Pakistan, Gilgit - Baltistan

Attabad Landslide Dam – Risk Management Suggestions

At the request of Government of Pakistan (GoP) and Aga Khan Foundation (AKF), a World Bank mission composed of Mr. Alessandro Palmieri (Lead Dam Specialist, OPCQC) and Mr. Haris Khan (Natural Hazard Specialist, SASDU) visited the Attabad Landslide Dam over 14-15 March 2010. The mission debriefed GoP and AKF on its findings and suggestions on 17 March in Islamabad. This report summarizes the mission's findings and suggestions.

Executive Summary

- *Strengthen and expand existing measures being undertaken on mitigation by partners with more Government involvement.*
- *Ensure Strategic Planning of ongoing construction works within a risk management context.*
- *Urgently define alarm levels, with GoP taking the lead on it.*
- ***Recommended Course of Action**: Engineer the dam to resist overtopping this year, and drain the lake after the flood season.*
- *Blasting should be considered only as a last resort/backup plan to the recommended course of action above.*
- *Current situation of seepage is not yet of concern. However the phenomenon should be kept under close watch and control as seepage outflow areas could move closer to the toe of the dam, emerge on the downstream slope, or seepage rates could significantly increase as lake levels raise.*
- *Dam overtopping cannot be avoided, therefore it must be managed. Management requires the following:*
  - *a) Forecast the overtopping date;*
  - *b) Prepare engineering design and construction plans for the overtopping area, referred to as "spillway" in the following; and*
  - *c) Implement construction plans with the time constraint indicated by the best estimate of the overtopping date.*
- *Ensure presence of a full time experienced dam engineer to coordinate the above activities - strongly recommended.*
- *Undertake strategic risk management planning for:*
  - *a) Awareness and early warning of community downstream;*
  - *b) Planning and managing dam engineering activities, and ;*
  - *c) Informing upstream communities of expected lake level.*
- *Improve existing monitoring systems*
- *Commence post emergency planning.*

References

[1] Petley D., March 4, 2010
The landslide at Attabad in Hunza, Gilgit/Baltistan: current situation and hazard management needs. Initial indicative report prepared for Focus Humanitarian Assistance, Pakistan, based upon a rapid field assessment on February 26 – March 4, 2010.
Author: Professor David Petley, International Landslide Centre, Durham University, United Kingdom
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[2] A. Palmieri and H. Khan site visit, March 14-15, 2010

1. General on Risk Management

Two parallel sets of actions are used to manage risk:

a) Minimize consequences of lake outburst by means of non-structural measures; and
b) Reduce probability of failure by means of structural measures.

It is essential that the two lines of actions are implemented in parallel, and cross-fertilize each other. While this is being done at the Attabad Landslide dam, current measures and provisions need significant improvement and strengthening. Activities are underway on both lines, with GoP largely dealing with structural measures, and Focus Humanitarian Assistance (FHA) dealing with consequence minimization.

There is a clear need to:

a) Strengthen and expand existing activities of work with more GoP involvement; and
b) Undertake strategic planning of ongoing construction works within a risk management context.

This Report examines the two aspects and provides suggestions for consideration by the GoP. Given the clear emergency situation, the mission strongly advises that urgent consideration should be given to the suggestions.

2. Minimizing Consequences of Lake Outburst

GoP should increase its involvement in monitoring and early warning activities. FHA has put in place a simple but efficient system which requires strengthening and extension downstream of Gilgit along the river.

Definition of alarm levels requires urgent attention, and GoP needs to take the lead on that. Useful suggestions in that regard are contained in ref [1] and summarized in Annex 3.

3. *Decision Making Framework*

Presently, three options can be identified which are to be considered by decision makers in relation to the best course of action for risk mitigation.

Option	Risks	Rewards	Assessment
a) Engineer the dam to resist overtopping this year, and drain the lake after the flood season	Time not enough for adequate spillway reinforcement; extremely high floods could still breach the dam.	Economic losses can be minimized, allowing faster recovery of affected communities.	**Recommended option**
b) Blast the dam	High probability of ineffective blast; hazard could increase. People could be secured, but economic losses cannot be avoided.	If successful, could quickly remove the hazard.	**To be considered only as a last resort, and a backup plan to option (a) above.**
c) Do nothing; leave dam as it is	Overtopping would occur in the height of the flood season, with devastating effects in terms of economic losses. Even with the best warning efforts, causalities could still occur.	Minimum costs involved	**Should not be considered**

This Report focuses on option (a). Some considerations on option (b) are provided in the following section.

4. *Blasting*

In a few cases globally, recourse has had to be made to blasting to drain hazardous barrier lakes. Those cases involved very remote areas, where it was impossible to mobilize construction equipment. In the case of Attabad, blasting is not recommended for the following reasons:

a) Smooth blasting techniques (starting drilling for high up on both dam abutments, directing blasts towards the spillway channel, removal of debris from the channel, etc.) would require too much time. Therefore, heavy blasting (coyote blasting, or the like) would have to be used.

b) Heavy blasting is very likely to trigger further mass movements which would aggravate the situation.

c) The body of the dam has a lot of voids, especially in the upper part, and those voids would vent blasting gas, largely reducing blast effectiveness.

d) Since there is a very high probability that blast holes would cave, the chance of choked blasts or partial firing is very high. The attempt could thus fail and would leave explosive material in the dam body, making it impossible to undertake any further work .

If for unavoidable reasons, decision is made to blast through the dam, assistance should be sought from experts who have done similar works. There is extremely limited expertise in the world, with perhaps China with relevant experience following the successful Tangjashan Lake drainage (June 2008). **However, it needs to be reiterated that blasting should be the last resort, after having done all possible efforts to implement the above described dam engineering measures.**

5. Reducing Probability of Lake Outburst

5.1 Critical failure mechanisms

Site visits on March 14-15, 2010 confirmed the observations of ref. [1] in terms of current situation of the landslide dam. Such conditions are summarized in Annex 1. A panoramic picture of the dam is shown in Annex 2. FHA monitoring team have prepared sketches of the internal composition of the dam body, largely based on visual observations, slope failure reconstruction, and evidence from other mass movements in the area.

Four critical failure mechanisms, with the potential of causing lake outburst are described in the following table:

Failure mechanism	Description	Remarks
1. Overtopping	Uncontrolled overtopping would lead to dam toe erosion and rapid deepening of the saddle area in the form of a breach.	Failure would require from less than 1 hour to a few hours, resulting in very high flood discharges.
2. Internal erosion	Water seeping from the lake finds area of low hydraulic resistance and exits from the downstream slope with a hydraulic gradient high enough to remove soil particles from the body of the dam. This would result in progressive erosion, slope failure, and ultimately overtopping.	Can be detected at early stages by adequate monitoring and, to some extent, counteracted. If failure develops, similar effects as overtopping would develop.
3. Mass movements	Landslides and rock falls in the lake can create waves which could overtop the dam.	Overtopping might not necessarily result in an outburst, depending on wave height and available freeboard.
4. Earthquake	Dam crest settlement due to dynamic shaking, and earthquake-induced mass movements could lead to overtopping.	Same as above.

Preventive measures can be implemented in relation to failure mechanisms 1 and 2. Such measures can partly reduce probability of failure associated with mechanisms 3 and 4. Monitoring and early warning are relevant to all of them.

Overtopping is by far the most risky mechanism, because:

a) River flows are such that overtopping of the dam is certain during the flood season, and
b) It represents the common mode of failure for all four mechanisms.

Overtopping is dealt with in greater detail in section 5.3.

5.2 Internal Erosion Mechanism

Seepage rates are regularly monitored by FHA, albeit with rudimentary methods. Maximum seepage rate so far is in the order of 0.5 m3/s. Location of current (March 15, 2010) areas of seepage outflow is far for the dam toe. Moreover, part of the seepage is associated with drainage of the fine materials entrapped in the body of the dam, which is probably the main reason for the observed turbidity. Current situation is therefore not yet of concern. However, the phenomenon should be kept under close control, because seepage outflow areas could move closer to the toe of the dam, or emerge on the downstream slope, and seepage rates could significantly increase as lake levels rise.

The following indicators are recommended for use in identifying and classifying emergency situations associated with internal erosion (see also annex 3).

Indicator	How to measure	Triggers/ Threshold values
Seepage gradient	Ratio between seepage head (lake level minus elevation of outflows) and length of minimum flow path	Value of concern: 0.1, or 10% Critical value: 0.3, or 30%
Distance of outflow from dam toe	Direct measurement	Rapid changes of location
Seepage rate	Improve measurements with installation of calibrated V notch weir.	Plot discharge against lake levels; accelerating seepage rates, uncorrelated with lake levels, require attention.
Turbidity increase	Use turbidity meter (conductivity kit) to appreciate increases which visual observations cannot.	Plot turbidity (ppm) against lake levels; accelerating turbidity levels, uncorrelated with lake levels, require attention.

The following measures should be ready to react to any triggering:

a) Sand bags, to be placed around areas of water boiling, should that happen too close to the dam toe;

b) Stockpiles of soil material suitable for the construction of a reverse filter in areas where excessive turbidity is observed. Three classes of soil material should be available: Class A - sand size; Class B - sandy gravel (dmax 50mm); Class C - coarse gravel and boulders (dmax 200mm). Such materials should be stacked and compacted, with class A at the bottom, and class C at the top. Adding extra weight on the top of class C (by larger boulders) is recommended.

Should such measures prove ineffective, the alert system (see Annex 3) should be activated.

5.3 Overtopping Management

Since overtopping cannot be avoided, it must be managed. Management requires the following:

a) Forecasting the overtopping date;
b) Prepare engineering design and construction plans for the overtopping area, referred to as "spillway" in the following; and
c) Implement construction plans with the time constraint indicated by the best estimate of the overtopping date.

A positive element at Attabad is that earth moving equipment was already working on the Karakorum Highway (KKH), and could therefore be quickly mobilized. Earthworks started soon after the landslide took place and involved:

a) Opening an access road to the saddle[1] area of the dam;
b) Removing larger blocks from the saddle area; and
c) Starting excavation of the spillway channel.

Activities are directed by the Pakistan Army using road equipment of the Chinese Contractors who were working on the Karakorum Highway. Works were in progress at the date of the visit. The structural measures carried out so far are the right ones in terms of priority; what is now required is strategic planning along the lines described above.

Overtopping date: Suggestions pertaining to forecasting the overtopping date are contained in Annex 4.

Preparation of Engineering Design and Construction Plans: For the spillway to minimize lake outburst likelihood, design criteria should, as much as possible, conform to those of a proper spillway of a man-made dam. However, given the largely unknown composition of the dam and the severe time constraints, it will be necessary to accept significant trade-offs between fully satisfactory engineering design and speed of construction.

Two design layouts should be developed:

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[1] It is the area of minimum elevation along the crest of the dam and, consequently, the area with lower freeboard.

a) Best achievable spillway layout, and
b) Minimum acceptable spillway layout.

Suggestions pertaining to the two layouts are described in the following table. Measures highlighted in bold represent essential design elements that need to be given priority in the implementation plan. Sketches in Annex 5 help visualize the recommended reinforcement measures.

Best achievable layout	Minimum achievable layout	Remarks
Spillway level as low as possible, preferably not more than 30 m above river bed.	Whatever spillway achieved to the date of overtopping	Controlled by forecasted overtopping date.
Spillway width is not less than 40m.	**Spillway width is not less than 40m.**	Current excavations have that width; further deepening should not reduce with below 40m.
Spillway slopes are not steeper than 45 degrees (1:1).	Spillway slopes steeper than 1:1.	May require re-handling of slopes above spillway channel.
Dam toe adequately protected from erosion in the energy dissipation area at the end of the spillway chute.	**Dam toe adequately protected from erosion in the energy dissipation area at the end of the spillway chute.**	Protection over a length of at least 50 m, by placing large rock blocks (D>2m) in the muddy material until they reach solid bottom and/ or emerge on the surface; place additional layer of mixed size blocks (0.5<D<2m) to a thickness of at least 2m; build wall at downstream end of the toe protection, using large blocks (D>2m) to at least 2 m above protection level.
Spillway invert has reached granular material and the latter has been strengthened by cement admixture and compaction (hardfill)	Spillway invert compacted only	Hardfill specs: cement content 100 kg/m3, target density 2 t/m3. Two layers of 0.5 m, compacted with at least four passes of dozer. Maximum rock particle 0.25m.
Spillway slopes have been protected with gabions or rip-rap to a height of at least 5m, and slope toes to a distance of 3m from the base of the slopes.	Slope toes protected only.	Rock-filled gabions are preferred, in alternative large size rock blocks (D>0.5m) should be used.
Reinforcement to upstream end of spillway channel	No reinforcement	Protection by means of gabions, or large rock blocks over full width and over a

		length of 3 m.
Reinforcement to downstream end of spillway channel (beginning of chute)	**Reinforcement to downstream end of spillway channel (beginning of chute)**	Protection by means of gabions, or large rock blocks over full width and over a length of 3 in the channel and 3m along the chute.

Attention must be drawn towards the necessity to start protection of the energy dissipation area at the toe of the spillway chute as soon as possible, and to proceed with that in parallel to spillway channel excavation and reinforcement. In order to associate credible construction programs to each scenario, the following should be done.

a) Prepare cross sections and transversal sections of the dam to scale, using combination of total station surveys and GPS. As a minimum, three longitudinal sections (along the spillway, the left side, and the right side of the dam, and one transversal section along the axis of the dam.
b) Draw on the sections, the best estimate of the limits among the different materials included in the body of the dam (ref. [1]). Further geological observations during the works should be added when available.
c) Prepare bill of quantities (excavation volumes, slope protection works, etc.) for each design layout.
d) Prepare construction programs (bar charts) using realistic production rates for each design layout.

The combination of overtopping date forecast and construction programs should be at the base of risk management strategic planning. The objective of strategic planning should be the implementation of the best possible configuration, between layouts **a** and **b**, under the constraint of the expected (forecast) overtopping date. It should be made clear that the planning instrument is a "Flexible Plan". Flexibility is inevitable due to: (a) unknown composition of the dam; and (b) stochastic nature of river inflows.

Strategic risk management planning should be used for:

a) Awareness and early warning of community downstream,
b) Planning and managing dam engineering activities, and
c) Informing upstream communities of expected lake levels.

The above described tasks are beyond the capacity of officials working on site. It is absolutely essential that an experienced Dam Engineer is present full-time on site to coordinate technical activities.

6. *Monitoring System Improvements*

The basic monitoring system that FHA has put in place is of high value. At the same time, it needs prompt upgrading. GoP attention to this need is strongly recommended. Key improvement measures are summarized in the following table.

Item	Recommendations
Monitoring station on the right bank	More powerful spotlights should be installed for night view, as well as night vision cameras; this is particular important for early detection of new location of seepage outflow.
Flow measurement station at the upstream end of the lake	Improve velocity measurements (currently done by floaters) and calibrate with existing gauging stations to improve accuracy.
Movements of downstream face of the dam	Several reference points are being monitored by FHA; the system needs to be upgraded to be suitable for remote monitoring (laser scanner) of some critical points.
V notch weir for seepage measurement	Build masonry weirs and install steel plates with calibrated V notches to improve accuracy of seepage rate measurement.
Turbidity meter	Make a couple of kits available on site for early detection of turbidity surges in seepage flows; visual observations are currently used.
Boreholes and piezometer installations	Drilling borehole to bedrock in the downstream slope of the dam, left side. Install open-type piezometer (manual reading) to signal excessive raising of water table in the downstream slope.
The stability of the slope at Attabad	The slope above the landslide dam site continues to ravel, and there is the potential for additional, larger scale mass movements. Active monitoring of these slopes should be initiated.
The state of the slopes above the lake	Regular (weekly) inspection of the slopes by an expert, ideally by helicopter, to determine whether cracks are opening on the slopes; recording of rockfall activity, and in particular notable increases in rockfall rates at particular locations, which may indicate that instability is developing.

7. *Post Emergency Planning*

Once the emergency situation is successfully managed, i.e. sometime in late October – November 2010, consideration should be given to preventive measures aimed at increasing preparedness, and response, to similar events in the future. It is impossible to remove the mountain hazards from Hunza Valley, but it is perfectly possible to increase preparedness and response capacity.

A regional Mountain Hazard Mitigation Program (MHMP) should be prepared to:

- Cover all type of hazards, such as landslide dams, GLOFs, avalanches, earthquakes;
- Carry out preliminary risk assessment by means of remote imagery/ sensing techniques and using empirical relationships[2];
- Carry out site inspections at carefully selected hazardous features;
- Establish a permanent monitoring system (satellite, air surveys, site visits, local communities involvement);
- Carry out inundation analysis, with due consideration to debris entrainment;
- Prepare Emergency Preparedness Plans;
- Carry out community awareness and preparedness activities; and
- Implement preventive measures, where possible (e.g. GLOF siphoning).

[2] See for example: "*Remote sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps*"; Christian Huggel, Andreas Kääb, Wilfried Haeberli, Philippe Teysseire, and Frank Paul; Can. Geotech. J. 39: 316–330 (2002)

Excerpt from [1]: Mechanism of Failure and Material Composing the Landslide Dam

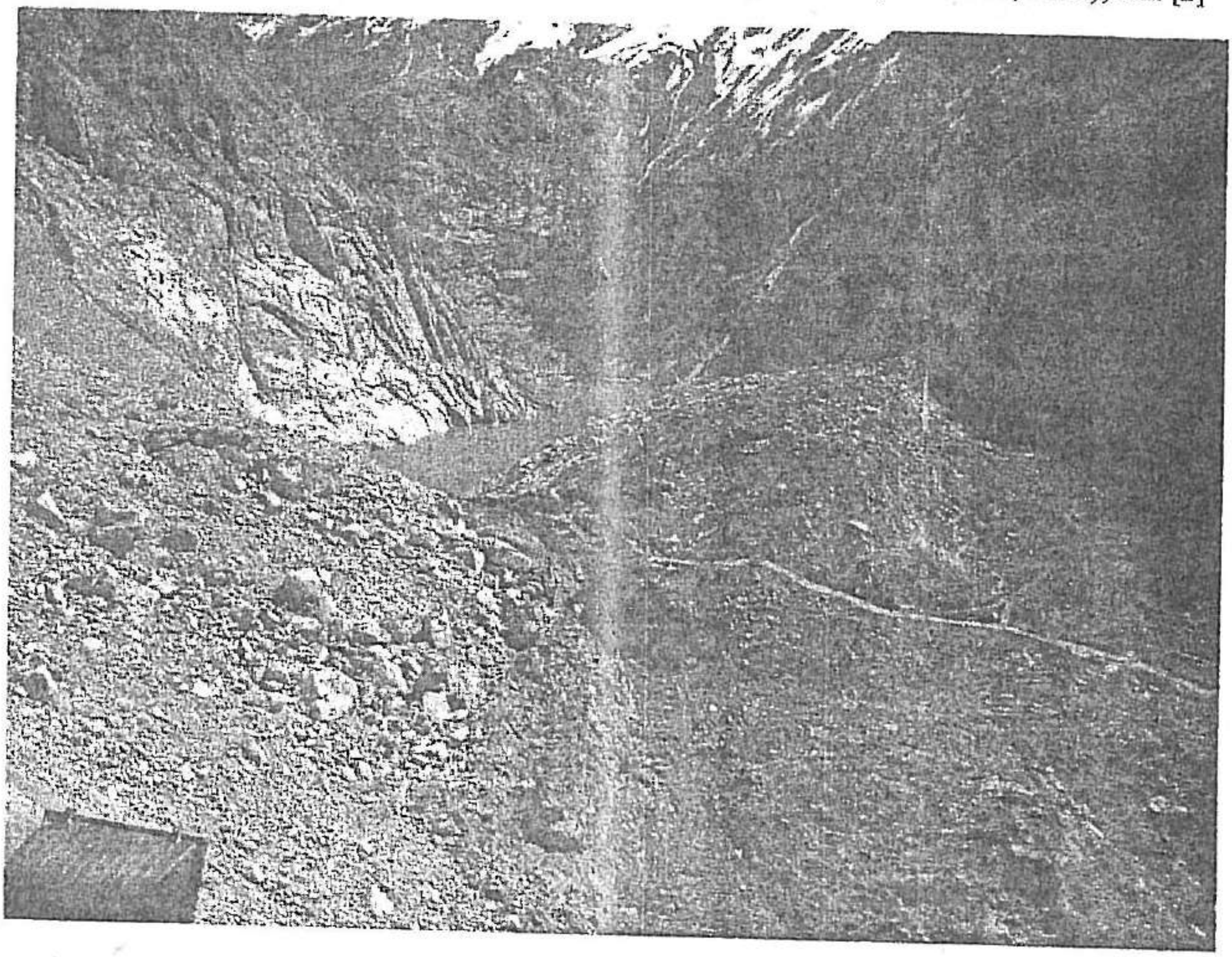
The 4th January 2010 landslide at Attabad in Hunza, Northern Pakistan was a complex failure on a slope with known stability issues. Previous work at the site, primarily by geologists from Focus Humanitarian Assistance, allowed evacuation of the potentially unstable area. No fatalities were recorded in this zone, primarily as a result of these actions to relocate the population. However, the slide mass, which has an initial estimated volume of 30 million m3, fell from the northern valley wall onto saturated lacustrine sediments that had probably been deposited in the river bed in a lake formed by the 1858 landslide dam at Salmanabad, a few kilometers downstream. These sediments were mobilized though undrained loading and possibly liquefaction to form two mudflows. One mudflow travelled upstream for about 500 m, whilst the other flowed downstream for about 1.5 km. This latter flow hit a small settlement close to the river at Sarat, killing 19 people. This secondary mudflow event could not have been foreseen.

The emplaced landslide mass consists of a c.140 m high (at the saddle – the lowest point) rock and debris deposit, blocking the valley for a distance of over a kilometer. The main part of the landslide dam is a colluvial material consisting of a fine, sandy matrix with isolated clasts (rock blocks) of granite and granodiorite. The clasts are generally angular, ranging in size from a few centimeters to >10 meters. The deposit is matrix supported (i.e. the blocks are mostly not in contact with each other, probably deriving primarily from a pre-existing colluvial deposit on the hillside at Attabad. On the upstream side of the dam on the south side of the landslide there is a large rockslide deposit formed primarily of large and very large boulders, with little or no matrix support. This deposit appears to represent a late stage collapse of a large block of bedrock. The saddle of the landslide and the downstream face is mantled with a thick layer of the lacustrine deposit, consisting primarily of clay- and silt-sized particles, with some rounded fluvially-transported pebbles and cobbles. This material has a very low plasticity index and appears to have low permeability. The surface of the material appears dries readily to leave a reasonably thin but strong surface layer, underlain by material with a high water content. This material behaves in an unusual manner, deforming readily when loaded without the surface layer breaking. This is proving to be problematic for the plant at the site, which breaks through the crust and becomes bogged down in the wet materials beneath.

The morphology of the landslide deposit is not unusual. The main landslide mass has banked up on the far (south) side of the valley, leaving a saddle on the near (north) side. The upstream face of the landslide mass is reasonably steep, but with no signs of significant instability. The downstream face is less steep as it is mantled along its whole length by the mudflow deposit. Three distinct mudflow channels are evident, although the mudflow deposit covers the entire downstream slope. Compression ridges are evident in this material, as are pools of water on the lower slope. Staining on the rockwalls show that during the passage of the mudflow the landslide was c. 5 m thicker than at present, indicating high mobility when saturated.

A large landslide lake has developed on the upstream side of the landslide. At the time of writing this is c.11.5 km long and >60 m deep. The lake level is currently rising at c0.6 m per day. The freeboard is currently c.60 m. The dam appears to be essentially stable under current conditions, with only minor seepage on the downstream face, primarily associated with drainage of the mudflow deposit, and few signs of slope distress.

View of the Dam from the Observation Point on the Right Bank (March 15, 2010), ref. [2]



Suggestions Pertaining to Alarm Levels, from ref. [1]

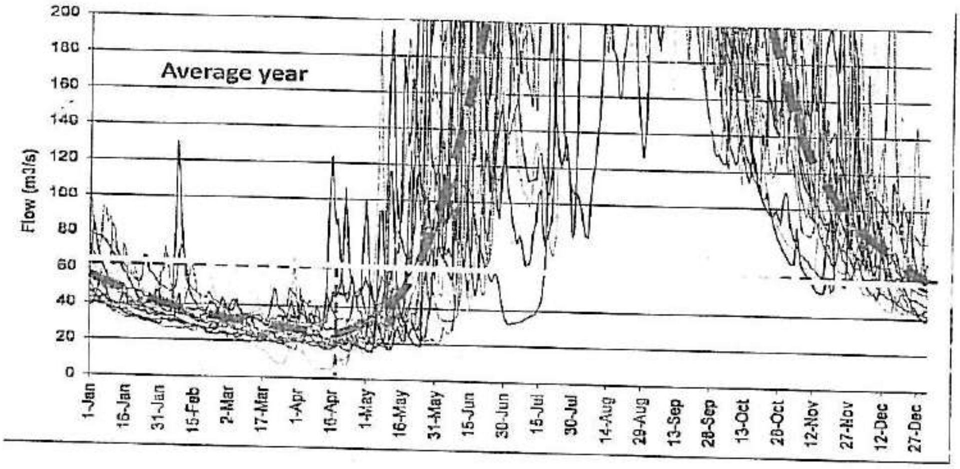
Alert State	Trigger	Suggested Actions
1: Landslide aware	Current state	Development of preparedness and evacuation plans for all potentially-affected communities; development of communication system; 24 hour monitoring of the dam state; evacuation drills undertaken; recovery and rehabilitation plans developed; and basic living necessities stockpiled.
2: Landslide alert	Lake level reaches agreed level (10 m?) below the spillway	Evacuations of all population between Attabad and Gilgit located within 60 m of current water level, plus those close to terrace edges and on known landslides; full monitoring team in place 24 hours per day. Downstream communities warned of potential need to relocate at short notice
3: Landslide warning	Water starts to flow across spillway as a result of continual increase in lake level	Evacuation of all potentially evacuated population to Gilgit; Population downstream prepared to move relocate. Communication system fully operational. KKH closed between Attabad and Gilgit.
4: Severe landslide warning	Sudden increase in flow through or over the dam **AND/OR** development of erosion and scour of spillway or downstream face	Evacuation of all population below 60 m level between Attabad and Tarbela, plus those at a similar level in tributary valleys, plus those close to terrace edges and on known landslides; Tarbela dam prepared for rapid inflow event; KKH closed and all sections of road below the 60 m level cleared; all bridges on KKH and associated roads closed; emergency response plan activated.

Forecasting the Overtopping Date

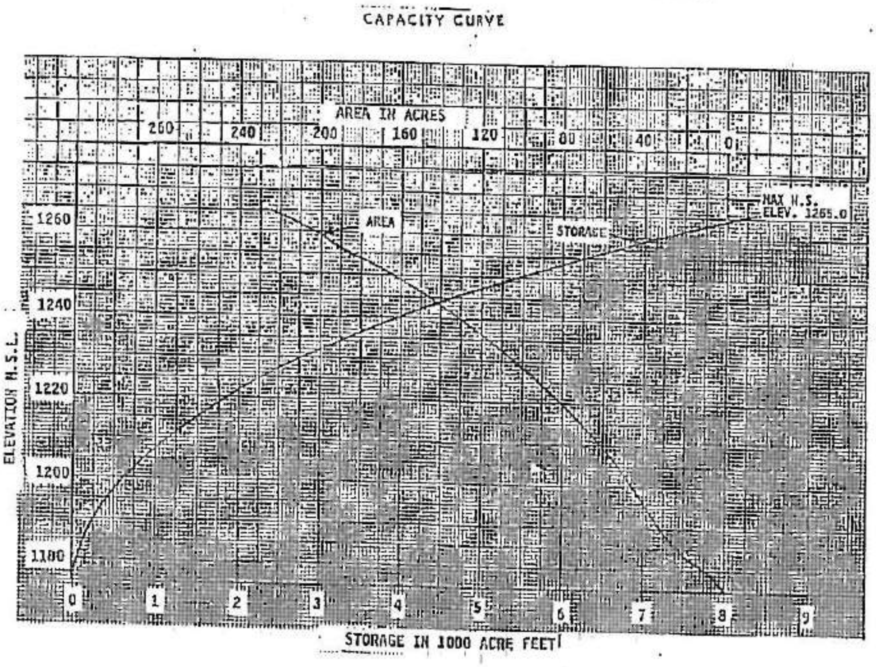
This is a priority task that can be carried out with easily available data on:

- Historical sequences of daily flows at the dam site
- Stage- capacity curve of the lake

The former can be done by 'transporting' flow records form the closest gauging station to the dam site; if necessary with catchment area correction. Data should be checked for errors and inconsistencies. An average curve should be calculated from the family of annual curves. An example is shown in the following figure.



Lake volume vs. elevation can be easily obtained for topographical maps, possibly to 1:50,000 scale or lower. A typical representation is shown below.



Using the two sets of information, and dopting the average curve for the river flows, step integration of the continuity equation allows to make an initial forecast of the overtopping date:

Vi+1= Vi + Qin*t

Qout= Qin – [(Vi+1)-(Vi)]/t

Where:

Qin : discharge entering the lake,

Qout: discharge over the spillway,

Vi: initial volume of the lake,

V1+1: volume of the lake after receiving Qin over a period of time "t",

T: integration time: can be one week until end of March, early April, and reduced to 1 day afterwards.

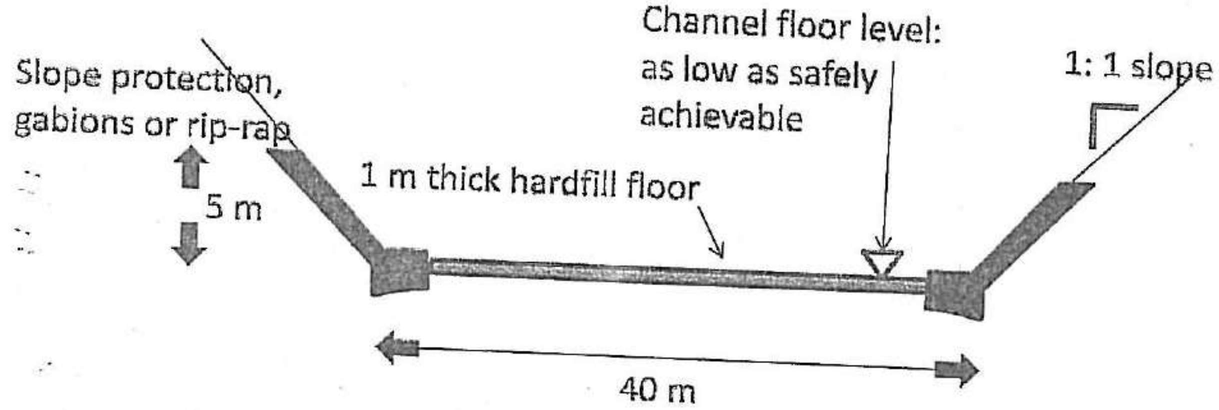
Seepage and evaportion losses should be neglected.

The forecast can be progressively improved, as actual flow measurements get available, using probabilistic methods suach as the Bayes' theorem[3].

The above described procedure will provide forecast of the likely overtopping date for different elevations of the spillway crest.

3 http://en.wikipedia.org/wiki/Bayes'_theorem#Likelihood_functions_and_continuous_prior_and_posterior_distributions

Location of Spillway Reinforcement Measures



Longitudinal profile of the spillway