THE NEW ZEALAND SOCIETY ON LARGE DAMS

NZSOLD

GUIDELINES ON INSPECTING SMALL DAMS

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SMALL DAMS

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Whakamarino Dam, Waikaremoana, Hawkes Bay, New Zealand. Downstream face, showing culvert outlet with fence and spillway gate arms.

Photo: Courtesy of Electricity Corporation of New Zealand Ltd.

PREFACE

The Management Committee of the New Zealand Society on Large Dams (NZSOLD) has promoted the publication of this booklet to assist owners of small low-hazard dams in completing visual safety inspections of their structures.

The information and recommendations included in the booklet are provided in good faith. In providing the information, NZSOLD, its officers, managers and members:

- do not make any representations, express or implied, as to the accuracy, completeness or appropriateness of any of the information or recommendations provided for use in any particular circumstances;
- do not accept responsibility for the use or application of, or reliance on, any of the information or recommendations provided for any purpose or reason whatsoever.

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1. INTRODUCTION

This booklet has been prepared by the New Zealand Society on Large Dams (NZSOLD) to provide owners of small low-hazard dams with information and guidelines for making visual safety inspections. It is directed towards owners who are not, or do not employ, professional technical staff. It is hoped that those who use this booklet will be better able to recognise early warnings of unsatisfactory performance of their structures and prevent potential failures occurring.

A *small* dam is one less than four metres in height, i.e. from the base of its foundation with the natural ground to its crest. A small dam is also defined as one which retains not more than three metres of water depth and not more than 20 000 cubic metres of water. The limitation on water depth provides for a minimum freeboard of one metre. Such a dam is also exempt from a building consent under the current legislation. Owners of dams larger than this, or of dams which represent significant hazards to life and/or property, should consult the NZSOLD “Dam Safety Guidelines” for information and procedures for the safe operation of their dams.

These guidelines are intended to give a general overview of what to look for, and why, when inspecting a small dam. It covers the majority of cases, but does not cover each and every circumstance. It is not a design or construction manual. Where the dam owner has some doubt over the interpretation or applicability of the content, professional assistance should be sought.

Routine visual inspections are a key element for the safe operation of any dam. They can lead to the early detection of potential problems, and hence reduce the potential for serious damage. As some problems may not be immediately obvious, even dams that appear in good condition should be regularly inspected. Problems may be very slow to develop or may occur suddenly after a severe event like a storm or an earthquake.

When a potential problem is detected or suspected, the owner should inform the local territorial authority (TA) as soon as practical.

2. COMPONENTS OF A DAM

2.1 General

A dam is a structure capable of storing or diverting water. Commonly, small dams are constructed of earth fill, but they may be made of concrete, boulders (rockfill), or timber. A natural event such as a landslide or slip may form a natural water barrier behind which water ponds. These guidelines do not apply to natural landslides or slips.

For economic reasons and convenience most small dams are constructed of earth. Even though this booklet will focus on earth dams, the principles and examples used have general application to other types of dams.

2.2 Earth dams

A dam and its associated foundation must be stable, control any seepage that occurs, and safely manage all water flows entering the reservoir. Typical earth dam details are illustrated in Figure 1.

Factors which affect dam stability include foundation conditions, compaction of the earth fill, steepness of the side slopes, and drainage at the downstream toe. A well constructed dam of impermeable fill material on a sound foundation, using good construction techniques with a well designed toe drain, should have minimum side slopes of three horizontal to one vertical for the upstream slope and 2.5 horizontal to one vertical for the downstream slope.

The topsoil must be removed from the dam foundation area to ensure a good bond between the foundation and the earthfill. Most small dams utilise a single material for the bulk of the structure. This should be either a clay, a clayey silt, or a mixture of clay, silt, sand and gravel. Highly plastic clays that shrink and crack when they dry out are not suitable. Good earthfill compaction is important, especially around any structures or pipes passing through the dam.

In spite of these measures, dams become saturated with time. Therefore, for most dams a granular filter should be constructed into the downstream toe of the dam. A filter is a layer of sand and gravel, much like a concrete "builders' mix", which permits the passage of the natural seepage while preventing soil particles from passing through. If a dam does not have a filter, seepage may emerge on the downstream slope, weakening it and causing slumping.

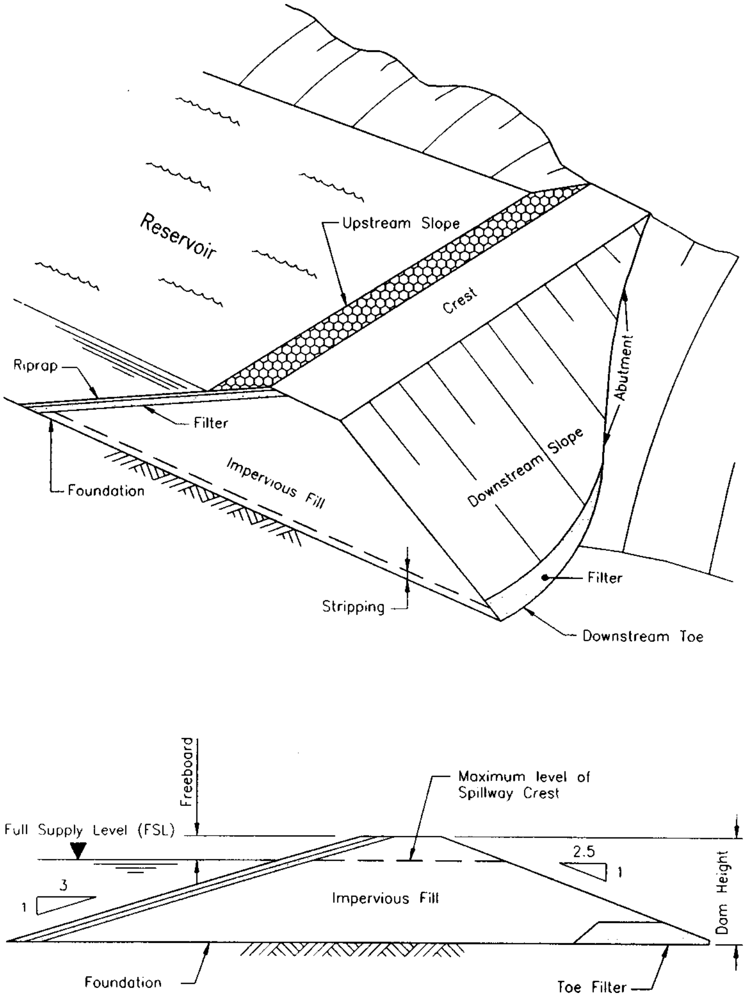


Figure 1. Typical earth dam cross-sections

Potentially more damaging, the emerging seepage water may carry soil particles and lead to internal erosion of the dam. This internal erosion can quickly develop into the formation of “pipes” through the embankment leading to the dam failure. Hence the expression of a “piping failure”.

The tops of the upstream slopes of earth dams are usually protected from wind-generated reservoir waves by a layer of protection gravels at least 200 mm thick. This protective layer is called “rip-rap” and should be a “well graded” material comprising a good assortment of sizes. If only large rocks are used, the smaller underlying filter gravels may be washed out through the voids in the rip-rap by the wave action. In its turn, the underlying filter is to prevent the earth dam soil particles from being washed out through the rip-rap by waves and currents in the reservoir.

If the reservoir is less than 100 m long and the upstream slope of the earth dam is about one vertical to three horizontal, then a rip-rap layer of well graded gravel up to 200 mm diameter maximum size may be sufficient.

Many earth dam failures are caused by overtopping. All earthfill dams should include sufficient freeboard allowances above “full supply level” to ensure the dam is not overtopped during operation or flood flows.

2.3 Canals, headponds, and races

There are many cases where water is channelled by the use of canals or races to a headpond or small reservoir. Where these are formed in earth, the sides act as dams confining the water. Stability is most likely an issue only when the channel is in fill material or in highly erodible materials (e.g. volcanic deposits). In these cases, the comments relating to earth dams for materials, seepage control, wave protection, and provisions to prevent overtopping are relevant.

2.4 Spillways

All dams require operable spillways. They should be designed to pass the catchment flood without the dam overtopping or suffering significant damage. They may be constructed as open channels, excavated in rock or lined with flow-resistant material such as concrete, gravel-filled wire baskets, and interlocking paving. Piped spillways are not favoured because of their increased susceptibility to blockage, leading to possible overtopping and subsequent failure of the dam.

It is preferable spillways be constructed over natural ground rather than over the constructed dam, and that particular attention is paid to sound construction practice, as they have to function safely in the most adverse storm conditions.

The spillway must be proportioned and set at such a level that, under the most adverse flood, there is still adequate clearance (freeboard) between the flood level in the reservoir and the top of the dam to prevent storm waves from overtopping the dam. Generally a one metre freeboard is considered adequate.

If appropriate, an emergency spillway can be constructed to pass flows that exceed the capacity of the main spillway. Often they are set at a higher level than the main spillway and consequently come into operation less frequently.

2.5 Low-level outlets

Low-level outlets are often pipes set near the dam foundation to provide a controlled water release downstream. In times of flood they may be used to augment the spillway. An important use is to lower the reservoir level below the spillway crest in times of emergency to remove some of the water load from the dam. The lowering of the reservoir can also be for inspection purposes.

Many dam failures have been caused by the erosion of dam fill materials along their contacts with low-level outlets. Special care is necessary during design and construction to ensure that the opportunities for uncontrolled seepage and erosion along such interfaces are minimised.

2.6 Rockfill dams

The main body of a rockfill dam comprises boulders or large gravel-sized particles. Often the material is well graded with smaller particles filling the voids between the larger sizes. An impermeable barrier may comprise a central “core” of clay or a concrete wall. Alternatively it may comprise a lining of the upstream slope with a concrete facing or a plastic or rubber sheet. The number of small rockfill dams that have been built is very limited. They require design by professional dam engineers.

2.7 Concrete dams

Solid concrete gravity dams gain their strength from their mass providing resistance to sliding and overturning. Because of their lack of flexibility they are generally founded on rock. 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.

3. INSPECTION GUIDELINES

3.1 General

Inspecting a dam frequently under normal conditions and after unusual events provides the best opportunity for the early detection of potential problems. This will allow the owner to take appropriate action before the structure is compromised. In general, each structure should receive a detailed inspection immediately after each significant flood and earthquake and not less than once a year.

What to look for is influenced by dam failure mechanisms and their causes. The most common failure mechanisms for earth dams are surface erosion, internal erosion (i.e. piping), and embankment slumping. These failures arise from many defects such as spillway inad-

Table I.

Form	**Characteristics**
Erosion by overtopping.	Flow over the top of the embankment washing out dam.
Erosion by waves.	Erosion of upstream face.
Erosion by outlet discharge.	Erosion of embankment toe near spillway or low-level outlet.
Erosion by rainfall.	Erosion of downstream face of dam by rainfall and surface runoff.

equacy, uncontrolled seepage, construction deficiencies, unexpected events, and a lack of adequate maintenance.

Tables I, II and III outline the characteristics of the three failure mechanisms, their various causes, and possible preventive measures.

3.2 Reservoirs

The banks of the reservoir should be examined for undercutting, erosion, depressions, and any other evidence of the initiation of a possible slip or landslide. Depending on the size of the reservoir, a landslide could displace enough water to overtop the dam, block the reservoir, headpond, race or spillway, or reduce the reservoir capacity. All of these events could jeopardise the safety of the dam.

3.3 Earth dams

3.3.1 Upstream slope

The upstream slope of an earth dam should be examined for any sign of erosion, beaching, or slumping. These may be caused by wave action, flooding, or a rapid drop in the reservoir level.

A damaged upstream face reduces the stability of the dam by limiting its ability to resist wave action and high reservoir levels.

Surface erosion failures

Causes	**Possible preventive measures**
Inadequate spillway capacity.	Design spillway for larger flood.
Clogging of spillway with debris.	Install trash racks where possible or periodically remove debris.
Insufficient freeboard due to settlement of embankment.	Regrade crest to design elevation.
Insufficient rip-rap or incorrect grading.	Place well-graded rip-rap and filters.
Spillway outlet or low-level outlet located too close to dam.	Discharge water away from the embankment. Provide toe protection adjacent to all outlets.
Poor surface drainage and lack of adequate grass cover on the downstream slope.	Provide drains or ensure adequate grass cover on downstream face.

Table II.

Form	Characteristics
Piping	Progressive internal erosion of material from downstream side of dam or foundation in an upstream direction, eventually leading to a breach through the dam.

Table III.

Form	Characteristics
Foundation slide	Sliding of upstream and/or downstream slope with heave of foundation in direction of movement.
Upstream slide	Slide in upstream face.
Downstream slide	Slide in downstream face.

Damaged areas should be filled with well-graded rip-rap and, where necessary, filter materials. Sufficient large rocks are required to resist wave action and enough small sizes are required to fill the voids between the rocks and protect underlying materials from being washed out.

3.3.2 Crest

The crest should be examined for shape and cracks. A variation in level across the top of the dam may indicate normal settlement or possibly an underlying void. Settlement above a low-level outlet may be an indicator of poor compaction of material around the pipe, possible erosion of this surrounding material, or collapse of the pipe. Any set-

Internal erosion (piping) failures	
Causes	**Possible preventive measures**
Concentrated seepage from downstream slope.	Install toe drains or filters.
Seepage along low-level outlet/dam fill interface.	Grout along outside of outlet to fill voids, install filter and drainage protection around downstream section of outlet, replace outlet using proper construction techniques.
Leaking low level outlets.	Seal joints.

Embankment slumping failures (slides)	
Causes	**Possible preventive measures**
Soft or weak foundation.	Flatten slope. Construct berms.
Excess water pressure in foundation.	Provide drains, and filters.
Steep slope.	Flatten slope. Construct berms.
Rapid reservoir drawdown.	Avoid lowering reservoir by large amount over a short time period.
Steep slope.	Flatten slope. Construct berms.
Saturation of slope by seepage.	Provide proper drainage by installing toe filters.

tlement above or in the vicinity of a low-level outlet could have very serious implications for the safety of the structure and professional advice should be sought.

A low point on the crest may require filling to maintain the required freeboard in times of flood.

All cracks on the dam crest should be inspected carefully, and their dimensions should be noted. Each crack represents a potential leakage path for the erosive action of rain or reservoir water. Even apparently small cracks may have their true lengths and depths obscured by surface disturbance.

Transverse cracks, running upstream/downstream, are usually formed as a result of differential settlement (refer Figure 2). Deep cracks may collect rainfall and lead to erosion. Those cracks which extend from the reservoir to the downstream face usually lead to an erosion failure of the dam. Professional advice should be sought to assess the significance of any cracks increasing in size or depth.

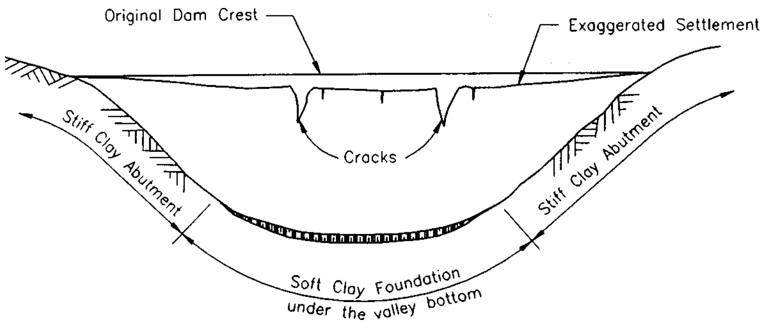
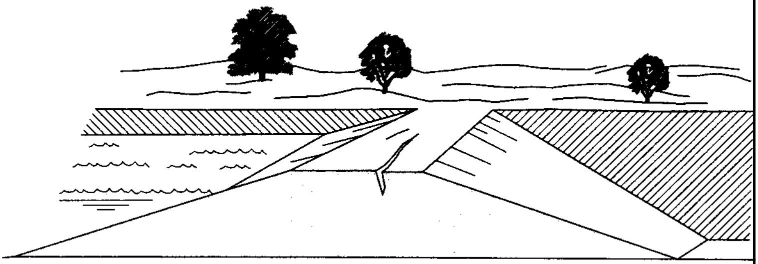


Figure 2. Transverse cracks formed by differential settlement.

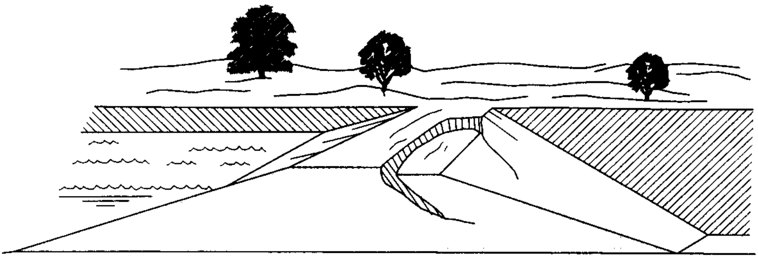
Longitudinal cracks running along the length of the dam can form on the crest or slopes of an earth dam. They usually precede the development of a slide. If the cracks do not enlarge, the situation may be stable. It is important that measures be taken to prevent rainfall and runoff from entering these cracks. However, once the material on one side of the longitudinal crack settles, the potential for a slide exists, and the dam may be on the verge of a slope failure (refer Figure 3). Expert advice should be sought in this case.

3.3.3 Downstream slope

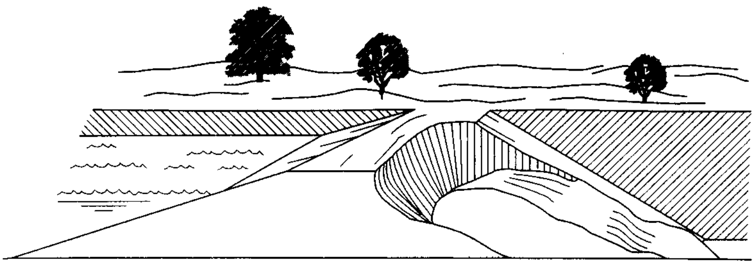
Ideally, an inspection for seepage should be made when the reservoir is at or near its highest level. Areas to be examined include the downstream slope, downstream toe, abutments, areas near spillways, and around and adjacent to outlets. Seepage areas can be identified by wet spots or muddy areas, usually accompanied by the lush growth of tussock and other grasses. Placement of stakes around the perimeter of a seepage area provides a good reference for determining if the wet area is increasing in size.



(a) Longitudinal cracks form and runoff water enters



(b) Cracks widen and the ground settles on one side of the crack



(c) The slope fails

Figure 3. Development of a slide.

Embankments and foundations are not impermeable. Therefore small amounts of seepage (not concentrated flows) do not represent a serious condition, as long as controlled drainage is provided and ponding is not allowed to occur. Excessive quantities of seepage warrant an investigation by a professional engineer.

Seepage emerging from the downstream slope (i.e. above the toe line), tends to saturate the surrounding material. This may lead to an embankment slump, since saturated soils have reduced strength. A wet area at an abutment contact may indicate a poor bond between the embankment and abutment, and a weaker zone of material which could be susceptible to failure.

Concentrated seepage is undesirable, and if particles of material are being carried by the water, "piping" may be taking place. This may be obvious from the presence of soil particles in the seepage flow or its "milky" appearance. A water sample allowed to settle in a glass jar will confirm the presence or absence of eroded soil particles.

Excessive seepage from the downstream slope, at abutment contacts and adjacent to low-level outlets, and any concentrated seepage carrying eroded soil particles requires immediate remedial action.

Erosion-proof layers (e.g. grass cover) must be maintained on downstream slopes to avoid surface erosion of embankment material by rainfall. Excessive amounts of runoff allowed to flow over downstream slopes, at abutment contacts, or along spillway channels in earth can form erosion gullies. Once an erosion gully is formed, it becomes progressively wider and deeper with successive rainfall. Continued erosion of this form can threaten the stability of a dam. Erosion gullies should be backfilled with properly compacted material. The downstream face should then be grassed or a protective layer of well-graded gravel placed on the surface to resist any future erosion.

Grass on the downstream slope helps to prevent erosion but trees and dense shrubs are hazards to small dams and should be removed. Trees and dense shrubs can:

- fall down, displace a large amount of soil, and initiate a dam breach;
- result in decayed roots and provide potential paths for piping failures;
- blow down and block the spillway; and
- hamper visual inspections.

3.4 Spillways

When more runoff water enters a reservoir than the spillway can safely pass, the spillway may be damaged and/or the dam may be overtopped.

Overtopping is the most serious risk to earth dams and the most common cause of their failure. Therefore the operation of the spillway is critical to dam safety. Overtopping is a risk which continues throughout the life of the structure.

During an inspection of a spillway, it is essential to check that it is clear of any obstacles which may impede the flow. The reservoir, approach channel, and headpond should also be free of any floating material which may be carried into and block the spillway.

Debris screens are often erected over piped spillways. These should be regularly cleared.

The spillway itself should be inspected for erosion damage from the passage of floods. Scoured areas, including those immediately downstream of the spillway where the high-velocity flow returns to the natural channel, should be promptly repaired with protective rip-rap. Spillway erosion left unrepaired can quickly lead to rapid deterioration of the whole spillway, putting the structure at risk.

Concrete spillways should be inspected for cracks and displaced slabs. During spillway operation, water can enter cracks and displaced slabs and erode the underlying materials. High-velocity water flow can also lift cracked and displaced slabs. Large cracks should be grouted or otherwise sealed, and displaced slabs should be repaired.

3.5 Low-level outlets

Where safe access is possible, piped spillways and low-level outlets should be inspected internally to ensure the pipe barrel is intact. Joints often leak, and metal pipe seams can fail. Both of these cases can threaten the safety of the dam, and specialist advice should be sought.

The crest and shoulders of the dam should be inspected directly above the low-level outlet for any evidence of subsidence. This condition could develop in two ways – a hole or crack in the pipe could provide access for water to flush out embankment material leaving a void or, alternatively, poor compaction around the pipe could provide a seepage path for water along the dam fill/pipe contact surface and result in the removal of embankment material. Both cases are potentially serious problems, and specialist advice should be sought.

Low-level outlets should be opened periodically to flush out sediment which may have accumulated at the inlet and also to demonstrate that the low-level outlet will work in an emergency.

3.6 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.

3.7 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.

3.8 Ancillary concrete structures

The inspection guidelines provided above also apply to ancillary concrete structures such as walls, slabs, anchor blocks, and foundations. Rotations, settlements, and movements may be an indicator of a hidden adverse condition. Such movements should be monitored. Natural events such as earthquakes and floods may initiate movements, and it is prudent to inspect all concrete structures after such events.

4. INSPECTION TIMES AND RECORDS

All dams should be inspected regularly under normal operating conditions and immediately following any unusual event such as first filling, a flood, or an earthquake. Suggested times for normal inspections, at specific locations and for potential problems, are summarised in Table IV.

Table IV. Suggested inspection times

Location	Potential problems	Time
Upstream slope	Slope failure.	After rapid drawdown of reservoir.
	Slope protection.	After severe winds.
Crest	Settlement.	After heavy rains.
	Tree and shrub growth.	Year round.
Downstream slope	Seepage.	During and after high reservoir levels.
	Slope failure.	During and after high reservoir levels.
	Tree and shrub growth.	Year round.
Downstream toe	Seepage.	During and after high reservoir levels.
	Bulging indicating a slope failure.	During and after high reservoir levels.
Spillway	Debris blocking spillway or trash racks.	Before spring runoff, periodically throughout the summer and after heavy rains.
	Erosion.	After heavy rains.
Low-level outlet	Piping.	During and after high reservoir levels.

To encourage the early detection and repair of any abnormalities and/or deteriorating conditions, all dam owners should prepare inspection checklists and keep inspection records for their structures.

Obviously any checklists or records should be tailored to reflect the particular characteristics of the dam and its associated structures. A suggested inspection report format for dam owners is attached.

SMALL DAM INSPECTION REPORT

File# Date:

Owner:

Location:

Inspector:

Date constructed:

Engineered by:

Last inspected:

Next inspection

1. EARTH DAM

Dam size and material

Dam height: Reservoir

Top width: Crest length:

Material:

U/S slope

Vegetation: Condition:

Comments:

U/S protection

Size: Condition:

Comments:

D/S slope

Vegetation: Condition:

Seepage:

Comments:

2. OUTLETS

(a) Pipe

Location: ______________________________

Condition: ______________________________

Type: ______________ Size: ______________

Inlet: ______________________________

Outlet: ______________________________

Barrel: ______________________________

Valve / Gate ______________________________

D / S ______________________________

Comments: ______________________________

(b) Spillway

Location: ______________________________

Condition: ______________________________

Type: ______________ Capacity: ______________

Inlet channel: ______________________________

Bed width: ______________________________

Head walls: ______________________________

Floor slab: ______________________________

Chute walls: ______________________________

Wing walls: ______________________________

Outlet ______________________________

Drains: ______________________________

D / S ______________________________

Comments: ______________________________

(c) Emergency spillway

Location: ______________________________

Condition: ______________________________

Type: ______________ Bed width: ______________

Comments: ______________________________

3. ABUTMENTS

Erosion: ______________________

Seepage: ______________________

Condition: ______________________

Comments: ______________________

____

____

4. RESERVOIR

Use: ______________________

Level: ______________________

Source of supply: ______________________

Drainage ______________________

Condition: ______________________

____

____

5. CONDITION D/S OF DAM

Channel ______________________

Vegetation: ______________________

Habitation: ______________________

Structures: ______________________

Tributary to: ______________________

Comments: ______________________

____

____

6. REPAIRS RECOMMENDED

____

____

____

7. PHOTOGRAPHS

____

____

8. LICENCEE

Address: ______________________________________

____

Phone:

Work: ____________________ Home: ____________

9. SKETCHES AND ADDITIONAL COMMENTS