Sri Lanka Dam Safety and Reservoir Conservation Programme

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SYNOPSIS. The history of dam engineering in Sri Lanka dates back some 4,000 years to when ancient Ceylon developed control of the water streams to satisfy the needs of an advanced civilisation. These great works of irrigation are even more impressive, and attract even more interest, than many remains of ancient monuments, palaces and temples. Dam engineering practice in Sri Lanka has been continued to date to include large reservoirs such as Victoria, Kotmale, Randenigala, Samanalawewa.

Under the Dam Safety and Reservoir Conservation Programme (DS&RCP) 32 major dams were inspected and studied by Jacobs GIBB. The scope of the investigations included inspection and technical studies covering seismicity, instrumentation, stability, spillway adequacy and reliability. In addition water quality, sedimentation and catchment land use were assessed. Institutional issues included a review of dam safety legislation, establishment of a data management centre, identification of local research resources and training and skill enhancement for the local engineers.

PROJECT BACKGROUND

DS&RCP of Mahaweli Reconstruction & Rehabilitation Project (MRRP), funded by the IDA and managed by the Joint Committee (JC) has an objective to implement a qualitative management system for all major dams in Sri Lanka in order to improve their safety. The JC comprises the staff from the three dam owners, namely the Mahaweli Authority of Sri Lanka (MASL), the Irrigation Department (ID) and the Ceylon Electricity Board (CEB).

In year 2000, under the MRRP a Risk Assessment study of the 32 major dams in the Mahaweli river basin and adjoining basins was conducted. The study showed that while the modern dams have generally been built to current standards of the world's best-used practices, the same cannot be said

Long-term benefits and performance of dams. Thomas Telford, London, 2004

for the other dams. Many dams are showing signs of ageing while others have significant deficiencies in monitoring, maintenance, reservoir conservation and other issues. A vast majority of dams including numerous dams managed by ID have not had an overall safety review and risk assessment.

The main objective of the DS&RCP is to assess safety of the selected 32 major dams and to recommend remedial works as well as to assist Sri Lanka in establishing a long term dam safety programme.

PROFILE OF DAMS

The DS&RCP covered 32 dams out of a total dam population in the island of over 300. The 32 dams, whose location is shown in Figure 1, can be categorized as follows:

Mahaweli multipurpose dams

4 of the 32 dams are large modern dams on the Mahaweli river serving both hydropower and irrigation purposes: Kotmale and Randeningala (rockfill), Victoria (arch) and Rantembe (concrete gravity). In addition, Polgolla diversion barrage supplies the Sudu Ganga and associated power stations and irrigation schemes. The five dams are owned and operated by the MASL.

Hydropower dams

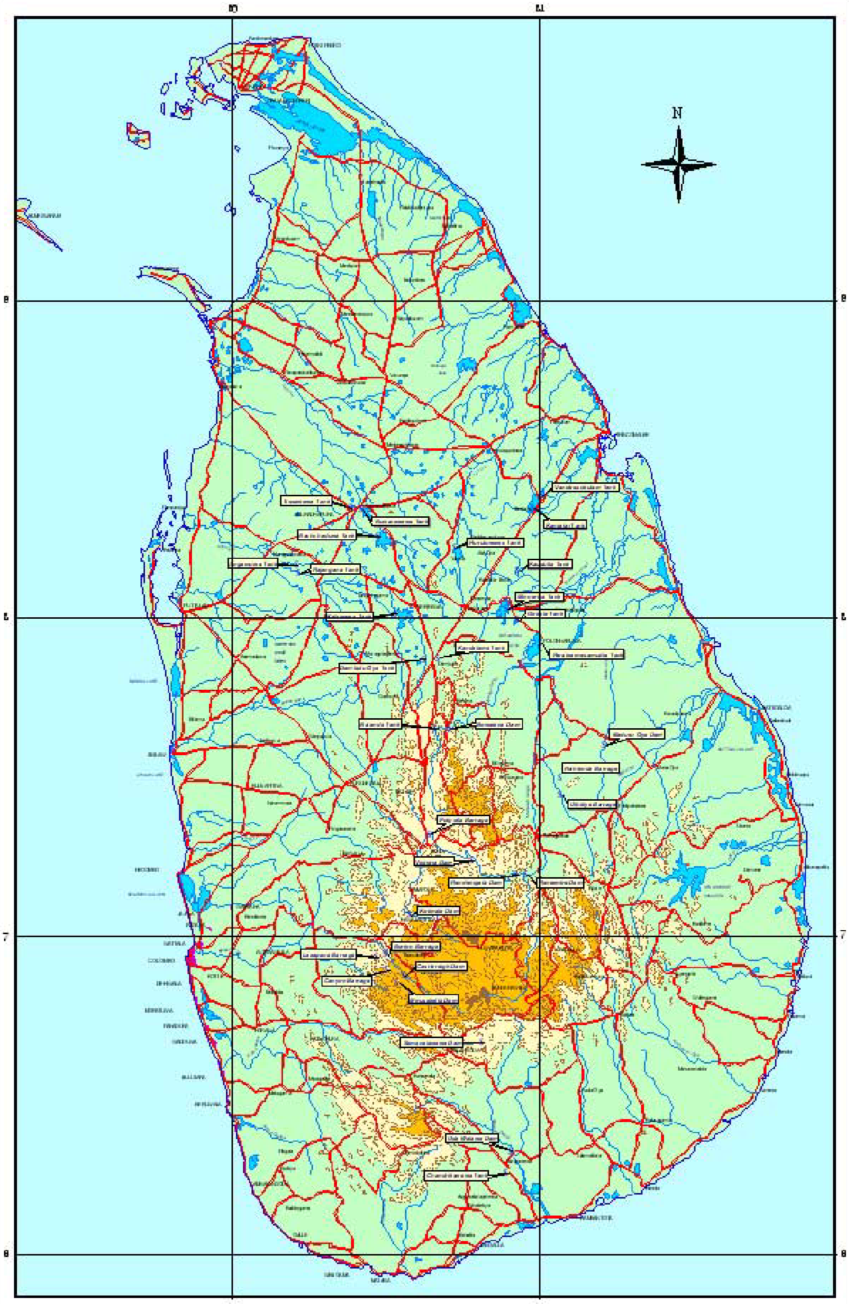
6 of the 32 dams are single purpose hydropower dams owned and operated by the CEB. 5 of these dams are concrete gravity dams on the Laxapana river system constructed in the 1950's. The sixth, Samanalawewa is a rockfill dam constructed in the 1980's.

Irrigation dams

The majority of the dams are single purpose irrigation dams and are owned and operated either by the ID of the Ministry of Agriculture or the MASL. 13 of the irrigation dams owned and operated by the ID were originally constructed over 1500 years ago and are still in use after successive rehabilitation and reconstruction campaigns.

Inspections

All 32 dams were inspected early in the programme following a procedure typical for a periodic inspection under the UK Reservoirs Act 1975. Of the 32 dams, all the 14 dams owned and operated by MASL had previously been inspected, by staff of the Sri Lankan consultancy CECB, and reports were available. Irrigation dams are generally inspected monthly or quarterly by ID staff who complete a proforma report. There is no evidence of CEB dams having been previously inspected.



Mahaweli Restructuring & Rehabilitation Project
Dam Safety and Reservoir Conservation Programme

Dam Location Map
FIGURE 1

Figure 1 Location map of dams

CONDITION OF DAMS

Summary of condition

Our conclusion on the overall safety of the 32 dams from the work carried out under this activity is that there are very few unsafe dams, but that there is a range of issues that need to be addressed in order to preserve and in some instances to improve the status quo. Adequate dam safety depends on three separate factors: design, construction, and operation / maintenance.

Although the design of the dams ranges from the simple homogenous embankments of the ancient dams to the sophisticated double curvature arch of Victoria, there is no instance where the safety of a dam is jeopardised by poor design.

There are several dams where the standard of construction has been below an acceptable level, and at several dams poor construction may jeopardise dam safety.

Generally maintenance is barely adequate, and if this situation is not improved the safety of the dams will slowly deteriorate.

Recommendations

Recommendations were made in the report of:

- Remedial works, categorised by priority
- particular maintenance items
- instrumentation and monitoring
- investigations and studies
- the nature, frequency and scope of future inspections

Spillways

Spillway capacity

Assessment of adequacy of spillway capacity comprised, for all 32 dams, the collection, review and detailed analysis of all hydrological data relevant to the dams.

Two methods were used for estimation of the design inflow floods: the statistical approach which is based on historic records of the annual maximum flows recorded at all gauging stations in Sri Lanka and the unit hydrograph method.

The statistical approach is based on the maximum annual flows for each year of record for the 80 gauging stations in Sri Lanka, providing some 2,000 station years of record. The results of the study are presented as a graph of the standardised flood peak versus the probability or return period of the flood (Figure 2). Three curves are presented, as follows:

- Curve no. 1 grouping all Sri Lankan gauging stations together
- Curve no. 2 for areas where the mean annual rainfall is < 2000 mm
- Curve no. 3 for areas of average rainfall
- Curve no. 4 for areas where the mean rainfall is > 3,400 mm

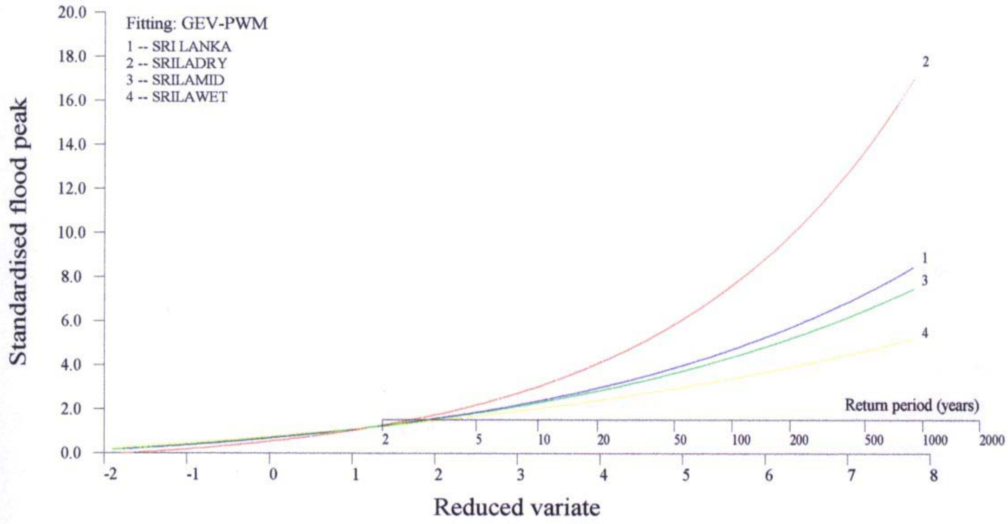


Figure 2: Regional Flood Frequency Curves

Because of the high density of population downstream of the dams, spillway capacity was also checked for the PMF. The PMF inflow hydrographs were obtained by a simplified version of unit hydrograph method and the estimation of the probable maximum precipitation (PMP) over the catchment. The PMP was estimated from the maximum recorded rainfall at each meteorological station over the period of record, which for many stations exceeds 100 years.

The check of the adequacy of the spillways and other outlets of the 32 dams showed that all but three of the spillways had adequate capacity: for these dams extra capacity can be economically and safely provided by heightening the dams concerned.

Spillway reliability

Of the 32 dams, 22 are either wholly or partly dependent on gated spillways for their safety. Of these spillways, 19 are electrically actuated, although most are capable – in theory – of manual operation. Nine of the 22 gated spillway were rated high reliability with no significant remedial works required.

Stability

Embankment dams
Among the 22 embankment dams, only the 4 modern rockfill dams and one zoned embankment had geotechnical information available from the original design stage which proved that the dams were stable. The geotechnical information for the remaining 17 earth embankments (13 of which are ancient) was either very poor or non - existent. Therefore stability of these 17 dams was carried out using an assumed range of lower bound strength parameters.

Based on the stability results 17 dams were grouped into the following three groups:

- Group 1 - FOS<1.3 - Investigation required (4 dams)
- Group 2 - 1.3<FOS<1.5 - Investigation required if high ground water levels or specific defects were identified in the inspections (7 dams)
- Group 3 - FOS>1.5- No investigations required (6 dams)

It was recommended that for four dams from the first group site investigations be carried out and the stability reassessed using the parameters from the investigation. In addition, three other dams from the second group also required investigations because of defects identified during the dam inspections.

Concrete dams
Out of 10 concrete dams, 9 are gravity dams with heights varying from 18.3m to 42m, and Victoria dam, a 120m high concrete arch dam on the Mahaweli Ganga.

Safety of the dams to sliding and overturning as well as the stress at the key points was checked for the normal, unusual and the extreme loading conditions.

Seven dams were found to be stable with an adequate safety margin under all loading conditions. However, three dams, Castlereigh, Nalanda and Norton dam were found not to have sufficient safety margin and appropriate remedial works – improved foundation drainage - were recommended.

Instrumentation

It was found during our inspection that the dams constructed recently were equipped with electronic instrumentation to measure seepage, pore pressure, deformations, deflections, movements, temperature and various other parameters. This equipment, whilst operating well for a number of years, has rarely been serviced or calibrated. Where equipment has failed there has been little funding available for its maintenance or repair which has resulted in the equipment being abandoned. In some cases, a lack of understanding of a system has led to equipment being abandoned or deemed inappropriate.

The dams that were constructed in mid 20th century have fewer instruments, and the ancient dams usually have no instrumentation at all.

Currently, dam monitoring is undertaken by dam owners and on many of the sites the monitoring is carried out on a regular basis. However, data recording and handling procedures often vary from site to site. The instrument monitoring staff has a basic understanding of the instrument operation but the data handling procedures are not standardised.

Following the inspection, we have recommended and specified additional instruments: these comprise for most dams the collection and measurement of seepage and the provision of survey monuments to enable settlement surveys to be carried out. Standardisation of data recording and presentation was proposed. It was also proposed that the records will be in a centralised data record library within the Data Management Centre in Colombo and will be available via the GIS system.

OPERATION AND MAINTENANCE (O&M)

The perceived shortcomings in present O&M procedures are as much the product of inadequate budgets and the failure of management to recruit, train and financially reward staff of the calibre necessary to operate and maintain large dams, as they are deficiencies in management procedures and practices. This in turn may be seen as being a failure by Government to recognise the importance of the security of the nation’s stock of large dams to the national economy, and the threat that unsafe dams pose to the public at large. For this reason, it has been necessary to take full recognition of the initiatives that have been discussed to restructure the main water management agencies, to introduce a new Water Act and to set up a regulatory framework for dam safety. The form that the regulatory framework will take will impose obligations on dam owners that will significantly affect the procedures to be adopted for O&M and safety surveillance.

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

Prior to the preparation of Guidelines for Improvement of O&M and Emergency Procedures we examined the current practices which are applied within each of the agencies. They are summarised below.

O&M

Procedures for O&M of the large MASL dams are now well established. All of the new dams have O&M manuals prepared by the designers which set out routine procedures for O&M as well as emergency procedures, particularly in the event of a major flood.

Procedures for operation of CEB dams are determined in Colombo to meet energy requirements within the distribution system. The procedure adopted is that gate operating staff are assigned to provide 24-hour cover at each of these dams whenever the water level approaches FSL and continues until the water level has again fallen below FSL.

Operation of the ID dams is regulated by a departmental circular which covers the whole irrigation scheme as well as the headworks.

Emergency Preparedness

Some effort has been made at the big dams to prepare for emergencies, in that key staff have been listed with their home contact details, contact details have been compiled for the emergency services and other key authorities, and lists of emergency service providers have been made. But generally, there has been no attempt to identify risks, to set levels of alarm in response to different emergency situations, or to determine the actions and persons responsible in any set of circumstances. Also, there is no programme of formal training for operating staff in dealing with emergency situations.

Prepared Guidelines for Improved O&M and Emergency Action Plans (EAP)

We proposed that improved management practice for Sri Lanka's stock of large dams requires that the three principal agencies adopt a structured, simple and standardised approach to O&M and Emergency Preparedness. The guidelines were drawn up for preparation of Standard Operating Procedures (SOPs) and EAPs for all dams in Sri Lanka. Prototype documents were also produced that are intended for universal application by the three agencies.

RESERVOIR CONSERVATION

Extent of sedimentation and pollution

In world terms, Sri Lankan reservoirs are not severely affected by either sedimentation or pollution. However the pressures exerted by a rapidly expanding population have resulted in environmental degradation of one third of the total land area. Soil erosion is most severe in the high catchments on steep slopes at mid levels, which are used for market gardening and tobacco production: it is estimated that erosion rates for these land uses are 150t/ha/year, compared with 0-10 t/ha/year for paddy, forest and well managed tea. The actual sediment yield of the catchments varies between 0.5 t/ha/year to 4 t/ha/yr for lowland and upland reservoirs respectively. Of the 32 reservoirs studied only two, Polgolla and Rantembe are seriously affected by sedimentation.

Similarly water quality is becoming a more serious problem because of increasing levels of nutrients, pesticides and effluents entering the watercourses.

Conservation policy

A national conservation policy is required to reverse the adverse trends in sedimentation and water quality in order to protect the countries water resources. Sediment yields will be reduced and the water quality improved by:

- propagation of appropriate land use, including grassing or reforesting steep and high level areas currently used for agriculture, the prevention of overgrazing and the adoption of soil conservation measures
- the adoption of appropriate land use and fiscal policies to improve land tenure systems and discourage the fragmentation of land
- improvement of urban waste water treatment and the disposal of solid waste
- better management of fertilizers and pesticides
- enforcement of the 100m buffer zone of grassland and trees around the reservoir perimeter.

Considerable efforts are already being made in the conservation of the Mahweli catchments, including research, public awareness and farmer training. This work needs to be intensified and extended to all catchments.

TRAINING

Background

Inadequate skill levels were identified as a drawback to overall dam safety. Many of the skilled and experienced operators, technicians and site engineers have left the MASL, ID and CEB for better prospects. The younger operators, engineering and other relevant professional staff, are with limited experience and little exposure to appropriate best practices. It was recognised that there is a lack of a well-structured training and competency assessment programme, and that as a result staff training was an important component of the DS&RCP.

Training Framework

A training framework was produced based on assessments of the workforce capacity of 32 dams and their gaps in skills. The assessments were carried out based on the questionnaires, workshop and interviews with the staff and the senior management of MASL, CEB and ID.

The staff required training was grouped into the following groups:

Group A	Engineers in Charge/Chief Engineer: professionally qualified engineers generally with more than 10 years experience who are potential senior managers
Group B	Civil engineers and technicians engaged in dam monitoring who aspire to become Engineers in Charge or Chief Engineers
Group C	Electrical/Mechanical engineers and technicians who are responsible for the operation of spillway and sluices

A training programme was developed that comprised 9 training modules and technical presentations in 5 technical areas which were delivered by the Consultant. Around 150 staff received the training under this programme, namely 43 staff from Group A, 46 staff from Group B and 95 staff from Group C.

Nineteen local trainers were also identified from all three organisations. The trainers received technical training along with the trainees and in addition they also attended a course in communication and presentation skills. The trainers delivered one training course under our supervision when we had a chance to comment on their performance.

DAM SAFETY MANAGEMENT CENTRE

It is the intention that the three dam owning organisations combine to set up a Dam Safety Management Centre (DSMC), which would be a quasi autonomous body to coordinate the following activities for all dams in Sri Lanka:

- Data management and appraisal
- Emergency technical co-ordination
- Dam survey unit
- Implementation of dam safety programme for 32 dams

- Extension of dam safety programme to other dams
- Monitoring compliance with dam safety code of practice
- Steering group for dam safety legislation
- Training of dam owners staff
- Liaison with IESL and other stakeholders

DAM SAFETY LEGISLATION / CODE OF PRACTICE

As was required by the terms of reference, we prepared a paper outlining the main provisions of future dam safety legislation in Sri Lanka, based on a review of legislation in UK, USA, Sweden and India. The main provisions of the proposed legislation were:

- The dam owner is responsible for the safety of the dam
- A register of dams would be compiled and maintained by the enforcement authority
- Dams would be subject to mandatory inspections by independent engineers
- Recommended remedial works would be mandatory

After much internal discussion the Client decided that Sri Lanka is not ready for legislation and that the proposed provisions should be contained in a Code of Practice. The DSMC will be responsible for monitoring compliance with this Code.

PORTFOLIO RISK ASSESSMENT

Objective

Portfolio Risk Assessment (PRA) provides a rational method of improving the safety of a group or portfolio of dams in the care of a single owner or organization. PRA enables owners to determine

- How much dam safety expenditure is justifiable
- The priority of dam safety measures
- The rate of expenditure
- The risk profile of their portfolio

PRA involves the following steps:

- Engineering assessment of dams
- Assessment of risk posed by dams in their existing state and after dam safety measures
- Definition of dam safety programme

Risk assessment

The risk for all 32 dams was assessed both by the semi-quantitative “Failure Modes, Effects and Criticality Analysis” (FMECA) method and a quantitative analysis in which the probability of a dam failure and the cost of the consequences are expressed numerically.

In the semi quantitative estimate both the probability and the consequences of failure are expressed by a scoring system developed which is based on that and described in the CIRIA publication C542 Report, Risk Management for UK Reservoirs. In this the probability of failure of a dam can be expressed as the product of at least two factors:
- The probability of an event (slope instability, flood overtopping etc)
- The probability of the event resulting in failure of the dam

Both probabilities are expressed in terms of a score in the range of 1 (very unlikely) to 5 (likely).

In the quantitative assessment, event tree analysis is used to estimate the probability of failure and the consequence of failure is based on an estimate of the loss of life and economic loss from inundation mapping. The results of the risk analysis are shown on the F-N plot in Figure 3.

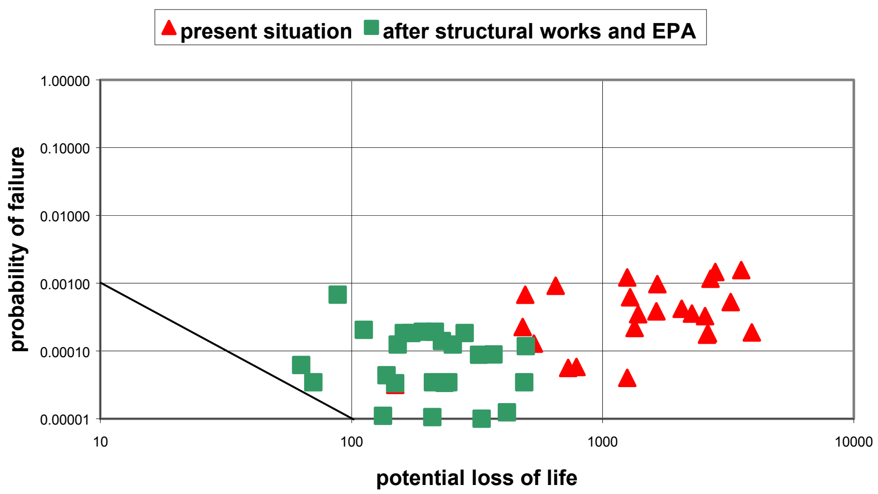


Figure 3 F-N plot

<u>Dam Safety programme</u>
The dam safety programme comprises both structural and nonstructural measures, as follows:

Structural measures

Improvements to spillways and outlets	Rs 434 million
Repairs to upstream slope protection	Rs 265 million
Dam and foundation drainage	Rs 338 million

Non structural measures

Monitoring systems	Rs 43 million
Early warning systems	Rs 67 million

The total capital cost of the entire programme is Rs 1150 million or US$ 11.5 million.

Evaluation

The evaluation of the economic viability of structural measures uses the concept of risk cost, which is expressed as product of the probability of failure and economic loss, to express the benefits.

Because the b/c ratio for the entire programme is low (0.2), consideration has been given to the early implementation of the most urgent and beneficial components. A plot (Figure 4) showing the decrease in risk cost with increasing levels of expenditure on structural measures will assist in deciding the extent of this initial phase.

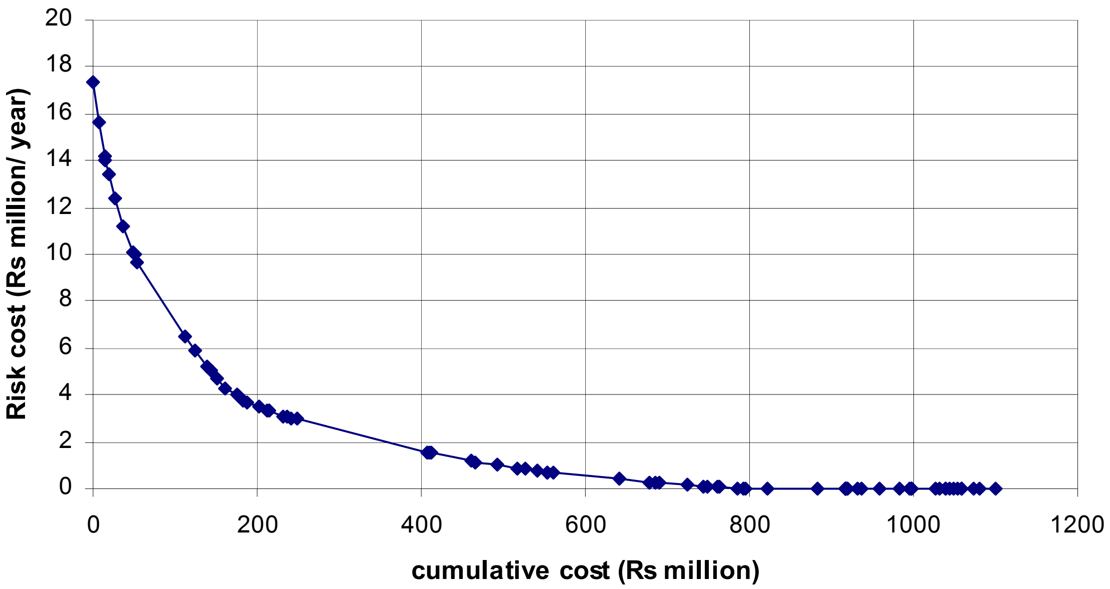


Figure 4: Risk cost vs cumulative cost of structural measures

CONCLUSION

While the full dam safety programme of Rs1,100 million is desirable, 85% of the dam safety improvements can be achieved with the expenditure of just half this sum. This reduced programme approaches economic viability and is recommended.

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

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