the unbreached sections, if any, be left in permanently stable condition?
- Is the proposed breach wide enough not to impound significant quantities of water under flood conditions? Has the short and long-term stability of any sediment deposits within the reservoir area been considered before commencement of the breaching operation?
- Is the breaching process acceptable from safety and damage perspective both at the dam and downstream?

Environmental aspects downstream must also be considered before a dam is breached. Siltation/sediment transport or erosion caused as a result of decommissioning could become a liability on the dam owner. It should be noted that the cost of rendering a dam that is of no further use safe (particularly against storm and flood events) could be considerable. For any dam being decommissioned or breached, professional engineering and environmental advice should be obtained.

10.1 Rehabilitation of Site

A dam breach that results in some portion of the dam wall being left in place is not necessarily sufficient action. This is because any flow obstruction effect during floods will be an obstacle compared to the natural waterway characteristics.

It would be difficult to defend due diligence where a flood event erodes the remaining dam structure and results in a sudden release of water or mud flows that causes loss of life or damage to property or the environment.

The site should be reinstated and revegetated to a stable condition. Care should be taken to make sure that no material (usually silt) can be washed downstream or affect other dams.

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12 Appendix

Appendix A : Technical Terms Definitions

Appendix B : Check list for site investigation

Appendix C: Check sheet to guide a review of a dam design

Appendix D : Common Problems in and around dams and Solutions

Appendix E: Conducting an Inspection

Appendix F: Terms of reference for study and detail design of a dam

Appendix G: Typical Plan, Profile and Section of a Small Embankment dam

Appendix A: Technical Terms Definitions

Abutment The natural ground formation between the base of the dam and its crest. The natural material below the excavation surface and in the immediate surrounding formation above the normal river level or flood plain against which the ends of the dam are placed.

Acceptable Risk –The level of risk (the combination of the probability and the consequence of a specified hazardous event) which the public are prepared to accept without further management. Acceptability of risk may be reflected in government regulations.

Appurtenant Works **Includes**, but are not limited to, such structures as spillways, either in or beside the dam and its rim; low level outlet works and water conduits such as tunnels, pipelines, either through the dam or its abutments.

Base of Dam The area of the lowest part of the dam resting on the foundation excluding the abutments. It excludes isolated pockets of excavation which are not representative of the base extending from heel to toe.

Beaching Rock placed to dissipate the erosive force of waves on banks. The term can mean dumped or hand placed rock, usually located on a prepared bed of gravel size material.

Catchment The area of land drained by the landform, streams or waterways down to the point at which the dam is located.

Consequences of dam failure Impact areas downstream as well as upstream of the dam resulting from failure of the dam or its appurtenances. The result of a dam failure in terms of loss of life and damage to property and/or services, as well as economic and environmental damage.

Contractor/constructor For the purpose of this document, a person employed to carry out construction works in accordance with plans and specifications in the construction of a dam.

Criteria: This term refers to the numerical values or other standards adopted by the world-wide dam industry for aspects of dam design and performance. It is important to note that technological advances or empirical evidence may lead to criteria changing with time.

Crest of Dam Used to denote the top level of a dam wall or embankment (not the spillway level). The uppermost surface of the dam proper, excluding parapets, handrails etc.

Cut-off An impervious barrier of material to prevent seepage flows through or beneath a dam. It is also used to prevent seepage flow along structures such as pipelines or spillways.

Dam: A structure, man made or created naturally, together with appurtenant works which will withhold a body of water, or other fluids.

Dams engineer A professional engineer who is suitably qualified and recognised by the engineering profession as experienced in the engineering of dams. Competent to undertake some or all of the investigation, design, construction supervision, repair and remedial work, operational, maintenance and abandonment activities associated with dams.

Dam Failure In terms of structural integrity, the uncontrolled release of the contents of a reservoir through collapse of the dam or some part of it. In terms of performance to fulfill its intended function, the inability of a dam to perform functions such as water supply, prevention of excessive seepage, etc.

Dam Safety: Relates to the wider issue of reservoir safety and the effect on people and property downstream.

Dam Safety Emergency Plan A continually updated set of instructions and maps that deal with possible emergency situations or unusual occurrences at a related dam.

Decommissioned dam Means a dam that is no longer used but has been made safe so that there is no requirement for operation or maintenance and it does not present a detrimental affect on the environment.

Design Flood The maximum flood for which the dam is designed taking into account the consequences of failure and likely rainfall.

Dispersive Clay A clay soil which has the property of the micro particles breaking apart (or dispersing) in contact with water in certain circumstances. Such clays present special difficulties and dangers for design, construction and operation of earth dams if they are incorporated in the embankment or foundation.

Embankment An earth structure built across a waterway to either protect adjacent land from inundation by flooding or to store water. It also applies to earth structures built to contain water off a waterway.

Emergency In terms of dam operation, any condition which develops naturally or unexpectedly, endangers the integrity of the dam and downstream life or property and requires immediate action.

Emergency planning Having the capability of responding to a potential or actual dam failure.

Environmental consequences The assessable consequences of a dam failure on the environment.

Extreme event An event such as flood, storm or earthquake that has a low probability of occurring but is considered possible and its potential forces are used for the design of dam components. It is usually expressed as Annual Exceedance Probability, being the chances of it occurring in any one year.

Foundation The material of the valley floor and abutments on which the dam is constructed.

Freeboard The vertical distance between the spillway crest level and the top of the dam (crest).

Full Supply Level (FSL) The maximum normal operating level of a reservoir, as distinct from flood surcharge. This is also the level of the spillway crest when water is just about to pass through the spillway.

Hazard: This term is used to describe a source of potential harm or a situation with a potential to cause loss. Factors such as earthquakes, floods, and possible deficiencies in the dam or its foundations, which may lead to unsafe behaviour of the dam can be considered hazards. Unsafe behaviour may result in the Potential Impact being realized.

Hazardous dam A dam is hazardous if, because of its size and/or location, could pose a threat to life, property or the environment, if it were to fail.

Height of Dam The difference in level between the natural surface level, bed of a gully, stream or waterway at the downstream toe of the dam and the crest.

Impervious Describes a relatively waterproof soil such as clay through which water percolates very slowly making it suitable as a water barrier.

Impermeability Describes property of a soil such as clay through which water percolates very slowly.

Infrastructure Includes roads, bridges, water supply systems, waste water systems, recreation facilities and other community investments.

Inspection An examination of a dam in accordance with a given Dam Safety Guidelines.

Interim Diversion Limit A means for estimating the water available for harvestable catchment

Maintenance Actions required to maintain existing works and systems (civil, hydraulic, mechanical and electrical,) in a safe and functional condition.

Monitoring Recording of data from measuring devices and visual observations to check the performance and behavioural trends of a dam and appurtenant structures.

Optimum Moisture Content This is the moisture content of earthen material with suitable clay content at which the best compaction can be easily achieved. (This is the general meaning. In the case of a particular soil, the Optimum Moisture Content is defined by a special standard laboratory test).

Organic Material Silt or clay containing plant remains. It has low bearing capacity and is compressible when it rots.

Outlet Works The combination of screen, intake structure, conduit, tunnel, control valves and meters that permit controlled release of water from the dam.

Owner Person or legal person, including a company, organization, government unit, public utility, corporation or other entity, which either holds a government license to operate a dam or retains the legal property title on the dam site, dam and/or reservoir, and which is responsible for the safety of the dam.

Permeability Property of a soil that allows the movement of water through its connecting pore spaces.

Piping Establishment of a seepage path through an earthen embankment resulting in erosion material caused by the flow of water.

Potential Impact: Potential Impact is related to the consequences (effects) of the dam failing, if it should release its stored contents. If a dam is assessed as having a high Potential Impact, it does not mean that the dam is unsafe. Indeed a high Potential Impact dam should have a higher level of safety than other dams.

Remedial Work The work required to repair, strengthen, re-construct, improve or modify an existing dam, appurtenant works, foundations, abutments or surrounding area to provide an adequate margin of safety.

Reservoir A dam or an artificial lake, pond or basin for storage, regulation and control of water, silt, debris or other liquid or liquid-carried material.

Reservoir Capacity The total storage capacity of the reservoir or dam up to Full Supply Level (not up to flood level).

Regulatory Agency/Supervising body or Authority : a government ministry, department, office or other unit of the Federal or Regional government entrusted by law with the responsibility for the general supervision of the safe design, construction and operation of dams and reservoirs, as well as any entity to which all or part of the executive or operational tasks and functions have been delegated by legal power.

Seepage The exit of reservoir water by percolation through, under or around the dam.

Spillway An open channel, weir, conduit, tunnel or other structure designed to allow discharges from the dam when water levels rise above the full supply level directing flow downstream of the toe of the dam. The spillway is principally to discharge flood flows safely past a dam without overtopping the embankment

Spillway chute An inclined open channel through which water flow is directed below the toe of the dam. Surface may be grass, concrete or beached.

Spillway Crest Usually the highest section floor in the spillway cut, which sets the level of the storage.

Surveillance The continuing examination of the condition of a dam and monitoring procedures in order to determine whether a deficient trend is developing or appears likely to develop.

Tailwater level -Level of water in the discharge channel immediately downstream of a dam.

Toe of dam -junction of the downstream (or upstream) face of dam with the ground surface (foundation). Sometimes "heel" is used to define the upstream toe of a concrete gravity dam.

Top of Dam (Crest) The elevation of the uppermost surface of the dam proper not taking into account any camber allowed for settlement or kerbs, parapets, guardrails or other structures that are not a part of the main water retaining structure. This elevation is usually the roadway or walkway.

Waterway/water course A term for any river, creek, stream, or watercourse and a natural channel in which water regularly flows but not necessarily continuously and a channel resulting from the alteration or relocation of a waterway.

Waterway with high ecological values A wetland or marsh; or values a waterway with remnant native vegetation (either in-stream or riparian); or a waterway known to support flora and fauna of conservation significance.

Appendix B : Check list for site investigation

- Topography –

Flat, gently undulating, rolling, sharp hills, mountains, difference between highest and lowest areas

- Sharp breaks in topography –

Ridges, canyons, depressions

- Surface soil –

Loose, hard, moist or dry, boulders and gravel (scattered or in zones), topsoil and organic matter

- Rock outcrops –

Surface, highway and railroad cuts, hillsides, weathered and unweathered

- Drainage pattern –

Dendritic, lattice, parallel, water gaps, waterfalls, direction of primary drainage

- Surface water –

Stream, seasonal or perennial, fluctuations, floods, lakes, marshes, disappearing rivers

- Ground water –

Wells, seeps, springs, artesian wells

- Erosion –

Severe or moderate, U or V shaped cross section, steep or gently sloping heads of gullies

- Land use –

Cultivated or barren, type of crop or vegetation, good or poor quality

- Existing structures, recollections of old residents

Appendix C: check sheet to guide a review of a dam design

The design of a dam will differ greatly depending on the type of dam, local geology, type of impoundment, size of structure, seismic zone, downstream hazard, upstream conditions etc. This is an example of the check sheet that Engineers uses to guide a review of a dam design. Not all components are applicable to all dams, but it gives the design engineer an idea of what will be under review. Ultimately the dam designer and owner are responsible for constructing and operating a safe structure and the review process in no way creates a warranty for the adequacy of the design. Some analyses (although not all inclusive) that could be parts of a dam design are as follows:

1. Stability Analysis - Many times this is included in the geotechnical report
 - Loading Condition with acceptable factor of safety :
 - End of Construction (static)
 - Steady State Seepage
 - Rapid Draw Down
 - Seismic
2. Foundation suitability
 - Liquefaction potential
 - Ability to support the load/settlement
 - Fault traces or bedrock fractures
 - Horizontally contiguous zones of high permeability, etc.
3. Embankment settlement
 - Seepage Analysis - flow net, numeric analysis, etc.
 - Sediment Transport - as it relates to inflow of sediment into the reservoir or scouring and deposition downstream.
4. Material properties
 - Susceptibility to alkali-aggregate reaction
 - Dispersive soils
 - Filter compatibility between zones
5. Describe the drainage area
6. Extreme events
 - Flooding
 - Storm choice design discharges.
 - Runoff calculation methodology
 - Flood routing through the reservoir
 - Earthquake
 - Stability analysis - especially for liquefaction
 - Deformation analysis
7. Embankment slopes
8. Elevation/discharge relationships
9. Curves showing elevation/discharge relationships for all outlets and spillways
10. Dam break/overtopping analysis
 - • Might be necessary for development of an EAP
 - • Inundation mapping
 - • Time to wave front

Appendix D: Common Problems in and around dams and Solutions

Introduction

The following information is presented to help the dam owner identify problems that could arise in and around dams and are likely to cause them to fail. The possible cause and concerns or potential consequences are also indicated, and appropriate action recommended.

A number of the conditions described in the following tables can be corrected by routine and periodic maintenance by the owner. However, significant proportions of the conditions which are identified herein threaten the safety and integrity of the dam and require the attention of an experienced professional engineer.

Quick, corrective action applied to conditions requiring attention will promote the safety and extend the useful life of the dam, while possibly preventing costly future repairs. It should be noted that it is not possible to cover in this appendix all the problems that might arise. Only the most commonly experienced ones are included.

As a general rule, if the owner has any concerns at all he should get help from an experienced professional engineer.

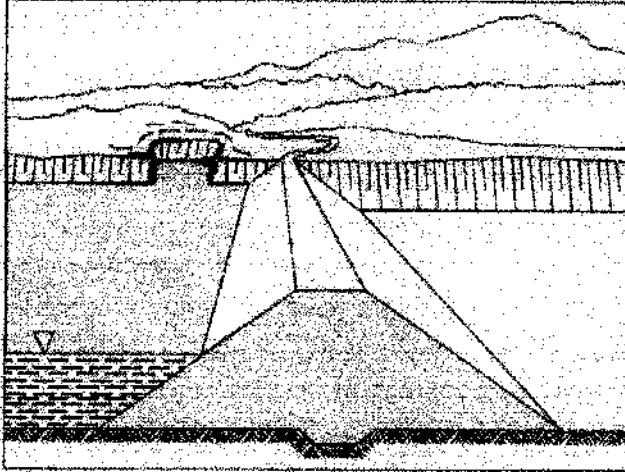
Note: 'experienced professional engineer' means an engineer who is qualified professionally and who is experienced explicitly in dam design and construction for the relevant type of dam. Experience in construction only is not considered appropriate. Note that even among professional civil engineers, most practitioners are not experienced in dams, which is a specialist area.

Reference:

Materials for this section are taken from the following publication: Inspection of small dams, Alberta Environmental Protection, 1998.

1 Reservoir problems

SLIDES AND SLOUGHS



Causes:

1. wave erosion creates steep slopes.
2. Toe of the slope becomes saturated by the reservoir.

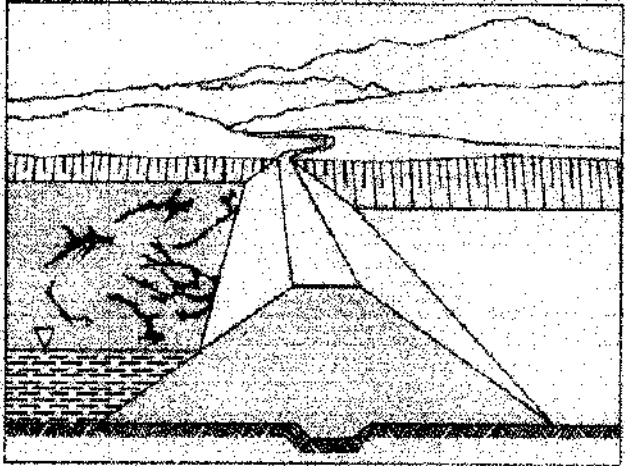
Concerns:

1. The slide or slough could block the spillway or outlet.
2. Waves caused by a slide may overtop the embankment.

Recommended action:

1. Monitor the area and contact an engineer if the embankment is threatened.

FLOATING DEBRIS



Causes:

1. Tree cutting.
2. Heavy runoff.

Concerns:

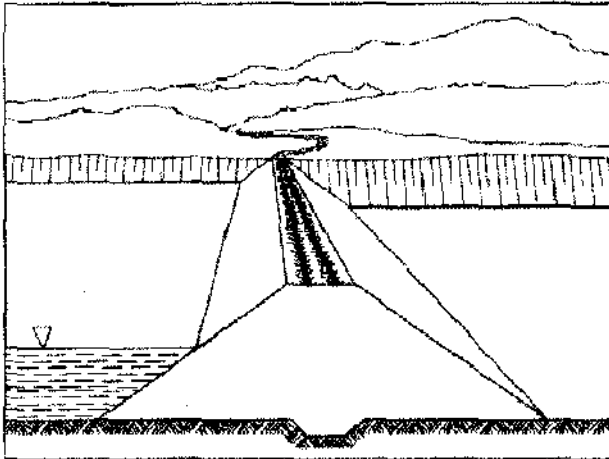
1. Debris and floating logs may block spillway or outlet.

Recommended action:

1. clean them as required after the rainy season and install trash racks where necessary.

2 Crest problems

RUTS ALONG CREST



Causes:

1. The main cause is inadequate drainage of the crest allowing water to stand.
2. Vehicle crossing when surface is soft or wet.

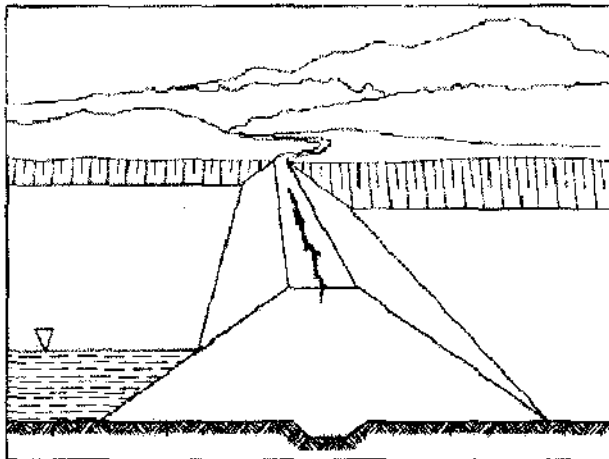
Concerns:

1. Allows standing water to collect and saturate the crest.
2. Vehicles crossing the crest can get stuck causing further damage.

Recommended action:

1. Re-grade and re-compact crest to original elevation with a slope toward the upstream slope.
2. Provide surface resistance to rutting by adding gravel.

LONGITUDINAL CRACKS



Causes:

1. Uneven settlement within the embankment or foundation.
2. Slope instability.

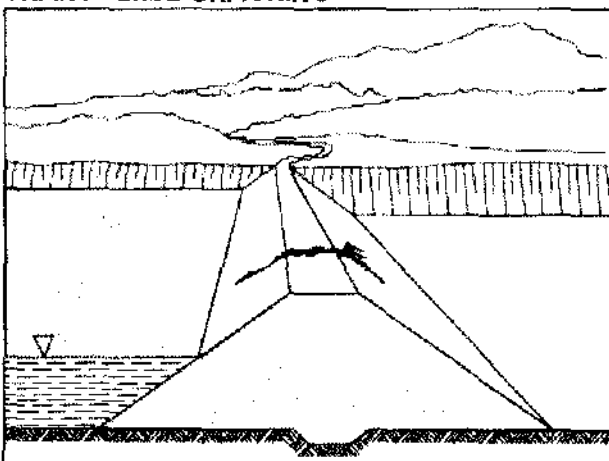
Concerns:

1. Provides an entry point for surface water which can promote movement.
2. Can reduce the effective crest width.

Recommended action:

1. An engineer should determine the cause of the crack and recommend a course of action.
2. The crack(s) should be excavated and backfilled with compacted material to prevent seepage.
3. Area should be closely monitored for future movement.

TRANSVERSE CRACKING



Causes:

1. Uneven movement between two adjacent segments of the embankment.
2. Instability of the embankment or foundation.

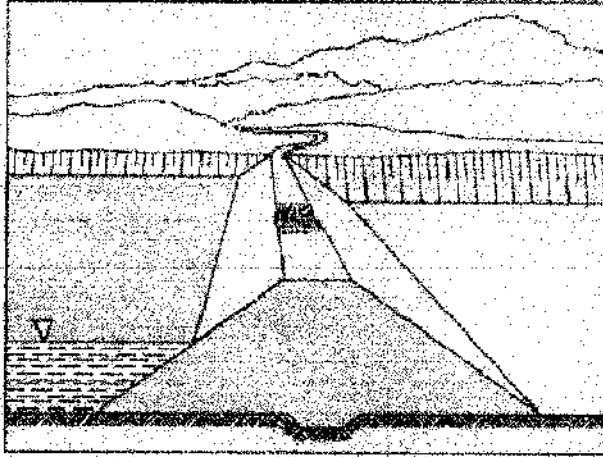
Concerns:

1. Provides an entry point for surface water.
2. May create a seepage path from the reservoir and a potential piping failure.

Recommended action:

1. An engineer should determine the cause of the crack and recommend a course of action.
2. The crack(s) should be excavated and backfilled with compacted material to prevent seepage.
3. Area should be closely monitored for future movement.

LOW AREA ON THE CREST



Causes:

1. Excessive settlement of the embankment material or the foundation (area of deepest fill usually settles the most).
2. Internal erosion of the embankment material.
3. Prolonged erosion from wind or water.
4. Poor construction practices.

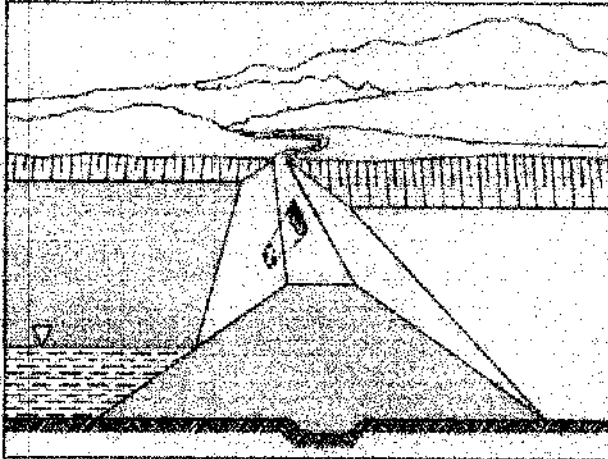
Concerns:

1. Reduces freeboard for safe routing of flood waters.
2. Concentrates flow at one area if the dam is overtopped.

Recommended action:

1. An engineer should determine the cause of the low area and recommend method to repair and prevent recurrence.
2. Re-grade the crest to original design elevation.

SINKHOLE ON THE CREST



Cause:

1. Internal erosion from seepage, for example piping into a hole in the conduit.
2. A breakdown of dispersive clays by seepage (this is a concern in some arid areas).

Concerns:

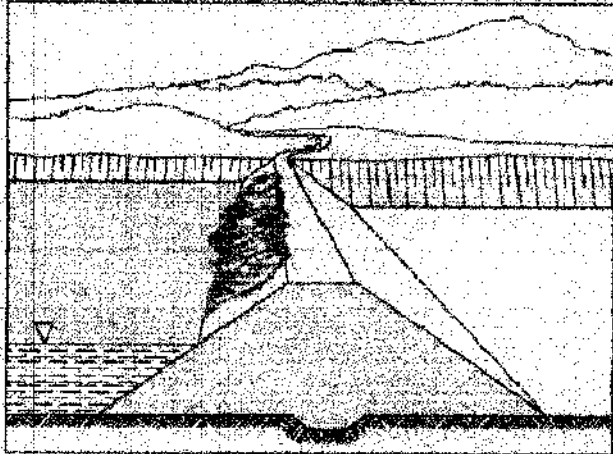
1. Sloughing / caving can occur in the sinkhole leading to embankment instability and development of a low area.
2. Provides an entrance point for surface water.
3. Depending on size and depth, may lead to failure.

Recommended action:

An engineer should determine the cause of the sinkhole and recommend a method of repair.

3 Upstream Slope problems

EROSION (Breaching and Scarps)



Causes:

1. Wave action.
2. Local settlement.
3. Inadequate erosion protection.

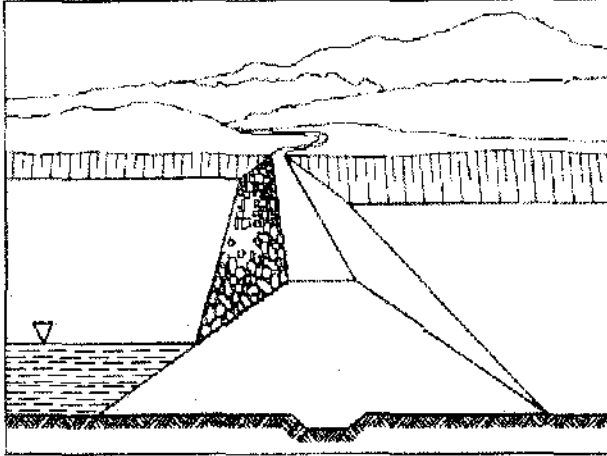
Concerns:

1. Continued erosion can reduce crest width and elevation leading to a possible overtopping.
2. May cause increased seepage.

Recommended action:

1. Re-grade the upstream slope to the original design grade.
2. Provide adequate slope protection or flatten slope by adding material.

DISPLACED OR WEATHERED RIPRAP



Causes:

1. Wave action.
2. Poor quality riprap.
3. Same size rock, leaving gaps which allow waves to erode underlying material.
4. over steepness of upstream slope

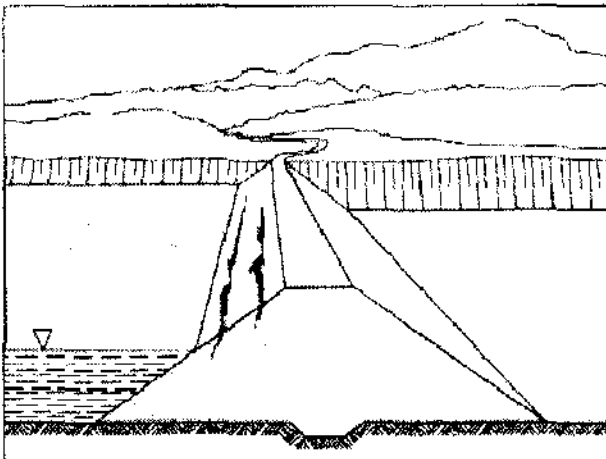
Concerns:

1. Allow increasing erosion which can reduce the width and height of the embankment.

Recommended action:

1. Repair erosion damage.
2. Re-establish adequate slope protection with underlying filter bed.
3. An engineer should determine the cause and recommend further actions to be taken

LARGE CRACKS



Causes:

1. Slope instability.
2. Differential settlement.

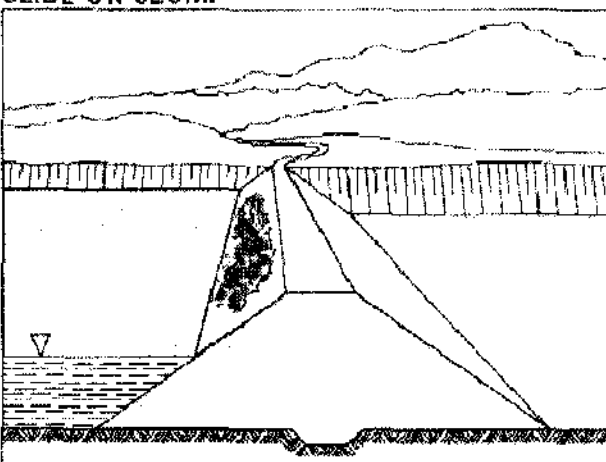
Concerns:

1. Almost always precedes a slope failure or large scale settlement.

Recommended action:

1. The reservoir should be drawn down.
2. The engineer should determine the cause and recommend a course of action.

SLIDE OR SLUMP



Causes:

1. A foundation failure.
2. Too steep a slope.
3. A rapid draw down of the reservoir.

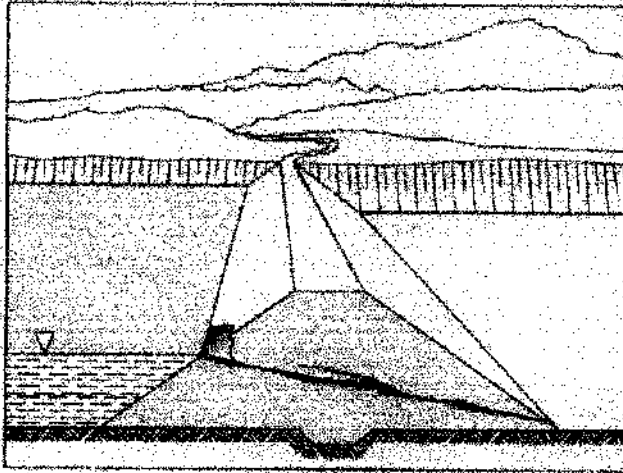
Concerns:

1. Can lead to a failure of the dam.
2. Slide debris can block low level outlets.

Recommended action:

1. Draw the reservoir down. Should advise affected downstream owners who would be affected by releases.
2. The engineer should determine the cause and recommend a course of action.

SINKHOLE



Causes:

1. Concentrated seepage begins to erode embankment material through the dam. This loss of material causes the inlet of the "pipe" to collapse forming a sinkhole.

Concerns:

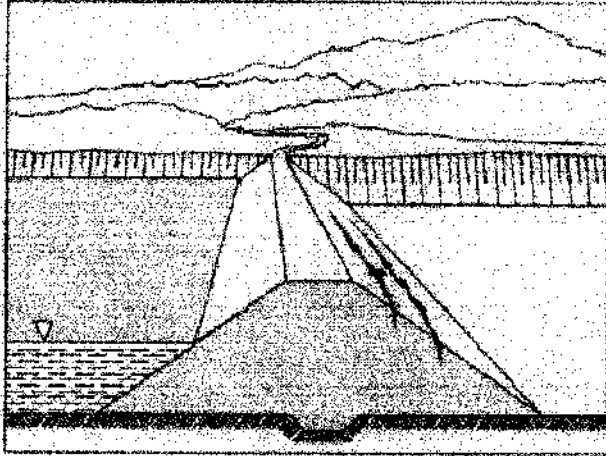
1. Usually results in a piping failure.

Recommended action:

1. Draw the reservoir down.
2. Look for other sinkholes and their exits.
3. Examine outflow for dirty water.
4. An engineer should evaluate the situation and recommend a course of action.

4 Downstream Slope problems

LONGITUDINAL CRACKING



Causes:

1. Drying and shrinking of embankment material.
2. Settlement of embankment or foundation material.
3. Slope instability.

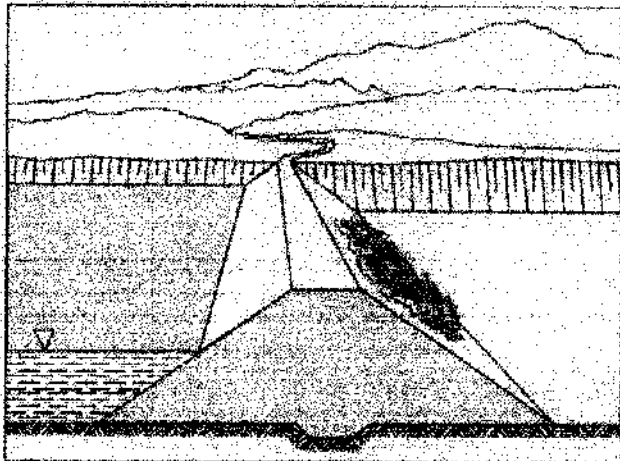
Concerns:

1. Provides an entry point for surface water.
2. Can be early warning of a slope failure, slide, or slump.

Recommended action:

1. Drying cracks should be sealed.
2. An engineer should determine the cause of the cracks and recommend a course of action.

SLUMP/SLIDE



Causes:

1. Too steep a slope.
2. Loss of embankment material strength from excessive seepage.

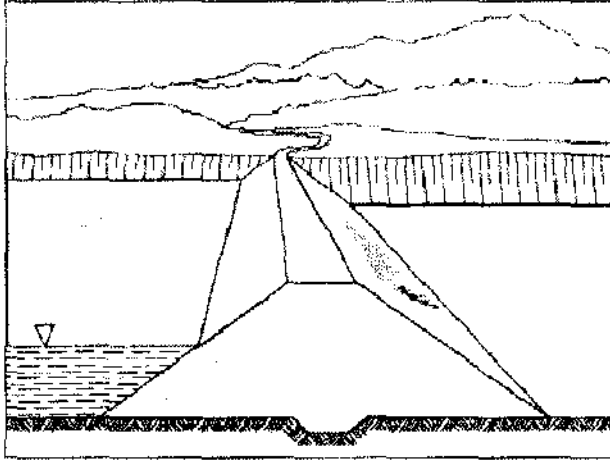
Concerns:

1. Can cause additional slumps / slide.
2. Can lead to embankment failure.

Recommended action:

1. Draw down the reservoir.
2. An engineer should determine the cause and recommend a course of action.

WET AREAS/SEEPAGE



Causes:

1. Seepage through the embankment or under the foundation.
2. Surface water entering through cracks or animal burrows.

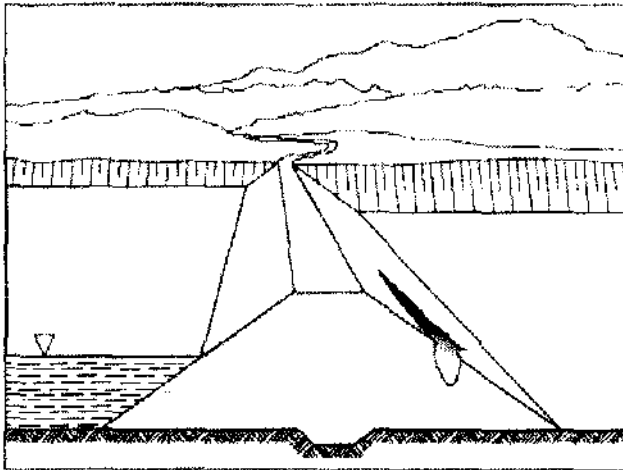
Concerns:

1. Creates slope instability which can lead to a failure.
2. Indicates the possibility of a piping failure.

Recommended action:

1. The outflow should be examined for dirty water - an indication that piping may be occurring.
2. The area and flow should be monitored and the reservoir drawn down if flows increase.
3. An engineer should assess the situation and recommend a course of action.
4. Consult an Engineer immediately if flow volume increases or dirty water is present.

CAVE IN/COLLAPSE



Causes:

1. Poor compaction during construction.
2. Internal erosion / piping through the embankment or foundation.
3. Animal burrowing.

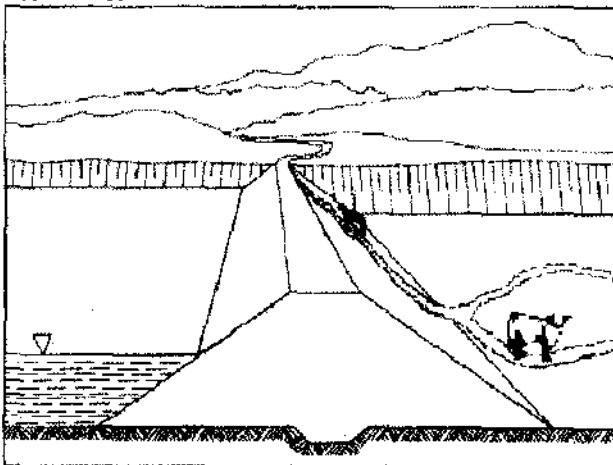
Concerns:

1. Can cause increased seepage.
2. Indicates a potential failure.

Recommended action:

1. Monitor the area for change.
2. An engineer should determine the cause and recommend a course of action.

EROSION



Causes:

1. Livestock traffic.
2. Surface runoff.

Concerns:

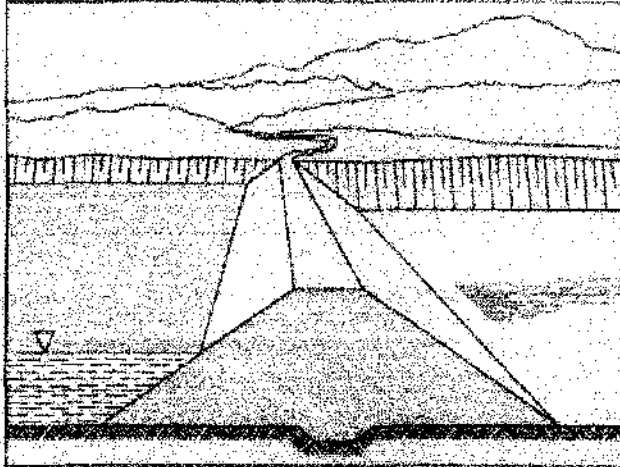
Encourages further erosion.

Recommended action:

1. Re-grade slope and sow a cover crop.
2. Keep livestock away from the embankment.

5 Downstream Toe problems

SEEPAGE WATER EXITING FROM A WATER BOIL



Causes:

1. A concentrated seepage path or "pipe" has developed through the foundation.
2. Seepage from the reservoir through a sand or gravel layer in the foundation.

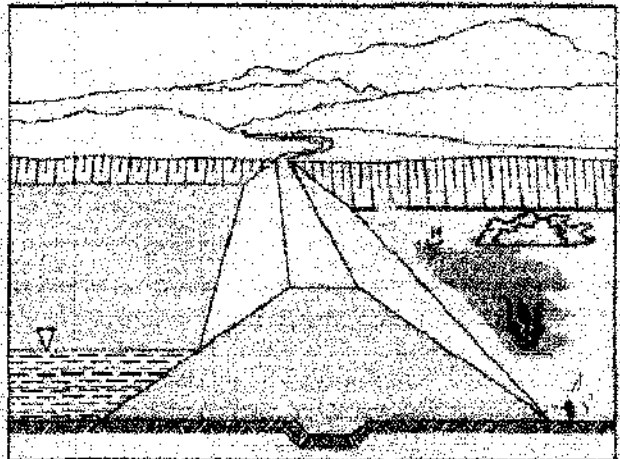
Concerns:

1. May result in a piping failure of the foundation and ultimately the embankment.

Recommended action:

1. The outflow should be examined for dirty water as an indication that piping may be occurring.
2. The area and flow should be monitored and the reservoir drawn down if flows increase.
3. An engineer should assess the situation and recommend a course of action.
4. Consult an Engineer immediately if flow volume increases or dirty water is present.

STANDING/PONDED WATER AT THE DOWNSTREAM TOE



Causes:

1. Heavy seepage.
2. Surface runoff.
3. Poor drainage away from the toe.

Concerns:

1. Obscures source and make flow rates difficult to estimate.
2. Saturates and destabilizes the downstream slope.
3. Can result in a slope failure.

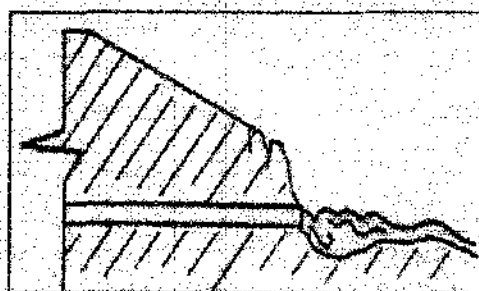
Recommended action:

1. Provide adequate drainage to prevent ponding.
2. Identify seepage path and consult an engineer if necessary.
3. Consult an Engineer immediately if flow volume increases or dirty water is present.

6 Downstream Abutment problems

7 Outlet Works problems

OUTLET RELEASES ERODING TOE OF DAM



Causes:

1. Outlet pipe too short.
2. Lack of energy dissipating pool or structure at downstream end of conduit.

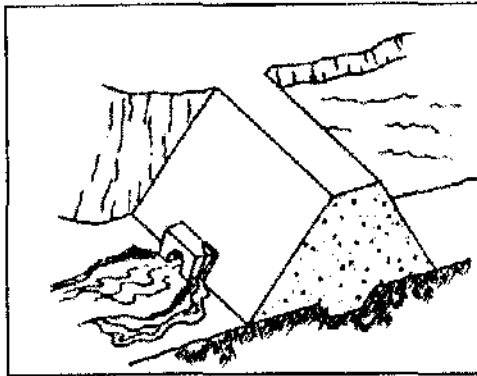
Concerns:

1. Erosion of toe over-steepens downstream slope causing progressive sloughing.
2. Eroded material causes environmental damage.

Recommended action:

1. Extend pipe beyond toe (use a pipe of same size and material, and form watertight connection to existing conduit).
2. Protect embankment with riprap over suitable bedding.

PIPING /SEEPAGE ALONG OUTLET



Causes:

1. A break in the outlet pipe.
2. A path for flow has developed along the outside of the outlet pipe. (poor construction).

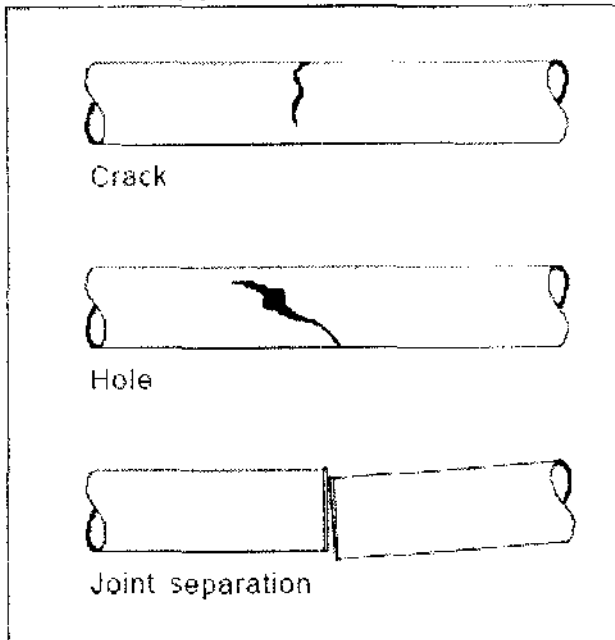
Concerns:

1. Continued flows can lead to rapid erosion of embankment materials and failure of the dam.

Recommended action:

1. Thoroughly investigate the area by probing to see if the Cause can be determined.
2. Determine if leakage water is carrying soil particles.
3. Determine quantity of flow.
4. If flow increases or is carrying embankment materials, dam water level should be lowered until leakage stops.
5. A qualified engineer should inspect the condition and recommend further actions to be taken

CONDUIT IN POOR CONDITION



Causes:

1. Rust.
2. Joint separation.
3. settlement or poor construction practice

Concerns:

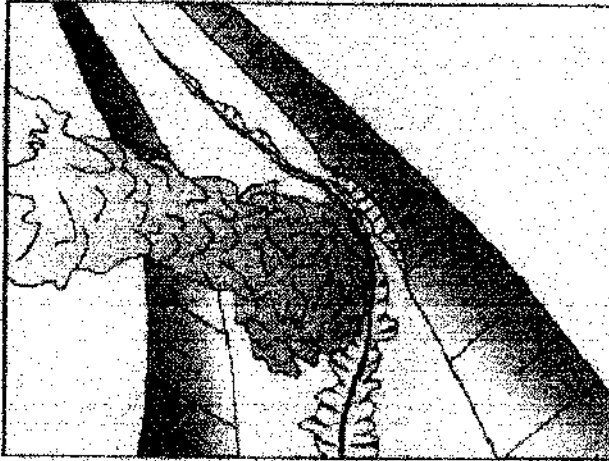
1. May lead to serious internal erosion and a possible piping failure
2. excessive seepage, possible internal erosion

Recommended action:

1. Check for evidence of water either entering or exiting pipe at crack/ hole/etc.
2. Tap pipe in vicinity of damaged area, listening for hollow sound that shows a void has formed along the outside of the conduit.
3. If there is any suspicion at all of a progressive failure, request urgent engineering advice.
4. Install upstream valve to isolate pipeline and enable inspections
5. An engineer should determine the cause and recommend a course of action.

8 Spillway problems

ERODED CHANNEL/SLIDE



Causes:

1. Inadequate erosion protection.
2. Too steep a gradient.

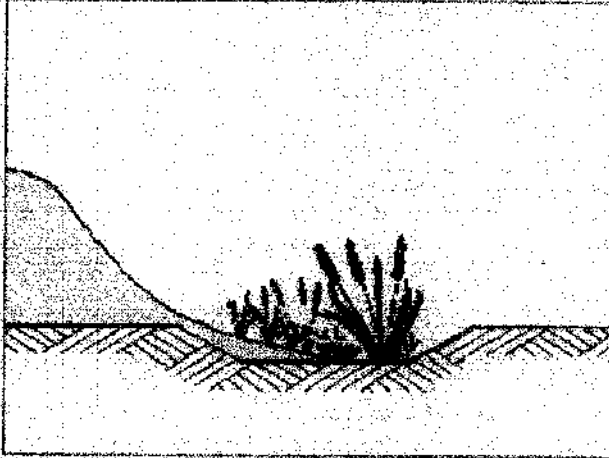
Concerns:

1. Erosion channel deepens and generally works its way upstream.
2. Can result in the reservoir draining through the eroded channel.
3. Slides can block the channel.

Recommended action:

1. Repair the eroded area with compacted fill.
2. Provide adequate erosion protection.
3. Re-grade the channel if necessary.

BLOCKED CHANNEL



Causes:

1. Floating debris.
2. Animal activity.
3. Man made.

Concerns:

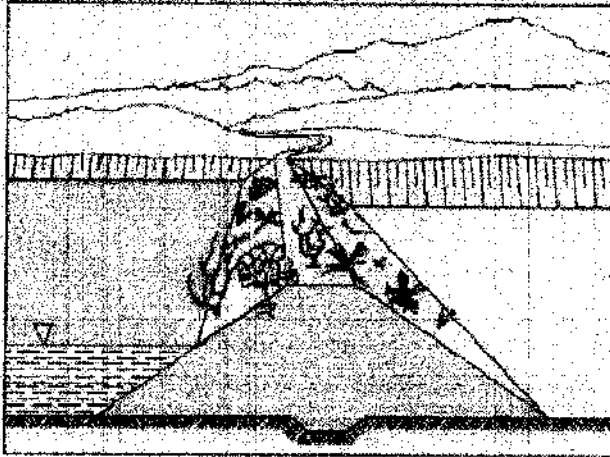
1. May restrict spillway channel flow causing the embankment to overtop.

Recommended action:

1. Remove the blockage.
2. Prevent future blockages.
3. Install trash racks if necessary.

9 Miscellaneous Problems

EXCESSIVE VEGETATION



Causes:

1. Lack of maintenance.

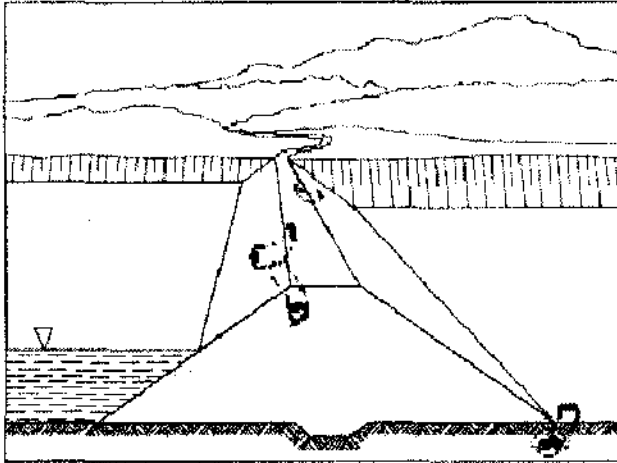
Concerns:

1. Prevents a thorough inspection.
2. If vegetation dies the root system could create seepage path.
3. If trees blow over the root ball could leave hole.
4. Prevents easy access.
5. Provides a habitat for burrowing animals.

Recommended action:

1. Remove excessive vegetation and root systems.

BURROWING ANIMAL ACTIVITY



Cause:

1. Burrowing animals.

Concerns:

1. Can weaken the embankment.
2. Can cause a piping failure.

Recommended action:

1. Control rodents.
2. Remove favorable habitat conditions.
3. Backfill rodent burrows with compacted fill.

Appendix E: Conducting an Inspection

To be able to conduct a thorough inspection of your own dam you may need to consult an experienced engineer who will provide a good insight into what you should be looking for and how to go about it. This would provide a procedure specific to your dam. The following material is provided for your information to assist in understanding inspection requirements.

Establishment of Reference Pegs

The purpose of an inspection as part of dam's safety surveillance is to monitor performance in such a way as to enable early diagnosis of potential problems. As mentioned in the text, this includes such things as noting where cracks or leakage has formed and noting whether there is any deterioration, and how fast or slowly that may be occurring. To enable such monitoring to be reliable, and to facilitate the keeping of records, it is essential that there be both a plan of the dam and a set of reference pegs, relative to which the location of any observation or trouble spot can be pinpointed and recorded.

The degree of sophistication of the plan and of the reference peg system will depend on the size of the dam, its type and its potential hazard category, and advice should be sought on this first. However, as a bare minimum, irrespective of size of dam, there should be established at least one key reference peg (the primary reference peg) at one end of the dam. Remember that recording of locations will need to convey the level (height) at each location as well as the distance along the dam length. It is preferably to place it at a level close to the dam crest level, but securely in place so that it can be readily found and so that it is unlikely to be knocked out or broken by persons, vehicles, plant or cattle. Ideally a secondary reference peg should be located elsewhere as a backup, preferably at the other end of the dam, with the distance away from the primary peg, and any difference in height being measured and recorded. If the dam crest is not straight, or if there are difficulties about this procedure, professional advice should be sought. With larger dams, or dams classified as potentially hazardous, more sophisticated arrangements may very likely be required, but for small and simple dams it is not essential that the position and level of the reference peg(s) be precisely defined by a land surveyor. Similarly for the latter dams the plan of the dam may not need to be precisely to scale, but there should be a reasonably reliable means of ascertaining the height level of any observation made and the distance of it from the primary reference peg.

Equipment for inspection

The following items are useful when conducting an inspection:

- Dam inspection check list - a reminder of items to be examined;
- Notebook or diary and pencil - to write down observations at the time they are made, thus reducing mistakes and avoiding reliance on the memory;
- Camera - to provide photographs of observed field conditions. Color photographs taken from the same vantage points are valuable in comparing past and present conditions;
- Shovel - useful for clearing drain outfalls and removing debris;
- Stakes and tape - used to mark areas requiring future attention and to stake the limits of existing conditions such as wet areas, cracks and slumps for future comparisons;

- Probe - a ten-millimeter diameter by one meter long blunt end metal rod with right angle "T" handles at one end. The probe can provide information on conditions below the surface such as depth and softness of a saturated area. Soft areas indicate poor compaction or saturated material; and
- Hammer- to test soundness of concrete structures.

Observations to be recorded

All measurements and descriptive details that are required to portray an accurate picture of the dam's current condition must be recorded. This information falls into three categories:

- Location - the location of any questionable area or condition must be accurately described to allow it to be properly evaluated. The location along the length of the dam should be noted, as well as the height above the toe or distance down from the dam's crest should also be measured and recorded. The same applies to conditions associated with the outlet or spillway;
- Extent of area - record the length, width and depth or height of any area where a suspected problem is found.
- Descriptive detail - a description of a condition or observation must be given which is brief but yet containing all relevant details. Some factors to include are:
 - Quantity of seepage from point and area sources;
 - Color or quantity of sediment in water;
 - Location, length, displacement, and depth of cracks;
 - is area moist, wet or saturated?
 - is protective cover adequate (topsoil/grass)?
 - is surface drainage satisfactory?
 - do batter slopes look too steep?
 - are there bulges or depressions on the slopes?
 - does deterioration appear to be rapid or slow? and
 - have conditions changed? (note in what way etc).

Note: A sketch plan of the dam is a helpful aid to recording observations. It should preferably be approximately to scale and the locations of all observations should be indicated on it.

This is not a complete list but serves as an initial guide. If a condition has changed since the last inspection, it must be noted; a photograph should also be taken and put in the diary, noting the date and a description of the scene shown in the photograph.

Remember, a primary purpose of the inspection is to pick up changes which have occurred since the previous inspection, and that if a situation looks as if it is worsening or otherwise causes concern the owner should not hesitate to get professional help.

A typical form of checklist for noting defects and keeping long term records of behaviors is given below.

Dam inspection checklist for Embankment dam

Date:...../...../.....

Owner: _____ Location: _____

Dam Name

Areas of dam	Items to address	Observations/ Change from last inspection
Upstream Slope	<ul style="list-style-type: none"> • Protection • Uniformity • Displacements, bulges, depressions • Vegetation 	
Crest	<ul style="list-style-type: none"> • Cracking • Low spots • Sinkholes • Vegetation 	
Downstream Slope	<ul style="list-style-type: none"> • Signs of instability and non-uniformity • Erosion • Burrows activity • Obscuring growth (trees) • Wetness • Changes in condition • Stock damage 	
Seepage	<ul style="list-style-type: none"> • Location • Extent of area • Characteristics of area (ie. soft, boggy, firm) • Quantity and color • Transported or deposited material • Spring activity or Boils • Piping and tunnel erosion • Changes in vegetation 	
Outlet	<ul style="list-style-type: none"> • Outlet pipe and valve condition • Operation • Leakage • Downstream erosion • Gate valve operation/ condition/ leakage 	
Spillway	<ul style="list-style-type: none"> • Condition of crest, chute and floor protection • Spillway obstructions • Erosion or back cutting in spillway 	

Dam inspection checklist for Concrete Gravity dam

Date:...../...../.....

Owner: _____ Location: _____

Dam Name

Areas of dam	Items to address/check	Observations/ Change from last inspection
Upstream Face	<ul style="list-style-type: none"> • Deteriorated joints • Cracking/Spalling 	
Crest	<ul style="list-style-type: none"> • Deteriorated joints • Cracking/Spalling • Poor alignment 	
Downstream Face	<ul style="list-style-type: none"> • Deteriorated joints • Cracking/Spalling • Seepage 	
Abutments	<ul style="list-style-type: none"> • Vegetation/erosion • Sloughing/slides/cracks • Seepage/wetness 	
Toe	<ul style="list-style-type: none"> • Erosion/undermining • Seepage/wetness • Foundation drains 	
Gallery	<ul style="list-style-type: none"> • Deteriorated joints • Cracking/Spalling • Seepage 	

Inspection Procedures

Getting the most out of an inspection requires some preparatory work:

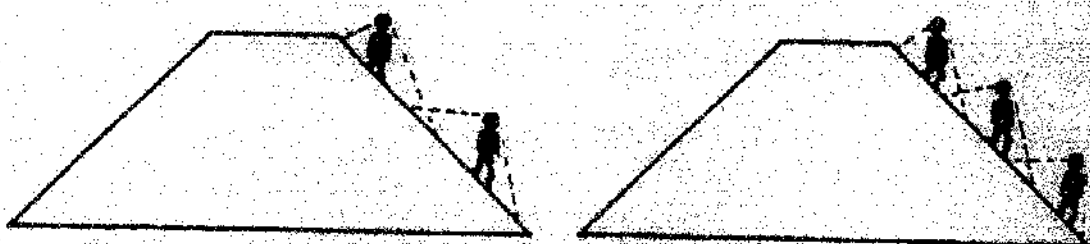


Figure 1 Successive passes

- The previous diary entries should be reviewed first to note any areas which will require special attention; and
- If the purpose of the inspection is to re-evaluate suspected defective conditions discovered during the last inspection, any available construction drawings should first be examined for a possible explanation of the situation (but do not speculate, obtain professional advice if there is any doubt or ambiguity in the situation).

To obtain the best results and allow for consistent recording of findings, it is best to follow a specific sequence when making the inspection, such as:

- Upstream slope;
- Crest (Top of Bank);
- Downstream slope;
- Any seepage areas;
- Outlet; and
- Spillway.

This will lessen the chance of an important condition being overlooked. It is best to report inspection results in the same sequence to obtain consistent records.

General Techniques

The inspection is conducted by walking along and over the dam as many times as necessary to see every square meter. From any given spot a person can usually obtain a detailed view for a distance of three to ten meters in each direction, depending on the smoothness of the surface or the type of material on the surface, ie. grass, concrete, rock, brush. Where visibility is limited, more attention is needed.

Successive Passes

To cover extensive surfaces properly, several walks are required (Figure 1).

Adequate coverage can be achieved using parallel or zigzag paths (Figure 1 and 2).

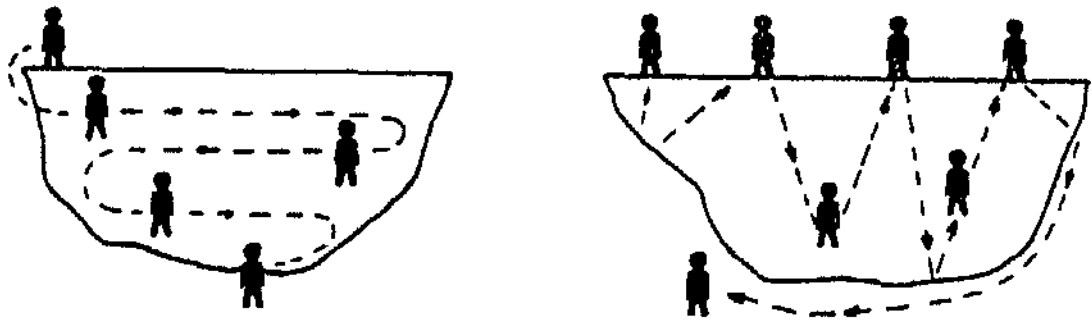


Figure 2 Parallel coverage path

On the downstream slope a zigzag path is recommended to ensure that any defects are detected.

Stop and Look

At several points on the slope, you should stop and look around through 360 degrees to check alignments and to be sure that some important feature of the slope has not been overlooked.

Particular Techniques

The following is a list of methods that can be used to monitor changes, which will occur over a period of time.

Sighting

A sighting technique, similar to that used when selecting straight pieces of timber, can be used in identifying misalignment as well as high or low areas along a surface. The technique is illustrated in Figure 3.

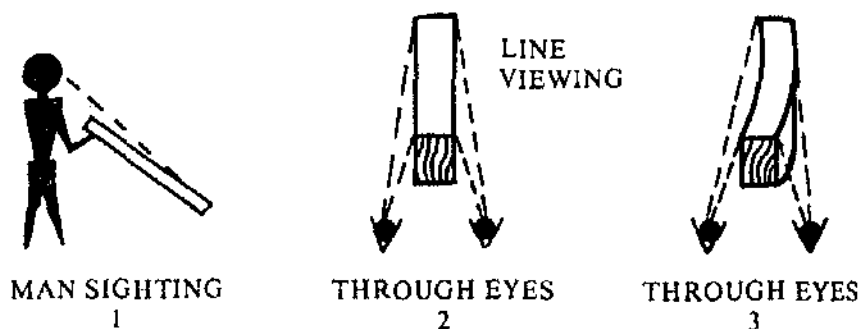


Figure 3 Sighting techniques

The same method can be used to sight along the crest of a dam (see Figure 4). Centre the eyes along the line being viewed. Sighting along the line, move from side to side a little to view the line from several angles.

Looking through a pair of binoculars will help to make any variations more obvious

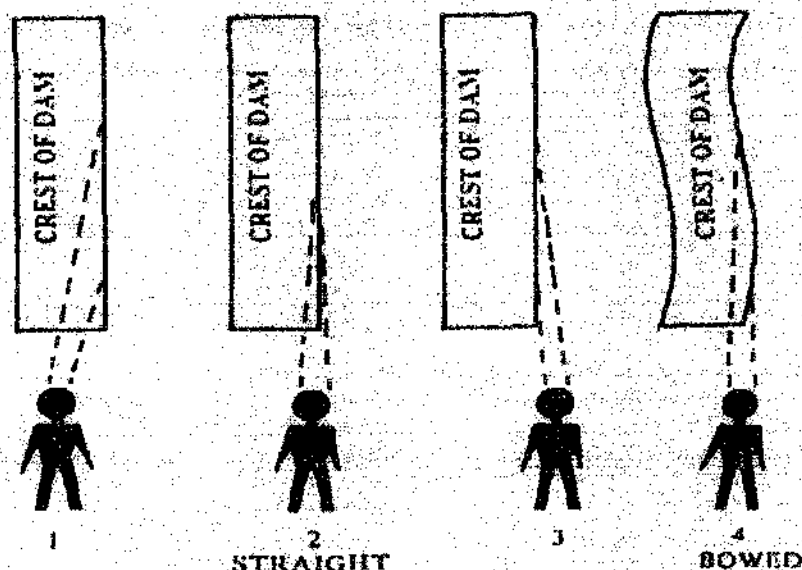


Figure 4: Sighting along crest

Probing

The probe is pressed into the earthen batter slopes, on the crest or at places being inspected. Conditions below the surface, such as depth and softness of a saturated area can then be observed. Also, by observing the moisture brought up on the probe's surface and the resistance to penetration, it is easier to decide whether an area is saturated or simply moist.

Pegging-stakes

The best way to find out if there is a leak is to check how fast water is disappearing from a storage by marking the waterline with a peg at regular intervals, say, weekly. If the storage is used for stock or irrigation, try to peg the waterline before and after use. Alternatively measuring staff can be permanently set into the storage to level measurement easier.

Measuring in this way is much better than simply guessing. A suspected leak, when measured, may turn out to be only evaporation loss. Evaporation per day can easily be five millimeters, and sometimes as much as ten millimeters in fine, dry, windy conditions.

Noting Slides and Signs of Surface Movement

Slides are often difficult to spot, because they do not always produce readily noticed cracks at the surface. Their appearance is often subtle, since there may be less than 200-mm of depression or bulging out at right angles to the slope in a distance of perhaps ten metres. On the other hand, when the dam was finished, the bulldozer operator may not have uniformly graded it, and in such a case the surface of the slope may have an apparent bulge or concavity when in fact no slide is present. A good familiarity with how the slope looked at the end of construction helps identify any slides.

A method of monitoring surface movement on the upstream or downstream slope is to place a straight line of stakes down the slope with a string tape attached to the top of each stake. The point at which a slide takes place will cause the uphill stakes to be pulled over, whilst those just downhill of the movement would show a slackening of the string tape.

Noting Changes in Vegetation

The density or lushness of vegetation can also be an indication of extra moisture at a particular location and the possibility of a leak. Probing the area will usually confirm whether or not a problem is developing.

Evaluation of Observations

The record of observations taken at periodic inspections is used to develop a mental picture of the dam's performance. Accurate measurements pay off here because small changes, which could go undetected if simply looked at rather than measured and recorded, will show a pattern or trend.

Immediately following the inspection, the observations should be compared with previous records to see if there is any condition, reading, or trend that may indicate a developing problem. The owner can then begin to address any potential problem before it becomes a threat to the dam. When a significant change is detected, any design drawings for the dam should be examined carefully to see if an obvious reason for the change could be found.

If a questionable change of trend is noted, a professional engineer experienced in the field of dam engineering should immediately be engaged to determine if any action, such as increased monitoring or detailed investigation of the condition, is required.

These actions will help ensure the safety, safe operation, and long, useful life of the dam.

Appendix F: Terms of Reference for study and detail design of a dam

Terms of Reference (TOR) for study and detail Design of a small dam by a Consultant

1. Objective of the Design

To undertake **feasibility studies and detail design works** of a dam & appurtenant structures a _____ Project.

2. Scope of the works

The scope of the services of the consultancy, during the development of the dam study and design shall contain, but not limited to the following:

i) Topographic Survey

- Review of previous relevant studies
- Topographic map of the main dam site at a scale not more than 1:500 and at a contour interval of not more than 0.5m, showing all the features upstream and downstream, right and left of the proposed site including observation pits shall be prepared.
- Dam site cross section at a scale of both vertical and horizontal shall be prepared at a scale of 1:100 indicating the pertinent features to the dam shall be prepared.
- All the required benchmarks and stations shall be established using stable features and shall be properly connected with the national grid stations and benchmarks of the proposed dam site.
- Topographic survey on the reservoir area to an appropriate scale with contour interval of 1m.

ii. Hydrology and hydro meteorological studies

- Collection and review of all available climatic data together with all existing climatological reports of the area.
- Collection and analysis of all existing hydrological data using quality control. Review of all previous hydrological reports related to the project area.
- Analyze quality of collected data.
- Filling of all missing data using standard procedures.
- Compute various frequencies of storms, probable maximum precipitation relevant to the design of spillways, drainage works and other relevant structures.
- Perform climatic studies to identify spatial and seasonal fluctuations of climatic variables.
- Extension of existing flow data to determine long term average flow and hence assess the yield at proposed dam site.

iii) Sedimentation

- Estimation of the sediment regime and total sediment transport (suspended plus bed load) of the river in the project area.
- Study of the proposed reservoirs trapping efficiency, forecasting of dead storage volume and the future rate of reduction of the live storage.

iv) Geology and Geo-technical studies

- Review of previous relevant studies
- Foundation investigation of dam sites including along the spillway and the retaining wall shall be collected.
- Geological test pit at a reasonable interval depending on the topographic feature of the dam sites along the cross section and longitudinal section of the site shall be taken.
- Analyze the geology and tectonic structures of the area and interpret the result.
- Analyze the seismicity and earthquake intensity of the area.
- Identification and recommendations of appropriate type of foundation treatment
- Perform soil and rock laboratory tests on foundation and construction material Conduct resistivity study (for rock fracture analysis overburden thickness analysis)
- The log profile shall indicate clearly the material composition of the foundation material, the foundation level, and ground water condition.
- The project shall also indicate the type and quantity, availability, quality and proximity of local construction material, and access road route shall be selected, whenever necessary.
- In addition, all other data considered necessary and relevant for the study shall be carried out.

v) Geology and Geo-technical design

- Interpretation of geotechnical investigations results and providing appropriate recommendations of design parameters for the dam and appurtenant structures design. Recommendations will be based on the suitability of the specific formations with respect to the proposed structures.
- Analysis of laboratory test results and suitability for the intended purpose
- Study and design foundation treatment works
- Reviews analyze all foundation conditions and decide on design parameter.
- Carry out detail design of dam with available construction materials to make easy construction work. The detailed design of the embankment dam will cover:
 - Review of all geotechnical investigations covering the embankment foundations and fill materials, including confirmation of quality and quantities of construction materials from borrow area and quarry sites;
 - Embankment zoning and internal drainage;

- Stability and seepage analysis using geo-slope software at various conditions;
- Design of foundation grouting and curtain grouting.
- Upstream and downstream slope protection;
- Instrumentation.

vi) Hydrology and hydraulic Design

The dam to be designed is expected to base on the following procedures but not exhaustive.

- Proper structural and hydraulic feasibility level designs shall be carried out for the dam and spillway with respect to maximum flood estimates and subsurface hydraulic analysis for the determination of maximum scour depth and the safe level of cut-offs keeping the geologic and geo-technique information in to consideration.
- Proper surface hydraulic design of the dam and spillway shall be carried out so as to ensure the safe economic arrangement of energy dissipating mechanisms. The energy dissipation mechanism shall be checked against the downstream effects to a considerable distance.
- Flood protection structures, spillways, retaining walls, intake, bottom outlet and all gates shall be designed properly considering both structural and hydraulic safety.
- Design the electromechanical system and components.
- Review and check the recommended measuring equipments for the dam.

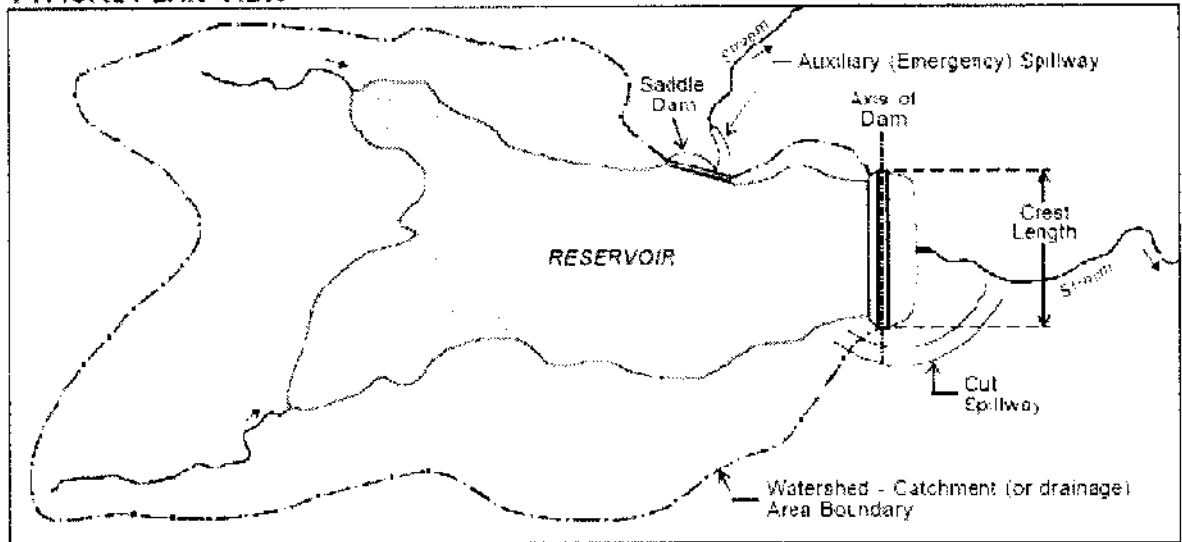
3. Outputs

After the execution of the works stated in the project activities the outputs expected are:

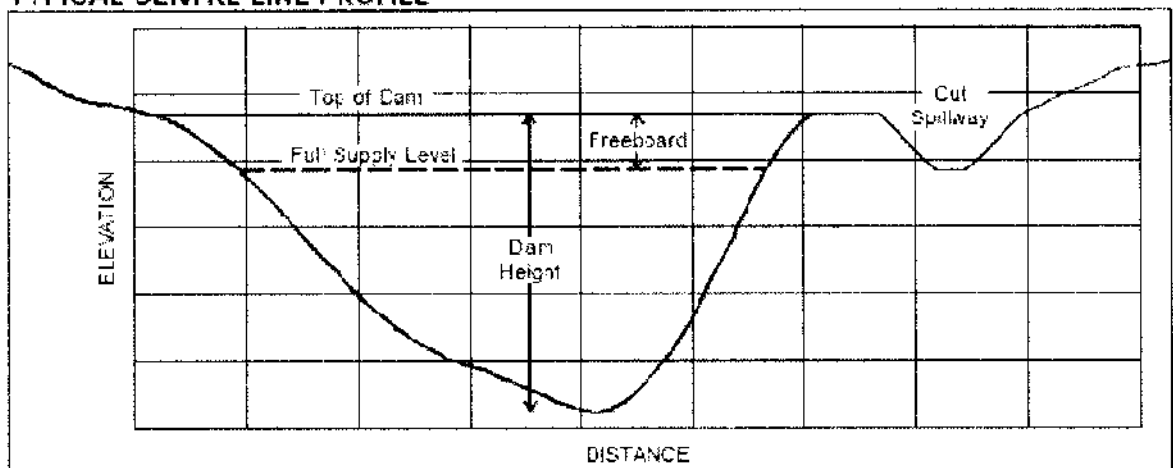
- Adequate number of the study and design reports.
- Detail Design for Engineering Works (dam and all appurtenant works)
- Preparations of Technical Specifications Document
- Design Calculations
- Preparation of Tender Documents and Design Report
- Preparation of Drawing Albums for Construction
- Preparation of dam operation and maintenance manual.

Appendix G: Typical Plan, Profile and Section of a Small Embankment Dam

TYPICAL PLAN VIEW



TYPICAL CENTRE LINE PROFILE



TYPICAL DAM SECTION

