World Bank / Lake Chad Basin Commission

APPRAISAL OF THE SAFETY OF MAGA DAM, CAMEROON

March 2002

Contents

1 INTRODUCTION

1.1 BACKGROUND

The Maga dam was constructed in 1979 as part of the second SEMRY project, the object of which was to expand and improve the cultivation of rice. The scheme that was constructed comprised a 7,000 ha rice plantation irrigated with water supplied by the Maga reservoir, which, with its associated flood protection dikes, also served to protect the plantation against annual floods from the Logone river.

The scheme was constructed at the onset of a prolonged drought and had undesirable consequences on the environment and the social economy of the wetlands downstream. As part of a recent drive to address these problems, which are widespread in the Lake Chad Basin, the Lake Chad Basin Commission (LCBC) commissioned a project entitled "The Reversal of Land and Water Degradation Trends in the Lake Chad Basin" This project comprised, *inter alia* six pilot projects, one of which was devoted the problems of the Waza Logone flood plains in which Maga dam is situated.

During the field work that was undertaken as part of environmental and social components of this pilot project the apparent hazard posed by the Maga dam was noted[1], and as a result the World Bank commissioned Mr L J S Attewill of Jacobs GIBB Ltd to prepare this appraisal of the safety of Maga dam.

1.2 TERMS OF REFERENCE

The terms of reference for this appraisal and that of two dams in Nigeria are included as Annex A to this Report.

1.3 PREVIOUS STUDIES

Previous studies consulted for this appraisal are:

- The Waza Logone Flood Restoration Study by Delft Hydraulics in 1994[2]. This study, funded by the IUCN, examined the various options by which the floodplain could be restored. Two options, C &D, involved a new spillway through the left abutment of Maga dam to take water directly to the western side of the flood plain. Both these options were found to be economically feasible.

- The Logone Floodplain Model Study Report by Mott MacDonald in 1999[3]. This report describes the mathematical model of the Logone floodplain and of the modelling of various options for the restoration of the floodplain. The study recommended that the floodplain could best be restored by an option which involved increasing the capacity of the Mayo Vrik to 100m^3/s. The Delft preferred option was not modelled.

- The Rehabilitation of the Waza-Logone Floodplain: Proposals for the Re-inundation Programme, by the IUCN in 2000[4]. In this report three further proposals, all economically feasible, for re-inundation were considered. The most expensive option involved increasing the capacity of Mayo Vrik to 100m^3/s.

1.4 PROGRAMME OF WORK

Mr Attewill's itinerary for this appraisal was as follows:

Thursday evening	28th February	Arrive N'Djamena
Friday morning	1st March	At LCBC offices in N'Djamena
Friday afternoon		Travel to Marua, Cameroon
Saturday	2nd March	Dam inspection
Sunday morning		Dam inspection
Sunday afternoon	3rd March	Discussions with Waza Logone Project staff
Monday	4th March	Returned to N'Djamena

1.5 ACKNOWLEDGMENTS

Mr Attewill wishes to acknowledge with thanks the contribution, assistance and support provided by the following:

LCBC staff

Mr Adamu – Executive Secretary
Mr Tochin – Administrative secretary
Dr Oguntola – Chief, Water Resources Unit
Mr Tchangtauf - Driver

Waza Logone Project staff

Mr Roger Kouokam – Chief DPP
Mrs Micheline Nono – Assistant Finance officer
Mr Emile Yanze – Logistics officer

SEMRY staff

Mr Yaye Zigla – Chief of the Unite des Travaux ret des Services

2 DESCRIPTION OF THE DAM

2.1 ACCESS

The Maga dam is situated some 85km east of the town of Magua, as shown in Figure 2.1

2.2 SCHEME LAYOUT

The SEMRY 2 scheme, of which the Maga dam is a part, comprises:

- the 27 km long Maga dam, with a maximum height of 6m. The dam extends from the village of Guirvidig in the west (left abutment) to Pouss in the east (right abutment)
- associated dikes along the left bank of the Logone, extending for 100km from Yagoua to Tekele, upstream and downstream of Pouss respectively
- the Djafga canal, which connects the river Logone and the upstream end of the reservoir
- a 750m long spillway which provides a hydraulic connection between the reservoir and the Logone river
- the main offtake at Maga and four smaller irrigation offtakes
- the 7000 ha irrigation area
- the Mayo Vrik which provide the main drainage to the area

The scheme layout is shown in Figure 2.2

2.3 HYDROLOGY

2.3.1 Reservoir characteristics

The characteristics of the reservoir are as follows:

		Reference
Full storage level	312.5m	Level given by SEMRY: 312.72 is shown on a the 1:200,000 Sogreah plan (Fig 2.2)
Minimum operational level	310.8m	Level given by SEMRY
Area at full storage level	400 km²	Mott MacDonald estimate
Volume at full storage level	680Mm³	Volume given by SEMRY
Volume at minimum operational level	280Mm³	Volume given by SEMRY
Direct catchment area	6000 km²	Author's estimate (very approximate)

A tentative height storage curve is shown in Figure 2.3

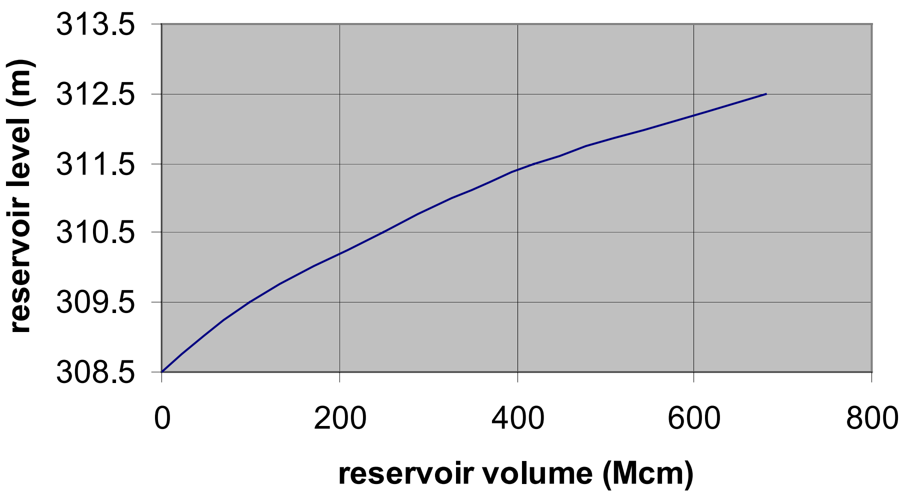

Figure 2.3: Maga reservoir height storage curve

2.3.2 Direct catchment inflows

Five ephemeral streams known as mayo, drain the direct catchment area, of which two main mayo, the Tsanaga and the Boula, whose catchments extend as far east as the Mandara mountains to the west. No data were available on their mean annual inflow. These mayo flow from August to October and are dry from November until July.

2.3.3 Indirect catchment inflows

Water flows into the reservoir from the Logone through three connections:

- The Mayo Gouerlou
- The Djafga canal
- The spillway

Inflows to the reservoir via the mayo Gouerlou and the spillway are uncontrolled. Inflows via the canal are controlled by an upstream weir and four 2.4mx1.78m sluice gates so as to maintain the reservoir level between 312.10m and 312.19m from mid October to mid February.

2.3.4 Floods

No flood data for the direct catchment were available for this appraisal.

Daily flows of the Logone river have been measured at Bongor, 75km upstream of Pouss, since 1948. A plot of the annual maximum flows is presented in Figure 2.4. This plot shows the marked reduction in flood peaks since the 1970's.

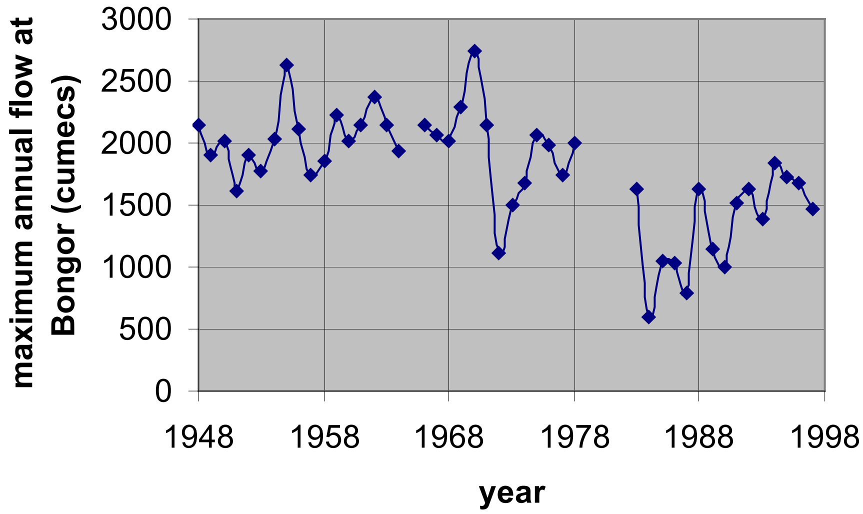

Figure 3.4: annual maximum flows at Bongor

2.3.5 Evaporation

Annual evaporation from the reservoir is estimated at 1.85m, with the daily rate varying between 3mm in August to 7mm in March-May: SEMRY estimate the annual loss of water from the reservoir to be 200Mm³.

3 THE INSPECTION

3.1 EMBANKMENT

3.1.1 Geometry

No construction details or drawings of the embankment were available for this appraisal. The embankment appears to be a homogeneous embankment of compacted silty clay, with the following dimensions:

- crest level: 314.25m
- crest width: 3m
- upstream slope: 1v: 5h
- downstream slope: 1v : 2h

With the nominal crest level of 314.25m and a reported maximum reservoir level of 312.5m the minimum freeboard would be 1.75m. The actual level varies considerably and in many places the minimum freeboard was observed to be considerably less than 1.75m. A level survey of the embankment crest is recommended.

3.1.2 Construction

For an embankment of this length it is most unlikely that the embankment fill was taken from one or more borrow areas: it is much more likely that the material was excavated from within the reservoir area, immediately upstream of the embankment. The evidence for this, in the form of a lagoon running the length of the dam, was clearly visible at the time of the visit. The fill material is a silty clay.

Similarly, it is probable that only the top layer of organic soil was stripped to a standard depth by way of foundation preparation before embankment filling. It is possible that a cut off trench was dug to reduce seepage, but prevailing high groundwater levels would have made the excavation and filling of anything but a shallow trench difficult.

3.1.3 Crest

The crest level is variable, which probably results from variations in the quality of the foundations resulting in post construction settlement. In addition there are regular dips of about 20cm in the crest level at the points where access ramps have been built up the downstream slope perpendicular to the dam axis. These ramps occur at approximately 100m centres.

3.1.4 Upstream slope

The upstream slope is not protected against wave attack except in the immediate vicinity of the outlet structures. As a result wave action, which is particularly severe in August and September when the reservoir is at its highest, has eroded material from the upper part of the upstream slope and deposited it at lower levels, as illustrated in Figure 3.1 and Photograph 1. This classic erosion process has already shortened the length of the seepage path at reservoir full conditions and will undoubtedly continue until the entire crest is eaten away, unless action is taken.

Figure 3.1: typical embankment cross section

Photograph 1: erosion of upstream shoulder
(photo credit: Nicholas Hodgson)

3.1.5 Downstream slope

The downstream slope shows no sign of instability but has suffered moderate erosion from rainfall. There is no sign of damage by burrowing animals and at the time of the visit the downstream slope and the natural ground between the road and the downstream toe appeared to be dry. However this strip of ground is widely reported to be wet when the reservoir is full.

3.2 HYDRAULIC STRUCTURES

3.2.1 Spillway between the reservoir and the Logone

The spillway comprises a 750m long concrete cill set into the ground at 312.19m level, as shown in Photograph 2.

Photograph 2: Maga/Lagone spillway in the dry season

The local guardian reports that the cill is submerged every year, with water flowing from the river into the reservoir towards its upstream end and from the reservoir into the river at its downstream end. This phenomenon is explained by the disparity between the gradient of the water level in the river (about 1: 7500) and the horizontal water level in the reservoir. Photograph 3, taken on October 7th 2001 after the flood peak, shows water flowing out of the reservoir. During a major flood the river levels would be such that the flow would be into the reservoir along the entire length of the spillway.

Photograph 3: flow from the reservoir into the Logone at the northern end of the spillway. *(photo credit Nicholas Hodgson)*

3.2.2 Main outlet works

The main outlet works discharge into the Mayo Vrik and is situated at chainage 11+65km. The structure comprises five outlet culverts, each controlled by two 1.4m x1.4m sluices with a maximum capacity of $10m^3/s$ each, giving a total capacity of $100m^3/s$. However the downstream discharge channel is partially blocked by vegetation and sediment deposits and its total capacity is reported to be only $6m^3/s$. The condition of this structure is good.

3.2.3 Irrigation outlet works

There are four separate irrigation outlet works situated at the following chainages (measured from the left abutment):

- 7+55km
- 15+6km
- 20+5km
- 26+5km

Each outlet comprises a concrete structure with two 2m x 2m sluices, each with $10m^3/s$ capacity, discharging into a concrete lined stilling basin.

4 THREATS TO THE INTEGRITY OF THE DAM

4.1 EMBANKMENT STABILITY

4.1.1 Upstream

The upstream slope of the embankment was constructed with a gentle slope and apart from the erosion damage which is discussed below shows no sign of instability.

4.1.2 Downstream

Although the downstream slope has been constructed to a relatively steep slope there are no signs of any instability. Should the upstream slope and crest continue to erode the pore pressures in the downstream shoulder will increase during increased periods of high reservoir level and slope and the risk of instability of the downstream slope will increase.

4.2 EXTERNAL EROSION

4.2.1 Waves

If no action is taken wave erosion will continue until the crest of the embankment is eventually breached and the dam overtopped. To prevent this the damaged sections should be repaired with compacted fill and the entire slope protected with stones between elevations 312m and 313m.

Alternatively, or until this can be achieved, the maximum reservoir level should be restricted to 312.2m.

4.2.2 Rainfall

The erosive effect of rainfall is not severe at present but should be kept under close scrutiny: any area of the downstream slope where the erosion becomes particularly severe should be repaired with compacted fill.

4.2.3 Overtopping

In the absence of any flood studies it is difficult to assess the threat posed by overtopping. The maximum annual flow data presented in Figure 2.4 shows that the maximum flood that has occurred in the Logone since the dam has been constructed was in 1994 when the peak flow at Bongor was 1840m^3/s. Unfortunately the records of river level at Pouss were not available for inspection so it is not possible to know what the peak flow or river level were at Pouss at that time. It is clear however that even the modest flood peaks that have occurred in the lifetime of the dam have caused the reservoir level to rise to at least 312.5m, leaving a freeboard of less than 1.75m . The 1994 peak flow was only 67% of the maximum recorded peak flow (2740m^3/s in 1970) which itself should not be regarded as a particularly severe event. It would seem to be probable that the return period of a flood in the Logone that would result in the embankment being overtopped may be relatively low, possibly as low as 1 in 100 years.

The situation is rendered even more complicated by the direct inflow into the reservoir of the Mayo Boula and the Mayo Tsanaga. The author is not aware of any flood study that has been carried out on these Mayo.

The ability of the embankment to resist erosion from overtopping is also difficult to assess: the embankment is constructed of clay which by its nature is resistant to flowing water and because the dike is very long the flow per metre length would also be low. This would imply a shallow depth of water over the embankment crest – perhaps only a few centimetres, and a low water velocity. It should also be considered that a major flood in the Logone may also overtop the flood protection dikes downstream of Pouss so that the entire area, including Maga would in any case be inundated.

However such considerations are always speculative and in the case of Maga dam, which is unusually complicated hydraulically, especially so. The wisest policy is therefore to prevent overtopping by means of additional spilling capacity. This can be achieved either by restoring the original capacity of Mayo Vrik or by constructing a new spillway near the left abutment. A detailed flood study would be required to determine the spillway capacity required to prevent overtopping for the design flood, which should be taken to be not less than 10,000 year return period.

4.3 INTERNAL EROSION

Anecdotal evidence suggests that there is considerable seepage through the embankment and possibly its foundations when the reservoir level is above 312,2m level. All dams suffer from seepage and seepage in itself is not necessarily a problem. The problem arises if the seepage velocities are such as to erode material and thus create a void in the embankment. Embankments composed of silt are especially vulnerable, clay embankments such as Maga less so. The classic means of controlling internal erosion are either to prevent the migration of solid particles by means of internal filters or to limit the hydraulic gradient so that seepage velocities are kept low. Maga dam was not designed with internal filters so the second option is the only one available. With the original embankment geometry the maximum hydraulic gradient would have been 1 : 8, which is safe. However the effects of the erosion of the upstream slope and the dam crest have shortened the seepage path length with the result that at full reservoir level the hydraulic gradient has increased to1 : 5. Further erosion will result in increases in the hydraulic gradient so that if the embankment does not first fail by sliding it will fail by internal erosion. It is therefore imperative to either repair the erosion damage or to reduce the maximum reservoir level.

5 EMERGENCY PLANNING

5.1 RESPONSIBILITY

It is understood that Cameroon Law holds the dam owner responsible for the safety of his dam. In the case of Maga the dam is owned ultimately by the Ministry of Agriculture through their wholly owned subsidiary SEMRY.

5.2 SURVEILLANCE

Although there is no formal safety plan at Maga, the daily records are kept of the reservoir level and periodic inspections are made of the embankment. Unfortunately the inspection was made at the weekend without any warning having been given to SAMRY, with the result that the record of reservoir levels was not available. M Yaye Zigla, the Head of the Unite des Travaux et des Services (UTS) was very helpful in providing a description of the surveillance provided by SAMRY and the dam safety issues.

5.3 POPULATION AT RISK

The total population of the Maga scheme is estimated by SAMRY to be 20,000. However many of these people live distant from the dam would not necessarily be at risk in the case of a dam failure. Because the area downstream of the dam is so flat, the escaping water would spread over a large area with relatively low velocities and depth. Therefore it is reasonable to suppose that only the population living close to the dam would be at risk of their lives. Clearly the most vulnerable population is that of Maga village, because not only do they live close to the dam but also the dam is higher adjacent to the village than elsewhere. The population of Maga is thought to number several thousand people.

5.4 WARNING SYSTEM

There is no formal warning system at Maga.

Warning systems work best when they can provide the population advance warning of a possible emergency so that they can retreat to a safe haven on adjacent high ground. They are usually triggered by a monitoring system that has identified unusual and unexplained signals. At Maga there is no monitoring system other than the vigilance of the local population and no adjacent high ground to retreat to.

However, as has been discussed in section 4 above, the most likely cause of an emergency at Maga would follow from unusually high reservoir levels of which the population at risk would be acutely aware.

5.5 EMERGENCY PREPAREDNESS

5.5.1 Routine maintenance

The annual budget available for the maintenance of all ten dams owned by the Ministry of Agriculture is F CFA 200million. The exact amount allocated to Maga dam is not known but assuming all their dams face similarly acute problems, it will approximate to F CFA 20 million or US$27,000

The SEMRY UTS have at their disposal the following plant in operational order:

- 1 scraper

- 2 bulldozers
- 2 trucks
- 1 loader

The use of this plant is often constrained for lack of funds for consumables – fuel etc, but effort appears to be concentrated on emergency repairs and preventive work during August – October when the reservoir level is at its highest. As an example, M. Zigli recounted that last year they had carried out emergency repairs to five points on the dam where there was excessive seepage.

5.6 CONCLUSION

The senior SEMRY manager resident at Maga, M Zigli understands his immediate responsibility for the safety of Maga dam and works hard to discharge that responsibility. He is of course severely restrained by lack of financial resources, but some technical assistance and a relatively small budget specifically allocated to dam safety would yield significant returns in terms of dam safety.

6 CONCLUSIONS & RECOMMENDATIONS

6.1 THREATS FACING THE DAM

There are two main threats facing the integrity of the dam:

1. continued erosion of the upstream face and crest of the embankment duse to wave attack at high reservoir levels. If this continues unchecked it will result in one of the following
   - overtopping
   - sliding failure of the downstream slope
   - piping failure

2. overtopping of the embankment by a severe flood which would probably result in a breach of the dam.

6.2 RECOMMENDATIONS: DAM SAFETY

6.2.1 Wave erosion

There are two options that could be adopted to prevent the failure of the dam as a result of wave damage, neither of which are easy or straightforward:

1. to repair the damaged portions of the embankment and protect the vulnerable zone of the upstream face, between levels 312 and 313m, against wave attack. This is the standard design imperative for the vast majority of embankment dams
2. to impose a limit on the maximum allowable reservoir level of 312.0m, some 0.5m lower than at present. This would result in the following:
   - waves will break on the flatter slope of the embankment below the eroded cliff. The flatter slopes will be effective in dissipating wave energy
   - the longer seepage path will reduce the hydraulic gradient and thus reduce the risk of piping failure

The repair and protect solution would of course be very expensive. The repairs would involve the excavation of the damaged portions and the replacement of clay fill compacted to the correct density and moisture content. The protection would involve the placement of at least three layers of granular fill: a layer of sand adjacent to the clay, a transition layer of coarse gravel or crushed rock and finally a layer of large rock or rip-rap. Alternatively a protective system involving precast concrete blocks placed on a geofabric could be considered. Even if only 10% of the upstream face requires to be treated, the total cost, whichever solution were adopted, would cost several million US dollars and would take several years to implement. Ultimately, of course, it may be necessary to treat the entire 27km length of the embankment.

Lowering the maximum allowable reservoir level would reduce the volume of water available for irrigation by approximately 100Mm^{3}but would be entirely effective in improving dam safety. The difficulty is how can the reservoir be controlled. The vast majority of the inflows into the reservoir – the inflow of the Logone over the spillway and the direct inflows of the Mayos Tsanaga and Boula cannot be controlled or even accurately measured. The only available means of reservoir level control – releases into Mayo Vrik – is quite ineffective. Thus controlling the reservoir level requires either increasing the capacity of the controllable outflow or by reducing the inflow.

The outflow capacity can only be increased by either dredging the Mayo Vrik or by costructing a new outlet structure as envisaged by Delft Hydraulics.

Inflows can only be reduced by raising the crest level of the 750m long Maga/Longone spillway and reinforcing the flood protection dikes further upstream as necessary.

Either of these options would be expensive, and like the repair-protect option would take several years to implement.

6.2.2 Floods

The vast majority of embankment dams are provided with a spillway to evacuate extreme floods so as to avoid overtopping. Maga dam is different from usual dams in that the maximum reservoir level will depend almost totally on the river level at Pouss rather than the volume of the inflow. Although a detailed flood study would be required to give a reliable estimate of the return period of the overtopping flood it is likely to be low (that is probable). Again there are two solutions available:

1. reduce inflows by raising the Maga/Logone spillway crest as discussed in 6.2.1 above and evacuate floods emanating from the direct catchment through the existing outlet structure into Mayo Vrik, suitably dredged.
2. construct a new spillway towards the left abutment near the village of Guirvidig

A flood study would be required to confirm the details of

- the height to which the spillway should be raised
- the capacity required in Mayo Vrik
- the capacity of a new left abutment spillway

It is considered that dredging Mayo Vrik, which in many ways is highly desirable, would not alone provide sufficient capacity to control the reservoir level in the event of an extreme flood.

The first option, dredging the Vrik and raising the spillway crest level, is a major undertaking which would require several years and many millions of dollars to implement.

The left abutment spillway could be a relatively cheap undertaking, comprising a break at a point where the embankment is 2-2.5 m high. The spillway would be uncontrolled and the crest would be simply a concrete wall as at the Maga/Logone spillway, but set a little lower at about 312m. It would be necessary to excavate a shallow unlined channel to direct the flow clear of the SEMRY estate, possibly using the Arezilmatay channel shown in Figure 6.2 of the Delft report and Figure 6.1 of this Report.

6.2.3 Conclusion

Option	Solution for Embankment erosion	Solution for Overtopping flood
Repair of embankment and protection against wave attack	✓	
Controlling max reservoir level by raising Maga/Logone spillway + dredging mayo Vrik	✓	✓
Controlling max reservoir level by constructing new left abutment spillway	✓	✓

Only two options would ensure that the dam is safe against both threats. The first, raising the Maga/Logone spillway, would in effect attempt to isolate the reservoir from the river by construction a new dam along the left bank of the river. This would concentrate all the flood flow of the Logone to the east of Pouss and would thus raise flood river levels.

The second option effectively provides more flood capacity and thus alleviates the constriction at Pouss. The left abutment spillway could be constructed relatively quickly and cheaply and could form the first stage of the option recommended by Delft in their Flood Restoration Study.

6.3 RECOMMENDATIONS: SAFETY PLAN

6.3.1 Monitoring

It appears from the meeting with M Ziogli that SEMRY is already carrying out the basic monitoring tasks. These however should be formalised and the results made more accessible. Essential records that should be kept are:

- Daily readings of reservoir and river level
- Weekly readings of controlled inflows through the can sluices and outflows
- Records of walk over inspections – monthly in the dry season, weekly or even daily at high reservoir level
- Record of all remedial or preventive works undertaken

In addition it is recommended that a detailed level survey of the embankment crest should be carried out.

These records should be kept in a record book at the SEMRY office. In many countries the law requires that such records should be checked for compliance annually by an external inspector: a similar provision should be adopted at Magra.

6.3.2 Early warning

Consideration should be given to the installation of a manually controlled siren situated at the Vrik outlet to provide the most vulnerable population of a warning of a dam burst.

6.3.3 Emergency stockpiles

Emergency stockpiles of materials and consumables should be maintained so that they are readily available should the need arise. The following are considered essential:

Materials	*Consumables*
- Clay fill	- diesel
- Sand	- spares
- Gravel	
- Sand bags	

References

[1] Lake Chad Basin GEF Project: "Integrated Environmental and Social Assessment" - January 2002

[2] Delft Hydraulics for IUCN: "Waza Longone Flood Restoration Study" – June 1994

[3] Mott MacDonald: "Logone Floodplain Model Study Report" – May 1999

[4] IUCN: "Rehabilitation of the Waza-Logone Floodplain: Proposals for the Re-inundation Programme" – May 2000