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Evaluation of Risks Associated with Environment Agency Flood Storage Reservoirs

R&D Technical Report W5B-028/TR1

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Statement of Use
This reports on the use of the CIRIA method for Agency flood storage reservoirs. It includes the results of an initial trial application to five reservoirs, a review of relative risks, a review of the CIRIA methodology, and recommendations for development and application of the methodology for flood storage reservoirs.

One issue which needs further investigation is that the standard methodology may lead to an overestimate of the risk of flood storage reservoir failure, since a valley downstream may already be flooded at times when a storage reservoir failure is most likely. This will require a further study to enable a realistic assessment of the impacts of reservoir failure under those conditions. Further testing and development of the methodology is planned prior to national implementation through the Flood Defence Operations group.

Keywords
Reservoir, Safety, Dams, Inspection, FMECA, Flood Storage Reservoir

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EXECUTIVE SUMMARY

CIRIA Report C542: 'Risk Management for UK Reservoirs' was published in 2000 following a study partly funded by the Environment Agency. The study involved the development of a risk assessment methodology to enable reservoir owners to rank their sites in terms of risk and hazard, and assist with the prioritisation of any works required. The CIRIA study concentrated on reservoirs that were full of water much of the time, which is not the case with most of the Agency's 109 flood storage reservoirs, which normally only impound water during floods.

This Agency R & D project is a pilot study into the use of the CIRIA methodology on flood storage reservoirs (FSRs). It involved the application of the CIRIA methodology to five FSRs of varying size and flood risk. The principal objective was to evaluate the application of the methodology to FSRs and determine any modifications needed to the methodology before it is used on all the Agency's 109 reservoirs which come within the ambit of the Reservoirs Act 1975, and any further research required to develop the methodology for such use. The study also considered the identification of risk mitigation measures in the unlikely event of failure of a flood storage reservoir.

The study made a comparison with risks in other industries and at impounding reservoirs. It concluded that the CIRIA methodology was valid and there were benefits in using it for flood storage reservoirs. These included: prioritisation of safety works, maintenance and monitoring etc.; identification of possible failure modes; preparation of emergency plans and ensuring good practice maintenance regimes are implemented. The study demonstrated that risk assessments are best undertaken by personnel who are well acquainted with the reservoir and its environment. Operation and maintenance were identified as key issues in ensuring that flood storage reservoirs function properly when required.

Some issues were, however, identified in the use of the CIRIA methodology on flood storage reservoirs. A particular problem was the difficulty in identifying the impact of dam failure on an already flooded valley, and further research into this issue is recommended. The 'Location Cause Indicator (LCI)' diagrams in the CIRIA methodology were not wholly applicable to flood storage reservoirs and a more appropriate LCI diagram for flood storage reservoirs has been developed during the study.

Additional research is recommended into the impact of dam failure on a flooded valley and also that risk assessments should be undertaken on all the Agency's flood storage reservoirs in flood categories A and B (i.e. those where lives are considered to be at risk). In order to ensure consistency, all the risk assessments should be reviewed by a single experienced reservoir panel engineer.

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1 INTRODUCTION

1.1 Background

A research project was undertaken for CIRIA in the late 1990s which resulted in the publication of CIRIA Report C542: "Risk Management for UK Reservoirs". The CIRIA study was partly funded by the Environment Agency and the CIRIA Report also formed the Environment Agency R & D Technical Report W232, produced through R & D Project WSC-008.

The CIRIA Report provides guidance on the application of risk assessment and risk management procedures to UK reservoir practice. It was written primarily for UK reservoir owners, panel engineers, regulators, insurance companies and others concerned with reservoir safety. It was intended to complement the guidance produced in recent years on floods, seismic risk, valves and pipework etc., to assist those undertaking duties in accordance with the Reservoirs Act 1975. The risk assessment methodology was developed to enable owners to rank their dams in terms of risk and hazard, and assist them in prioritising any works needed.

The risk assessment procedure comprises two basic stages:

1. An impact assessment, to determine the impact that failure of a dam would have on the community.

2. A Failure, Mode, Effects and Criticality Analysis (FMECA) which considers the components of a dam and how they may contribute to a possible failure of a dam. This enables the most critical elements of the dam to be identified.

The CIRIA methodology was developed for use with all reservoirs falling within the provisions of the Reservoirs Act 1975, but was biased towards 'normal' impounding reservoirs which contain water most of the time. The Environment Agency wishes to evaluate the application of the CIRIA methodology to its 109 flood storage reservoirs, which normally only impound water during floods. This project is a pilot trial to undertake risk assessments on some flood storage reservoirs and identify any changes that may be needed to the CIRIA methodology when dealing with such reservoirs.

This project has been carried out within the 'Risk Evaluation and Understanding of Uncertainty' Theme of the Combined Defra / Agency R&D programme. It is one of a range of projects developing the use of risk assessment and performance evaluation by the Agency and Defra. These are being developed within a framework for risk, performance and uncertainty set out in by Defra/Environment Agency (2002).

1.2 Objectives

The overall objective is to test the CIRIA methodology on flood storage reservoirs. More specific objectives included the following:

- To select at least one flood storage reservoir in each of the four flood categories (A, B, C & D) as defined in 'Floods and Reservoir Safety', and apply the methodology in the CIRIA guide.

- Assess the suitability of the methodology for each reservoir category, the accuracy of the results and comparison with other risks.

- Review the application of the methodology to flood storage reservoirs and make recommendations on modifications to the methodology for use on such structures.

- Compare risks at flood storage reservoirs with those at ‘normal’ impounding reservoirs and risks in other industries.

- Identify any risk mitigation measures to cover instances of failure of flood storage reservoirs or the design criteria being exceeded.

- Identify any further research required to develop the CIRIA methodology for use on flood storage reservoirs.

2. CASE STUDIES

2.1 Selection of Sites

The five trial sites used in this study were selected by the Environment Agency. A request was sent to all the Agency's Regions asking for possible sites to be identified, together with a list of the type of information that would be required by the research contractor undertaking the studies. The five sites were selected from the responses received using the following criteria:

- the reservoirs should all fall within the provisions of the Reservoirs Act 1975
- at least one reservoir in each flood category (A, B, C and D) should be included
- sufficient information should be provided to enable risk assessments to be undertaken
- various types of inlet and outlet control should be studied.

The five sites selected were as follows:

Site 1: A Category A reservoir which can impound up to 5,500 Ml during a flood. It lies upstream of a large town and is controlled by radial gates.

Site 2: This is a former water supply reservoir which is normally full up to spillway level. It impounds flood water between the spillway and embankment crest. Until 1999, the reservoir was classified in flood Category B, but it was uprated to Category A as a result of development downstream.

Site 3: A Category B washland reservoir, the majority of which is formed by a former railway embankment. Inflows and outflows are controlled by four penstocks.

Site 4: Five off-stream washlands reservoirs which are filled by overflow spillways from an adjacent river. The reservoirs are in flood Category C.

Site 5: A two compartment Category D washland reservoir which takes flood flows over spillways from an adjacent river.

More detailed descriptions of the sites are given in Section 2.4. The locations of the sites are not given in this report: two are in Southern England, the other three in Northern England. All sites contain embankment dams, which are the same as most, if not all, of the Agency's flood storage reservoirs.

2.2 Information used

The information available for the study varied for each reservoir: in general the information was more extensive for the Category A reservoirs, as might be expected since they pose a greater hazard. The following basic information was provided for each reservoir:

- drawings of the works (in the case of the Category B, C and D reservoirs this consisted only of a plan of the site)

- copy of last Inspecting Engineer's report under Section 10 of the Reservoirs Act 1975

- copy of last Supervising Engineer's statement under Section 12 of the Reservoirs Act 1975

- records of any surveillance and monitoring (e.g. settlement, drainage flows, piezometers)

- details of any problems that have occurred and any remedial works undertaken or proposed

- summary of the maintenance that is undertaken (e.g. frequency of grass cutting, debris clearance, inspection of dam for any damage/problems)

- summary of operation during a flood event

- copies of Sections 7, 8 and 9 of the Prescribed Form of Record giving basic information on the reservoir volume, dam type/height, spillway works, weirs, gates, etc.

- dam break flood maps (Site 1 only)

- the Agency's indicative flood maps for the channels downstream of the sites (Sites 2 – 5).

2.3 Methodology

The purpose of the study was to apply the CIRIA methodology to the selected sites. Some changes were, however, made to the methodology to concentrate the work on matters where the unique aspects of flood storage reservoirs could have an effect. This enabled the funds available for the study to be most appropriately directed. Principal changes to the CIRIA methodology were:

- Discussions were held with personnel who were acquainted with the sites to obtain information that would have been gained from site visits.

- No hydrological or hydraulic calculations were carried out to predict the discharge resulting from dam failure or the extent of flooding downstream. Where dam break analyses had been undertaken, the maps resulting from such studies were used in the impact assessment. In other cases, the extent of flooding was assumed to be similar to that on the Agency's indicative flood maps.

- A FMECA analysis was undertaken for all five sites, although the CIRIA report only recommends these be done for those with impact scores in excess of 175.

- An independent quality review was undertaken for one of the flood Category C washlands sites (Site 4). The outcome of this review is discussed in Section 2.4.4.

2.4 Site – Specific Studies

2.4.1 Site 1

Description of site

This reservoir is formed by a 1.3 km long earth embankment with a maximum height of 5.7 m across a flood plain. Flood flows are controlled by three radial gates: a computer system monitors river levels and optimises the operation of the gates. A railway line passes through the site on an embankment and a major road crosses over the flood area on a viaduct. The embankment impounds some 5,580 Ml and has been designated a 'Category A' reservoir in accordance with the ICE 'Floods and Reservoir Safety' publication. The scheme was completed in 1981 and has operated, on average, twice a year since then. It is designed to protect the urban area downstream against flood events up to a 100 year return period. The completed scoring tables are shown in Appendix 1.

Key issues

(a) Related to the dam and reservoir:

- The radial gates are electrically operated and there are back-up systems in the event of power failure.
- The gates, when fully open, were designed to pass the 1 in 10,000 year flood.
- The embankment was designed to allow for some overtopping during an extreme event.
- Crest levelling is carried out every six months.
- The reservoir is well maintained, with a site specific annual maintenance budget.
- A short length of the embankment is constructed over an old silt lagoon.

(b) Related to the area of potential flooding:

- A dam break analysis had been undertaken for the 'near' valley.
- Major urban area some 2 km downstream of site including properties, shops and trading estate.
- Another major town some 25 km downstream.
- Major railway line passes across potential flooded area.

- An industrial site some 4 km downstream.

- Power, water and sewage services would be affected by the flooding.

Impact assessment

The impact assessment was undertaken in accordance with Section 5.2.4 of CIRIA C542. The impacts in the 'near valley' within 5 km of the dam were determined from inspection of the 1:10,000 dam break maps prepared in 1998 and discussions with the Agency's operations staff. Impacts in the 'far valley' (5-30 km) were estimated from the indicative flood maps on the Agency website and from personal knowledge of the area. The impact scores for the near and far valleys were 2395 and 291 respectively, giving a total reservoir impact score of 2686. Our confidence in the accuracy of the far valley score was low because of the lack of detailed information on the maps. This did not, however, have a significant effect on the overall impact score as the total score is heavily weighted in favour of the near valley by the methodology: a 50 % error in the estimate of population at risk in the far valley would only alter the impact score by about 60.

The dam break analysis assumed that dam failure would result from overtopping following a PMF event, in which case much of the area downstream of the reservoir would have been flooded prior to failure. Many properties would therefore have been evacuated in such a situation. A smaller area would be flooded in the more frequent 'design' event of 100 years, but if dam failure occurred during this event, the impact on lives could, in fact, be greater as the 100 year flood defences downstream would be suddenly overtopped.

The reservoir impact score of 2686 results in a 3* grade of risk assessment being recommended in accordance with Section 5.3 of the CIRIA Report. This is the highest level of risk assessment and indicates a potentially high impact in the event of dam failure. This confirms the Category A status of the reservoir.

FMECA risk assessment

The FMECA assessment was undertaken in accordance with Section 5.4 of CIRIA C542. LCI Diagram 13 (embankment dam, height less than 15 m, completion post-1960) was used as the base diagram. Several branches of the diagram were not used because the reservoir was not a 'typical' reservoir full most of the time, and others (e.g. the control structure and silt lagoon) were added.

The highest criticality scores were:

- Twenty-four for failure by overtopping following external erosion by humans/animals.

- Eighteen for liquefaction of silt lagoons in a seismic event. Although this could severely damage the embankment, such an event is most unlikely to coincide with a flood event. This would be more likely to have operational consequences in that remedial works would be required and it may not be possible to impound water to the full depth.

The criticality scores for this high-hazard reservoir were generally low, reflecting the high level of maintenance, monitoring and supervision of the site and the reservoir specific maintenance budget.

2.4.2 Site 2

Description of site

The reservoir was formed in 1837 by the construction of a 150 m long, 3 m high, earth embankment across the valley of a brook. The brook was diverted around the site of the reservoir, with flood flows spilling into the reservoir. It was originally used for water supply, but is now only used for amenity, conservation and flood storage: it is normally full of water up to the crest of a spillway located at the right end of the dam. The flood storage volume is therefore only that between the spillway and embankment crests. A section of the spillway was lowered in 1988 to increase flood storage. The reservoir was classified in flood Category B until the 1999 inspection when it was uprated to Category A as a result of development downstream. The completed scoring tables are shown in Appendix 2.

Key issues

(a) Related to the dam and reservoir:

- Following the increase in flood category, the Inspecting Engineer recommended that the downstream face of the dam should be protected to withstand overtopping flows, and this was being implemented at the time of this study.
- Annual deformation surveys are carried out.
- The reservoir operates automatically during floods with the fixed spillways controlling flows; Agency staff visit the site during floods to check for blockages to the structures.
- There is a programme of regular maintenance visits and inspections.
- Deterioration in brickwork and leakage through it have been identified.

(b) Related to the area of potential flooding:

- A housing estate has recently been built within 100 m of the downstream toe of the dam.
- A major railway line crosses the flood plain some 1.5 km downstream on a viaduct.
- A large retail complex lies some 1.7 km downstream.
- There is a major river some 2 km downstream of the dam with a wide flood plain and a large area of flooded mineral extractions.

Impact assessment

An impact assessment was undertaken in accordance with the CIRIA Report. The Environment Agency provided details of their indicative flood maps together with an Ordnance Survey base map at 1:10,000 scale. This does not, however, indicate flooding of any of the properties at the toe of the dam. Some engineering judgement was used to estimate the likely extent of flooding immediately downstream of the dam: the accuracy of this could be improved by a site visit.

No impact assessment has been undertaken for the ‘far valley’ (5 – 30 km downstream). This is because it is considered that the impact would be minimal: the water discharging from the relatively small reservoir (68,000 m^3) would spread out into the wide flood plain and into the lakes formed by mineral extraction.

The reservoir impact score of 705 results in a 2* grade of risk assessment in accordance with Section 5.3 of the CIRIA Report. This is the type of score that was anticipated for a reservoir in a borderline flood category between A and B.

The impact assessment was carried out on the assumption that the dam failed during an extreme flood event. Since this reservoir contains a substantial amount of water most of the time, a ‘sunny day’ failure by other means such as piping is possible. The impact score from such a failure would be similar to that from an overtopping failure: although there may be an increase in the population at risk from recreation in the downstream valley on a sunny day, this would be offset by the number of people who had vacated their properties in an extreme flood prior to dam failure.

FMECA Risk Assessment

A FMECA risk assessment was carried out using CIRIA LCI diagram 7 (embankment dam, height less than 15 m, completion pre-1840) as the base. The highest criticality score of 24 was allocated to the problem of inadequate spillway capacity leading to overtopping of the embankment: works are now in hand to rectify this problem.

2.4.3 Site 3

Description of site

This is a triangular shaped washlands reservoir formed over the old course of a river. The majority of the reservoir is formed by a former railway embankment some 7 m high and 2.3 km long. The reservoir capacity is stated to be 1,416 Ml and it fills fully during floods exceeding a 30 year return period. Inflows and outflows are controlled by four 1.83 m x 1.52 m penstocks. The reservoir is classified in flood Category B. The reservoir water level is retained below existing ground level to a depth some 4.5 m below maximum operating level and is used as a wildlife sanctuary. A public road crosses the reservoir and divides it into two parts connected by a bridge opening beneath the road. There is a gap in the railway embankment where the road crosses and a subsidiary embankment with a maximum height of some 4 m was constructed to replace this missing section. The completed scoring tables are shown in Appendix 3.

Key issues

(a) Related to the dam and reservoir:

- The crest of the subsidiary embankment was uneven but this had been rectified in April 2000.

- The site is within an area where coal mining has taken place in the past. A report indicated that settlement due to this should have ceased.

- The control penstocks are inspected and tested on a monthly basis.

- The embankments can overtop in extreme (>150 year) flood events.

(b) Related to the area of potential flooding:

- A car park and riding stables adjacent to the subsidiary embankment could be inundated.

- The banks of the river downstream are used by fishermen and pedestrians.

- The river into which impounded water would go passes through a series of heavily urbanised areas beyond 10 km downstream of the reservoir. The flood plain generally contains non-residential property.

Impact Assessment

An impact assessment for the 'near valley' for 5 km downstream of the reservoir was undertaken in accordance with the CIRIA Report. The 'near valley' impact score was 128: this is the sort of figure that would be expected for a Category B or C reservoir.

A 'far valley' impact assessment was also undertaken using the Agency's indicative flood maps to estimate the extent of inundation. This may not, however, be representative of the damage caused by dam failure which would most probably occur during a major flood (in excess of, say, 200 years return period) when much of the area would be flooded anyway prior to the dam failure. Failure during a more frequent event could, however, be more significant if dam failure resulted in the sudden overtopping of flood defences.

The impact score for the 'far valley' was 247, giving a reservoir impact score of 375. This requires a 2* FMECA risk assessment in accordance with the CIRIA Report and confirms the Category B status of the reservoir.

FMECA Risk Assessment

A FMECA risk assessment was carried out using CIRIA LCI Diagram 13 (embankment dam, height less than 15 m completion post-1960) as the basis for the analysis. This was used since the reservoir had been formed in the 1960s although the railway embankment was constructed much earlier. This variation in age of structures is discussed later in this report.

Although the LCI Diagram was used as a basis for the study, many elements were not used (e.g. spillway, pipework) and additional elements were entered separately for the railway and subsidiary embankments. The highest criticality factors were:

- Twelve for instability due to rapid drawdown: low confidence was allocated to this, as there was no mention of the issue in the information provided.

- Eight for settlement leading to overtopping based on a history of settlement.

- Eight for internal erosion, since the watertightness of the embankments is uncertain.

Continuing maintenance of the site so that it is able to perform in a flood event was identified as a key issue. Repairs to make up settlement, filling in bare grass patches and checking the operation of penstocks are all matters that need to be addressed on a continuing basis to ensure good practice maintenance.

2.4.4 Site 4

Description of site

This site contains five washlands reservoirs, formed on areas of flood plain bounded by earthfill embankments on both river banks and by road and railway embankments, spoil heaps and natural ground rising away from the river bank. The embankments along the river are between 3 and 5 m high. They are off-stream reservoirs which are filled by flow over inlet spillways from the river when a flood gate in the river is closed. Outflow from the reservoirs is through pipes discharging into the river with flap valves at their downstream end. The reservoirs are classified in flood Category C. The completed scoring tables are shown in Appendix 4.

Key issues

(a) Related to the dam and reservoir:

- Overtopping of the embankments could occur during floods in excess of 150 year return period.

- Some shallow slips and bare patches identified by the Inspecting Engineer had not been repaired.

- The Supervising Engineer noted a general lack of maintenance and was unable to establish whether valves were being tested and operated.

(b) Related to the area of potential flooding:

- The reservoirs lie upstream of a series of towns and villages.

- The flood plain generally contains non-residential property.

- The Inspecting Engineer considered that the effect of a breach in one or more of the embankments would produce a flood peak of a low order.

Impact Assessment

An impact assessment only for the ‘near valley’ was undertaken in accordance with the CIRIA Report. This was because it was considered that the effect of the flood peak resulting from the reservoir failure would be insignificant in the ‘far valley’.

The impact assessment in the ‘near valley’ was undertaken assuming the extent of flooding was as shown on the Agency’s indicative flood maps and that dam failure occurred in an event greater than the 150 year return period design flood. This gave an impact score of 633, although it is almost certainly too large because much of the area would be flooded in any event prior to the dam failure during such an event. If failure occurred after the peak flow there would be a risk of some people having returned to the previously flooded area. Failure of the reservoir in an event with a return period of less than 150 years could also have a significant effect if it resulted in sudden breaching of the flood defences. The impact score of 633 is in the upper range for a 2* CIRIA assessment, suggesting that the reservoirs should be in flood Category A or B rather than C.

An independent quality review was undertaken for this site. The reviewer undertook the impact assessment from flood levels determined using the ‘rapid dam break’ method given in Sections 5.2.2 and 5.2.3 of CIRIA Report C542: this resulted in an impact score of 450 as opposed to the figure of 633 obtained using the Agency’s indicative flood maps. Although there is a significant difference in score, they both result in a 2* grade of risk assessment being required.

FMECA Risk Assessment

A FMECA risk assessment was carried out using LCI Diagram 13 (embankment dam, height less than 15 m, completion post-1960). Several elements on the LCI Diagram were inapplicable, as for Site No. 3. The highest criticality was 12, for the following elements:

- Instability due to rapid drawdown: the high criticality was due to a low confidence since no information on this matter was available.

- Instability and external erosion leading to overtopping; shallow slips and surface erosion had not yet been addressed.

- Surface erosion on spillways, where a good grass cover was required, but had not yet been addressed.

The independent quality review of the FMECA resulted in much higher criticality scores, the maximum being 60 for erosion of the crest. The difference was mainly due to the way in which individuals allocate scores, and confirmed the need for a review of a group of risk assessments to ensure consistency. The originator and reviewer both agreed on the difficulty in allocating scores without personal knowledge of the site.

2.4.5 Site 5

Description of site

This washland reservoir is formed by earthfill embankments between 3 and 4 m high adjacent to a high level carrier river, also used as a canal: one of the embankments is a railway embankment. Flood flows discharge into the two compartments of the reservoir over spillways from the high level carrier river. Outflow from the reservoir is via pipes to the canal with flap valves. The reservoir was formed in the 1970s, has a capacity of 280 Ml and is in flood Category D. The completed scoring tables are shown in Appendix 5.

Key issues

(a) Related to the dam and reservoir:

- A survey of one embankment had revealed settlement of the embankment, shear movement in the embankment and adjacent ground, and some heave in a drainage channel.

- The site is generally being well maintained.

- There has been some cracking of the outlet structures.

(b) Related to the area of potential flooding:

- The surrounding land is virtually flat agricultural land with a network of drainage channels. There is no valley into which water would obviously flow.

- There are three properties within 300 m of the reservoir, which were not considered to be at risk of inundation by the Inspecting Engineer. There is no indication of flooding in this area on the Agency's flood maps.

Impact Assessment

A simple impact assessment has been undertaken using the bunded reservoir methodology (Section 5.5.3 in CIRIA C542). There are no 'near' or 'far' valleys as such and an inspection of the surrounding land suggests that the only impacts of the seven CIRIA types that could apply would be those for recreation and agriculture. Impact scores of 1 for each of these produces a reservoir impact score of 15, which is well below the minimum score of 175 recommended by CIRIA for a FMECA assessment to be carried out. The low impact score confirms the low risk category of this reservoir.

FMECA Risk Assessment

Although the CIRIA methodology does not recommend a risk assessment for a reservoir with an impact score of 20, a FMECA assessment has been undertaken for the purposes of this study. LCI Diagram 13 was used as the base diagram. The most critical elements identified were:

- Instability under rapid drawdown: a low confidence factor value was allocated due to lack of information.

- Overtopping of embankments following settlement. There has been settlement in the past, which is now being monitored.

- Internal erosion: there is no information on the watertightness of the embankments.

- External erosion due to cattle, humans and rutting.

3 RELATIVE RISK

3.1 Comparison of risks at trial sites

The CIRIA methodology suggests that a comparison of risks at different sites be made by multiplying Criticality scores by the Impact Score. A summary of the maximum Criticality and Impact Scores for the five test sites is given below.

Site	**Impact Score**	**Max Criticality**	**Impact x Criticality**
1	2686	24	64,464
2	705	24	16,920
3	375	12	4,500
4	633	12	7,596
5	15	12	180

It should be noted that it is believed that some of the Impact Scores (especially for Sites 1 and 4) are greater than they should be because the figures include damage to areas naturally flooded prior to the dam failure. The above table may not, therefore, give a true picture of relative risk at the five sites. Assuming, for comparative purposes, that the above figures are correct, it shows the risks at Site 1 to be much greater than at the others. In fact, all elements with a Criticality greater than 6 at Site 1, when multiplied by its Impact Score of 2686, would be more significant risks than the most critical element at Site 2.

The impact assessments were all carried out on the assumption that dam failure occurred during a major flood. In such circumstances the Agency's flood warning system should ensure that much of the potentially flooded area was vacated at the time. Exceptionally, a 'sunny day' failure at Site 2, the reservoir which is normally full, and retains water above ground level, may in fact pose the greatest hazard at any of these sites. A more detailed analysis involving a site visit would be required to identify the true impact score.

3.2 Comparison with risks in other industries and at impounding reservoirs

3.2.1 Other industries

It is difficult to compare the recent safety record of UK dams with other industries because there have been no known fatalities since 1925 as a result of dam failure. Failures causing one or more deaths occurred on 12 occasions between 1831 and 1925, suggesting an improvement with the introduction of reservoir safety legislation in 1930. The CIRIA Report C542 discussed other industries with which UK dams could be compared, and this is summarised as follows:

- *Nuclear industry:* nuclear incidents have the potential to affect large areas: the precise area affected would be determined principally by wind, weather patterns, topography and geology, depending on the type of incident. The number of fatalities is also difficult to predict. This is in contrast to a dam incident, where the area at risk can be well defined. The probability of a major incident in the UK is considered to be very low.

- *Offshore industry:* this is a highly dangerous industry with hazards including oil, gas, fire, explosion and a limited number of people at risk working in a confined area. It is hazardous to those working in the industry but there is little risk to the public at large.

- *Industrial plant:* there are major hazards identifiable at factories and other industrial sites such as fire, explosion, toxic release and pollution. Risks are generally low, but incidents have occurred in the UK. As with nuclear incidents, the effect on the local area is dependent on weather conditions, especially the wind. A particular problem with existing installations is that it is not practicable to force people to move from nearby housing that was built before the risks posed by hazardous installations were recognised: this is a similar situation to population at risk downstream of dams.

3.2.2 Other Dams

The CIRIA Report considered risk levels associated with dam failure in terms of human, economic and environmental loss. The effect of such losses at flood storage reservoirs is considered as follows:

- The tolerable level of human loss should be no different to that at a 'normal' reservoir. Risk levels should be in line with the criteria published by the Royal Society Study Group in 1992 as follows:

  'While it is clearly not possible to set single quantitative guidelines on risk acceptability, some broad indicators of the current position can be noted. If the average expectation of life is 70 to 75 years, then the imposition of a continuing annual risk of death to the individual of 0.01 seems unacceptable. At 0.001 it may not be totally unacceptable if the individual knows of the situation, enjoys some commensurate benefit, and everything reasonable has been done to reduce the risk. At the other extreme, there are levels of assumed risk so low that the manager or regulator can regard them as trivial. The Study Group judges this figure to be commonly about one in a million.'

- The loss of business, factories, farmland, infrastructure, utilities etc. directly attributable to failure of a flood storage reservoir may not be substantial because much of the damage may occur anyway in a major flood whether or not there was a dam failure due to the extensive fluvial flooding.

- The loss to the Agency of its flood storage asset would have an economic effect from the additional flooding caused by its failure and which could be the subject of legal proceedings. There would also be costs incurred in reconstructing the reservoir or providing alternative flood defence measures. The Agency would also be subject to adverse media reaction in the event of reservoir failure.

- Environmental damage resulting from failure of a flood storage reservoir should be less than that from a 'normal' reservoir which would be expected to release substantial quantities of silt downstream. If, however, the flood storage reservoir was a nature conservation area, was used for recreation or other amenity use, then there would be some environmental loss which, depending on the extent of dam failure, could probably be reinstated.

It is considered that appropriate risk levels for flood storage reservoirs should be in line with those proposed in Section 2.4.4 of CIRIA Report C542: this suggests that the ALARP principle should apply, i.e. that where improvements involve investment costs then these costs should not be grossly disproportionate to the reduction in risk obtained by carrying out the work. (ALARP stands for '**A**s **L**ow **A**s **R**easonably **P**racticable'). The CIRIA Report also recommends following the HSE approach for hazardous installations. Where a risk management approach is adopted for dams, a period within 30 years is suggested for full implementation of the appropriate standards. This approach allows the dams posing the greatest hazard to be identified and be the initial focus of appropriate and effective risk-reduction techniques. Such a long delay in full implementation may not be appropriate for FSRs.

4. REVIEW OF CIRIA METHODOLOGY

4.1 Introduction

The CIRIA methodology was developed for application to any reservoir falling within the provisions of the Reservoirs Act 1975. These are defined as reservoirs holding more than 25,000 m^3 of water as such above the natural level of any part of the land adjoining the reservoir (including the bed of any stream). Specific benefits of the approach were considered to be (Hughes, Hewlett and Elliott, 2000):

- prioritising the implementation of safety recommendations and remedial works
- prioritising maintenance
- planning a surveillance, monitoring and instrumentation strategy
- identifying possible failure modes requiring detailed investigation and analysis
- checking that all hazards at a reservoir are systematically identified and considered
- preparation of emergency plans for dam operation and interaction with emergency services
- identifying the financial risk associated with the failure of a dam
- providing comparison with hazards in other industries
- avoiding complacency in respect of dam safety.

This study has confirmed that such benefits can be obtained from using the methodology on flood storage reservoirs. It has, however, identified some problems in the detailed use of the methodology which are discussed in the following sections.

4.2 Impact Assessment

4.2.1 Estimating the extent of flooding

Because of the limitations attached to this pilot study, no hydrological or hydraulic analyses were carried out to predict water levels downstream of the reservoirs in the event of dam failure. The impact assessments were, instead, based on a dam break analysis (Site 1), and the Agency's indicative flood maps (Sites 2-5). The dam break analysis that had been undertaken for Site 1 also investigated the extent of flooding in a PMF event which, not surprisingly, flooded a much greater area than shown on the Agency's maps, which are based on events in the 100 – 200 year return period range. The flood resulting from dam failure was, in fact, no worse than the PMF because it was predicted to occur several hours after the peak of the PMF. The PMF further downstream of the major urban area, beyond about 4 km of the dam, was not significantly different to the Agency's flood maps. Whilst evidence from this site suggests that the Agency's flood maps could be used for the 'far valley' impact assessment, similar dam break studies at other sites would be needed to confirm this.

The Agency's indicative flood maps were used in the impact assessments for Sites 2-5. These should give a good indication of the area that would be affected in the event of dam failure. There are, however, problems in using these maps:

- Dam failure is most likely to occur during a flood of the magnitude associated with the Agency's maps: there would therefore be an additional area flooded in the 'near valley', probably rapidly, following failure of the dam.

- There are difficulties in estimating the extent of the effect of the dam break on flooding downstream. At Site 2, for example, the flow from the reservoir discharged into a very wide flood plain a few kilometres downstream and it was assumed that there would be little direct effect from the dam break beyond this point. Outflow from a reservoir above a long valley of uniform cross-section would affect flooding much further downstream.

It is difficult to generalise the effect that failure of any dam will have on the extent of flooding downstream. It is considered that the Agency will have to look at its flood storage reservoirs on a site-by-site basis to determine the effect their failure will have on downstream flooding and identify the 'worst case' scenario as far as downstream impact is concerned. In the case of high-hazard reservoirs this would necessitate full dam-break modelling, while for lower hazard ones it should be sufficient to add dam-break flows to the models used in preparing the Agency's indicative flood maps. For sites where no Agency flood models or maps are available, then an analysis in accordance with Section 5.2.2 of the CIRIA report would suffice. In addition to investigating dam failure at the design flood for the reservoir (e.g. a PMF in the case of a Category A reservoir), it may also be necessary to look at failure during floods of lower magnitude when the effect of sudden flooding downstream may be more significant. As well as considering dam failures during flood events, the effect of a 'sunny day' failure on a normally full reservoir such as at Site 2 should also be investigated: although the flow from such a failure would be less, it could be more catastrophic since flooding would be unexpected downstream.

4.2.2 Predicting the impact of flooding

This is the process of allocating scores for specific impacts from the flooding and estimating the Population At Risk (PAR). It was undertaken for all the trial sites from an assessment of damage within the flooded area. Two significant problems were identified:

1. A lack of detailed local knowledge was a handicap in undertaking this work. The assessments were carried out using 1:10,000 OS plans, and, whilst the existence of residential properties, industrial sites, shops, roads, etc. were obvious, the number of people at risk could not be easily estimated. The type of property, the size of shops, the type of factory or industrial plant could not be ascertained from the maps. This made scoring of the impacts difficult. It is particularly important that the best estimate of PAR is made since this has the greatest influence on the overall impact score. This problem should be eliminated if impact analyses are scored by local Agency personnel or the Supervising Engineer who can visit the area at risk of flooding.

2. The impact scores derived in this study are probably all too high, except for Site 2 which is the reservoir that is normally full. This is because the impact scoring counts all the impacts on the valley and infrastructure: this includes those flooded as a result of the severe flood event occurring at the time of dam failure. The most realistic scenario is for the valley to be severely flooded prior to the dam failure, in which case many of the properties, schools, shops, etc. would have been evacuated. The impact mainly attributable to dam failure is that from the dam break 'wave' on properties and infrastructure at a level just above the area already flooded also taking into account the effects on 'barrier banks' remote from the main river embankments. There could also be some additional impact from the higher velocity of a dam break 'wave' in damaging buildings, power lines, etc. already flooded.

4.2.3 Need for impact assessment

The impact assessment in the CIRIA report has two uses:

1. To determine the level of FMECA risk assessment required in accordance with Section 5.3 of the report.

2. To enable a comparison of risks at different sites to be made either just by comparing reservoir impact scores, or by multiplying criticality factors by impact scores at various reservoirs to determine the most critical items.

Since this study has identified a number of problems in application of the impact assessment methodology, it is worth reviewing the need for one to be undertaken. In most cases the effect of failure of a flood Category C or D reservoir will be minimal and the need for an impact assessment unjustified. This should, however, be confirmed on a site-by-site basis, considering the effect that failure would have if it occurred during a major flood: it is possible that in some cases there could be properties at a level just above the indicative flood lines which could be affected in the event of dam failure. For reservoirs which do pose a significant risk to life and property, then an impact assessment, especially for Category A reservoirs, should be undertaken for the Agency's own contingency planning purposes taking account of any local impacts (e.g. breaches in flood storage reservoir embankments remote from the main river channel).

4.3 FMECA Risk Assessment

Application of the CIRIA FMECA risk assessment methodology was more straightforward than that of the impact assessment. Problems identified included the following:

- Although a substantial amount of information was available in the form of drawings, reports, etc., the lack of personal knowledge gained from a site visit was a drawback. The CIRIA methodology was developed on the assumption that the FMECA assessment would be undertaken with a close personal knowledge of the site, such as the Supervising Engineer, which has been confirmed by this study.

- A different thought process is required to 'normal' reservoirs in that the assessor needs to continually consider the effect that filling will have on a normally empty reservoir.

- Operational procedures during a flood event are critical to the safe operation of a flood storage reservoir and it is important that operational procedures are set down in the flood operations manual and implemented by staff who are trained in their dissemination and operation of gates, clearance of blockages, etc.

- Routine maintenance is essential so that a flood storage reservoir can function successfully on the few occasions that it has to. Key maintenance activities include: keeping spillways clear; regular testing of gates; making good any bare patches of grass and regularly visiting the site in case of damage by animals or humans (especially vandalism). This is facilitated by having flood storage reservoir site specific maintenance budgets.

- At reservoirs where there is a history of settlement, regular levelling (and making up of levels if required) is necessary: this would usually be required by the Inspecting Engineer under the Reservoirs Act 1975.

- It is difficult to predict whether leakage from a flood storage reservoir is a problem when there is little evidence from the rare occasions it floods. The assessor needs to consider the condition and properties of the embankment, the time for which the reservoir impounds and any knowledge of historical leakage in allocating scores.

- Rapid drawdown can be a critical factor in the stability of flood storage embankments and this should be considered as a matter of course in FMECA assessments of them.

- While the LCI diagrams are a useful tool in undertaking the analyses, several changes needed to be made for use on some of the flood storage reservoirs, and a separate LCI Diagram for flood storage reservoirs has been prepared as part of this study and is included in this report. Changes were mainly related to the spillways and inlet/outlet works.

- The LCI diagrams contain suggested values for 'Consequence' scores which vary according to the age of the dam. Some of the test sites had embankments of varying ages (e.g. an old railway embankment and newer flood defence embankments). Some engineering judgement is needed in such situations and it may be worth having separate LCI elements for each type (and age) of embankment (this was not done in the test cases due to a lack of knowledge of the properties of the embankments).

4.4 Development of methodology for other flood storage reservoirs

The aspect of the CIRIA methodology requiring most attention is the impact assessment, to address the problem of the valley already being significantly flooded at the time of dam failure. It is necessary to assess the increase in flooding resulting from dam failure during a major flood.

The tools for such an assessment are readily available (dam-breach models, EA models used for flood mapping etc.). The difficulty lies, as in all dambreak modelling, in judging the mode and time of dam failure, and the flood return period to be used in the modelling. The ‘least unlikely’ mode of failure of a flood storage reservoir embankment would be through overtopping of an embankment leading to erosion. In the event of embankments being designed not to overtop, then other failure modes such as piping would be applied.

It is suggested that two dambreak scenarios be investigated:

1. Failure during a flood corresponding to the Agency’s indicative flood maps.

2. Failure at the peak of the reservoir design flood (PMF for Category A, 1 in 10,000 year for Category B).

For scenario 2, it would be necessary to model the extent of flooding downstream in the reservoir design flood prior to dam failure, to determine the impact of the dambreak ‘wave’.

The scoring of specific impacts in the area inundated by the dambreak could then proceed in accordance with the CIRIA methodology for the worst case of the two scenarios outlined above: this will not necessarily be the larger scenario 2 flood as the increase in depth of flow in the valley should be less than under scenario 1. The location of properties etc. would also affect which of the scenarios was the worst case.

The FMECA risk assessment methodology was designed to be flexible, with the option of deleting or adding branches on the LCI diagrams. A more ‘user friendly’ LCI diagram for flood storage reservoirs has been developed during this study, with the deletion of most of the outlet works branches and the addition of such items as rapid drawdown (Figure 1). This LCI diagram is included in this report and should be applicable to most flood storage reservoirs. It will, however, still be necessary for the assessor to consider the need for additional branches on a site-specific basis. In the case of reservoirs which hold water all the time (as at test site 2) then the appropriate CIRIA LCI diagram should be used. For any flood storage reservoirs with concrete dams, the appropriate CIRIA LCI diagram should be applied, while scrutinising the ‘special flood storage reservoir’ LCI diagram for any other elements that should be considered.

4.5 Consistency of application

When the CIRIA methodology is used to compare risks at more than one reservoir, it is important that a consistent approach is adopted to all the reservoirs to avoid anomalies caused by abnormally high or low scoring of different assessors.

There should be little scope for inconsistency in the estimation of the extent of flooding provided rules for the dambreak scenarios are developed and followed. There could be anomalies in the allocation of impact scores from the categories of disruption (none/minor/appreciable/significant/major) but such anomalies are only likely to differ by one grade which would not significantly affect the overall impact score. The population at risk (PAR) is the key factor affecting the impact score and this should be estimated to the best of the assessor’s ability by local knowledge and a site visit if needed.

It is in the FMECA risk assessment where there is the greatest scope for inconsistencies. If, for example, one person allocated scores of 2 for Consequence, Likelihood and Confidence for a particular element and another gave a score of 3 to each item, the Criticalities from the two assessments would be 8 and 27: a substantial difference. Personnel undertaking the assessments should be directed to the guidance in Section 5.4.2 of the CIRIA report on the allocation of scores. If the assessor has doubts, then he/she should allocate a high Confidence score (i.e. low in confidence) to an element so that it is picked up at a later stage.

In order to ensure consistency of results within the Agency, it is suggested that all the assessments are reviewed by one suitably experienced person (e.g. a Reservoirs Panel Engineer) who feeds back comments to the assessment teams.

4.6 Mitigation of Risks Downstream

A risk assessment should help reduce the risk of failure of a flood storage reservoir to an acceptable level. There will, however, always remain a small chance of failure, especially if the design flood is exceeded. It is therefore advisable to have plans to deal with such an event. It is envisaged that these plans would include:

- Identification of areas where life and property could be at risk.

- Preparation of contingency plans, which should embrace all aspects of organisation and the procedures to be followed. This should clearly define the responsibilities of the Agency and of the various emergency services, together with a chain of command. Key personnel and their telephone numbers should be identified, and it should be clear who should make decisions, especially involving evacuation of properties.

- The contingency plan and associated maps should be regularly reviewed, and personnel trained in their duties in the event of a dam failure.

In many cases the above plans will involve an expansion of ones already in place to deal with major fluvial floods.

4.7 Approach for Agency flood storage reservoirs

A consistent approach to undertaking risk assessments at all the Agency's 109 flood storage reservoirs falling within the provisions of the Reservoirs Act 1975 is desired. It is not considered that any detailed assessments are likely to be required for flood Category C and D reservoirs: their failure should not have a significant effect on life and property downstream. (Note that although the impact assessment for test site 4 produced a high impact score, this was due to the natural flooding rather than that from a dam failure). A brief assessment of the effect of the failure of a Category C or D dam during a major flood should be undertaken from an inspection of the Agency's flood maps to identify any potential impacts above the naturally flooded area.

The suggested procedure for dams in flood Categories A and B is:

1. Identify the areas directly affected by dam failure over and above those subjected to natural flooding. This should be done for dam failure in (a) floods equivalent to the Agency's indicative flood maps and (b) the reservoir design flood.

2. Undertake an assessment of the impact of flooding in accordance with Section 5.2.4 of the CIRIA report. This should only consider the impacts in those areas directly subjected to the dambreak flood.

3. Determine the type of FMECA risk assessment from Section 5.3 of the CIRIA report.

4. Where necessary, a FMECA risk assessment should be undertaken by someone well acquainted with the reservoir (e.g. the Supervising Engineer). The LCI diagram included in this report for flood storage reservoirs should be applicable for most sites.

5. All FMECA risk assessments in a large group (e.g. one or more Agency Regions) should be reviewed for consistency by a suitably qualified individual (e.g. a Reservoirs Panel Engineer).

6. Address high risk elements.

7. Prepare contingency plans for use in the unlikely event of failure.

8. Maintain and update risk assessment and contingency plan as required. Circumstances that could necessitate a review include:

- alterations to the reservoir

- alterations to the inundated area downstream of the dam

- changes in inspection and maintenance procedures (e.g. a reduction in the frequency of visits by Agency staff to test gates, clear blockages etc

- updated knowledge on risk assessments.

5 SUMMARY

5.1 Conclusions

This study has confirmed that the risk assessment methodology in CIRIA Report C542 is broadly applicable to flood storage reservoirs. Some problems in its detailed use have, however, been identified which need to be addressed before using it on all the Agency's flood storage reservoirs. Particular issues identified included:

- Detailed local knowledge is required to undertake the impact assessment.

- FMECA risk assessments are best undertaken by personnel who have visited the site and are well acquainted with details of the reservoir (e.g. the Supervising Engineer).

- There are problems in separately identifying impacts downstream of a reservoir caused by dam failure on top of a valley already naturally flooded.

- Operation and maintenance are key issues in ensuring that flood storage reservoirs function successfully when required and site specific maintenance budgets should be allocated to flood storage reservoirs.

- Many of the items on the CIRIA LCI diagrams are inapplicable and others need to be added specially for flood storage reservoirs.

5.2 Further work

Before risk assessments are carried out on all the Agency's flood storage reservoirs, a study should be undertaken to investigate the increase in flooding directly attributable to dam failure on a valley already subjected to flooding. This should investigate (a) a flood corresponding to the Agency's indicative flood maps and (b) at the peak of the reservoir design flood. It is suggested that this is undertaken using available dam breach and hydraulic modelling software for a limited number of flood storage reservoirs. The dam break or other appropriate software would be used to obtain the breach size and flow rates whereas the hydraulic model (which should already exist downstream of most sites) would help to assess the flood area and depth. The studies could be based on a number of different combinations of dam failure and river flood flows, with each combination having a specific probability of occurrence. The results of these analyses should be compared with those based on the 'quick' method in Section 5.2.2 of CIRIA Report C542 (this method assumed negligible flow downstream at the start of the dambreak event and would therefore require modification). These studies should enable a methodology to be developed for the impact assessment of other Agency flood storage reservoirs.

5.3 Risk assessments at other Agency flood storage reservoirs

Once the study recommended in Section 5.2 above has been carried out, the following procedure is recommended for risk assessment of the Agency's flood storage reservoirs. (Note that it is recommended that this should include the sites tested in this study, with them being undertaken by people better acquainted with the reservoirs).

1. For flood Category A and B reservoirs the area directly attributable to flooding from a dam failure should be identified using the procedure to be developed.

2. For Category C and D reservoirs, a brief assessment of the effect that their failure could have on life and property downstream should be undertaken. This should be done from an assessment of the Agency's indicative flood maps, with particular attention being paid to any potential impacts just above the naturally flooded area. If any significant impacts are identified, then the dam failure should be analysed in the same way as for a Category A or B reservoir. If there are no significant impacts identified, then no further risk assessment need be undertaken.

3. An impact assessment should be undertaken in accordance with Section 5.4.4 of the CIRIA report. This should consider only those impacts attributable to the dambreak flood.

4. If the impact score is above 175, a FMECA risk assessment should be carried out by someone well acquainted with the reservoir.

5. Carry out a review of all FMECA risk assessments in the Agency. This should be carried out by a single experienced reservoir panel engineer to ensure consistency.

6. Address high risk elements and maintain/update the risk assessments as required.

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Royal Society Study Group, 1992. *Risk: Analysis, Perception and Management.*

Consequences: How directly is failure of this element related to complete (or partial failure) of the dam. (1 low, 5 high)
Likelihood: What is the likelihood of failure of this element? (1 low, 5 high)
Confidence: What is your confidence in the predictions of consequence and likelihood? (5 low, 1 high)

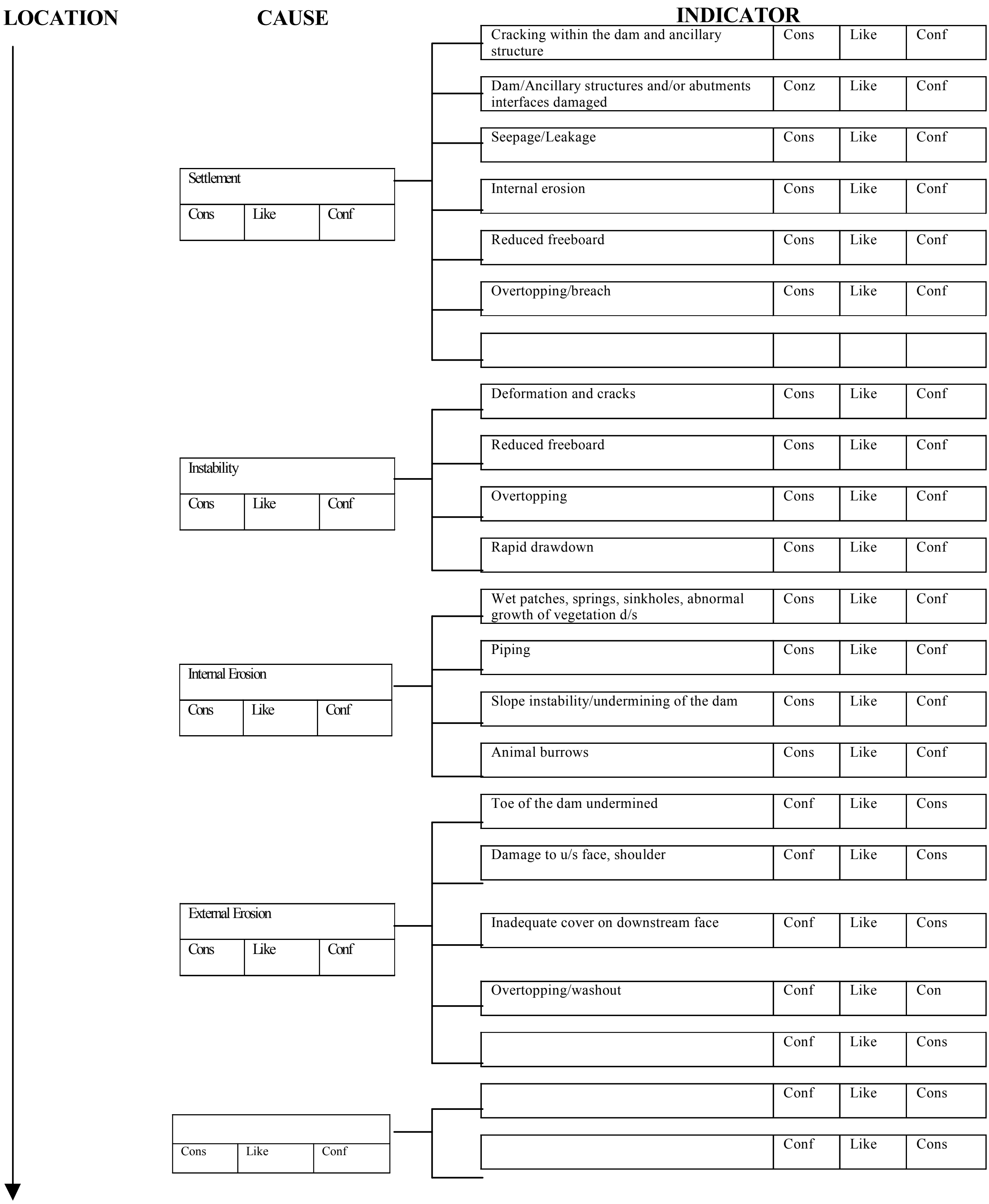


Figure 1. LCI diagram for Flood Storage Reservoirs

Figure 1 (continued from previous page)

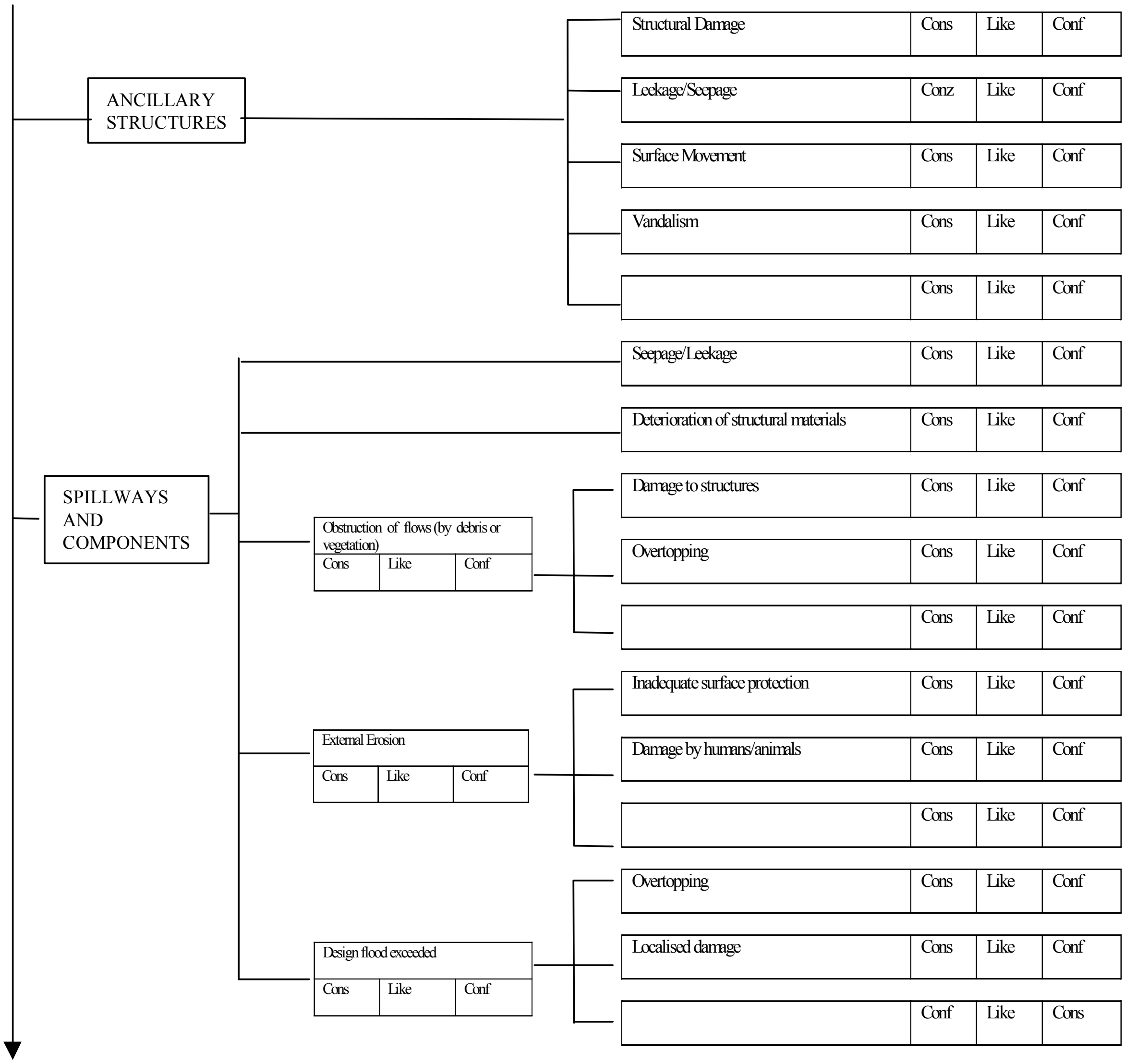
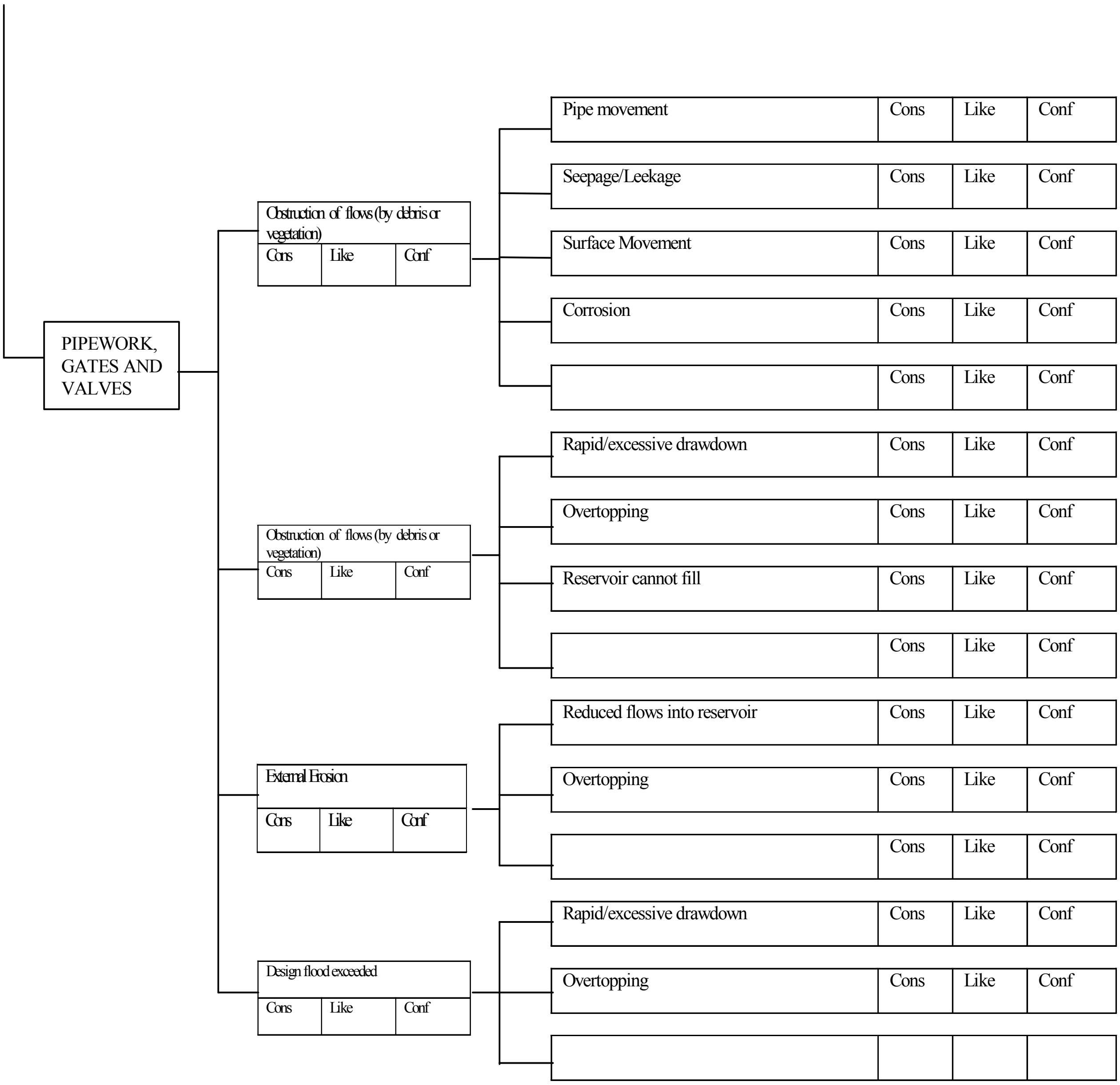


Figure 1 (continued from previous page)



Note: the above diagram should be completed separately for each embankment of significantly different age or design.

APPENDICES

Appendix 1 Scoring Tables, Site 1

TABLE 3 – NEAR VALLEY IMPACT ASSESSMENT – SCORE JUSTIFICATION
Site: SITE 1
Date: JUNE 2002 By: HKBR

Impact	Comment	Impact Score (0-4)	PAR Score
1 Residential Property	Housing in Town	4	2500
2 Non Residential Property	No hospitals, but shops and at least one school. Trading estate downstream of Town.	4	1500
3 Transportation Infrastructure	L to H railway line	3	100
4 Recreational Sites	Impact could be major on a 'sunny day'. Impact could only occur following extreme wet spell, and river flows unsuitable for canoeing. Assume 'Appreciable' in case of camping.	2	50
5 Industrial Sites	Industrial site downstream of Town	3	-
6 Utilities	Regional power/water supplies affected. Sewage works downstream of Town	3	-
7 Agriculture / Habitats	Farmland either side of Town.	2	-

Table 4 – Far Valley Impact Assessment – Score Justification
Site: SITE 1 Date: JUNE 2002
By: HKBR

Impact	Comment	Impact Score (0-4)	PAR Score
1 Residential Property	Various villages and principally Major town.	4	4000
2 Non Residential Property	Major impact assumed in centre of Major town.	4	2000
3 Transportation Infrastructure	Road and rail routes ➛ major international infrastructure.	4	500
4 Recreational Sites	As for near valley, impact would be major on a 'sunny day'. Dam failure and release of water only possible following wet spell. Assume 'significant' with camping in valley.	3	100
5 Industrial Sites	Assume 'appreciable' in Major town.	2	-
6 Utilities	Assume significant disruption.	3	-
7 Agriculture / Habitats	Substantial farming, archaeological remains, etc. in valley.	3	-

Table 5 – Reservoir Impact Assessment Summary Sheet

Site: **SITE 1**

Date: **JUNE 2002**

By: **HKBR**

NEAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK	
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value	
Impact 1	Residential Properties	4	0.15	0.60	2500	
Impact 2	Non Residential Properties	4	0.15	0.60	1500	
Impact 3	Transportation Infrastructure	3	0.10	0.30	100	
Impact 4	Recreational Sites	2	0.05	0.10	50	
Impact 5	Industrial Sites	3	0.25	0.75	---	
Impact 6	Utilities	3	0.25	0.75	---	
Impact 7	Agriculture / Habitats	2	0.05	0.10	---	
		Total Near Valley Score[1] =		**3.20**	Total PAR =	4150
					Pot^n loss of life[2] = (0.5 x PAR)	**2075**

Table 5 (continued)

FAR VALLEY ASSESSMENT		IMPACT: Impact Score (0 – 4)	IMPACT: Weight	IMPACT: Score (Score x Weight)	PEOPLE AT RISK: PAR Value
Impact 1	Residential Properties	4	0.15	0.60	4000
Impact 2	Non Residential Properties	4	0.15	0.60	2000
Impact 3	Transportation Infrastructure	4	0.10	0.40	500
Impact 4	Recreational Sites	3	0.05	0.15	100
Impact 5	Industrial Sites	2	0.25	0.50	---
Impact 6	Utilities	3	0.25	0.75	---
Impact 7	Agriculture / Habitats	3	0.05	0.15	---
		Total Far Valley Score[3] =		**3.15**	

Total PAR =	6600
Pot^n loss of life[4] = $(PAR^{0.6})$	**196**

Combined Impact Score	Score	Factor	Total
Near Valley Score[1]	3.20	100	320
Near Valley Pot^n Loss of Life[2]	2075	1	2075
Far Valley score[3]	3.15	30	95
Far Valley Pot^n Loss of Life[4]	196	1	196
Reservoir Impact Score =			**2686**

Table 6 – LCI Diagram Score Justification

Site: SITE 1

Sheet 1 of 3

Date: June 2002

By: HKBR

Element:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dam body, foundations & abutments	Settlement	Cracking within dam/structures – good maintenance.	2	1	1	2
		Internal erosion : land drains beneath dam.	4	2	2	16
		Overtopping : levels taken to minimise variation in crest level.	4	2	2	16
	Instability	Deformation/cracks : rapid drawdown during flood affecting u/s face.	3	1	2	6
	Internal erosion	Piping : burrowing animals could create potential wet patches etc : good maintenance minimises risk.	4	2	2	16
	External erosion	Toe of dam undermined : risk at control structure where gabions in poor condition.	2	3	2	12
		Damage to upstream face : wave damage during impounding : too short a time for serious damage.	3	2	1	6
		Overtopping : damage by humans/animals leaving bare patches susceptible to erosion.	4	3	2	24

Table 6 – LCI Diagram Score Justification **Date: June 2002**
Site: SITE 1
Sheet 2 of 3 **By: HKBR**

Element:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dam, etc.	Seismic	Liquefaction of silt lagoon (ref. Atkins' report of December 1998). Seismic event unlikely to coincide with flood event.	3	2	3	18
Control Structure	Obstruction of flows	Damage to structures –Debris hitting/blocking gates; gates should withstand low velocity impact; debris most likely to prevent closure of gate: risk of flooding d/s but not dam failure.	2	2	2	8
	Gate failure	Back-up power/hand operation means unlikely – especially for all 3 gates.	3	2	1	6
	Gate failure caused by seismic event	Low probability – ref. Atkins' report dated 1998.	2	1	2	4
	Vandalism	In unlikely event of vandals rendering gate(s) inoperable, some should be in the raised position and impounding would be limited. Timing of vandalism would have to shortly precede flood event.	2	1	2	4

Table 6 – LCI Diagram Score Justification
Site: SITE 1
Sheet 3 of 3

Date: June 2002
By: HKBR

Element:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Ancillary structures	P gate failure	Unlikely to occur; flow through culvert not significant in major flood event	1	2	2	4
	Pipes damaged (at H, P & L)	Pipe movement: no history in first 20 years Seepage/leakage: no history in first 20 years Surface movement: fracture of pipe could occur	2 2 4	2 2 2	2 2 2	8 8 16

Table 7 – Risk Summary Table
Site: SITE 1 **Date: June 2002**
Sheet 1 of 2 **By: HKBR**

Element Ref. Location	Element Ref. Cause / Indicator	Criticality Score	Crit. Rank	Cons. X Like.	C x L Rank	Conf. Score	Conf. Rank	Impact Score = 2686 Risk Score (Impact x Criticality)
Dam etc	External erosion/overtopping	24	1	12	1	2	2=	64,464
Dam etc	Seismic/liquefaction of silt lagoon	18	2	6	6=	3	1	48,348
Dam etc	Settlement/internal erosion	16	3=	8	2=	2	2=	42,976
Dam etc	Settlement/overtopping	16	3=	8	2=	2	2=	42,976
Dam etc	Internal erosion/piping	16	3=	8	2=	2	2=	42,976
Anc Struct	Pipes damaged/surface movement	16	3=	8	2=	2	2=	42,976
Dam etc	External erosion/toe undermined	12	7	6	6=	2	2=	32,232
Control Struct	Obst'n of flows/damage by debris	8	8=	4	10=	2	2=	21,488
Anc Struct	Pipes damaged/pipe movement	8	8=	4	10=	2	2=	21,488
Anc Struct	Pipes damaged/seepage	8	8=	4	10=	2	2=	21,488

Table 7 – Risk Summary Table
Site: SITE 1 **Date: June 2002**
Sheet 2 of 2 **By: HKBR**

Element Ref.		Criticality Score	Crit. Rank		Cons. X Like.	C x L Rank		Conf. Score	Conf. Rank		Impact Score = 2686
Location	Cause / Indicator										**Risk Score** (Impact x Criticality)
Dam etc	Instability/Deformation	**6**	**11=**		**3**	**13**		**2**	**2=**		**16,116**
Dam etc	External erosion/Damage to u/s face	**6**	**11=**		**6**	**6=**		**1**	**15=**		**16,116**
Control Structure	Gate failure	**6**	**11=**		**6**	**6=**		**1**	**15=**		**16,116**
Control Structure	Gate failure/seismic	**4**	**14=**		**2**	**14=**		**2**	**2=**		**10,744**
Control Structure	Vandalism	**4**	**14=**		**2**	**14=**		**2**	**2=**		**10,744**
Anc Struct	P gate failure	**4**	**14=**		**2**	**14=**		**2**	**2=**		**10,744**
Dam etc	Settlement/Cracking	**2**	**17**		**2**	**14=**		**1**	**15=**		**5,372**

Table 8 – Summary of Highest Risk Elements

Site: SITE 1 **Date: JUNE 2002**

Sheet 1 of 1 **By: HKBR**

Element Ref. Location	*Cause / Indicator*	Criticality Score	Crit. Rank		Cons. X Like.	C x S Rank		Conf. Score	Conf. Rank		*Comment*
Dam etc	External erosion/overtopping	**24**	**1**		**12**	**1**		**2**	**2**		Dam will overtop in extreme events
Dam etc	Seismic/liquefaction of silt lagoon	**18**	**2**		**6**	**6=**		**3**	**1**		Seismic and flood events unlikely to coincide
Dam etc	Settlement/internal erosion	**16**	**3=**		**8**	**2=**		**2**	**3=**		Land drains beneath dam
Dam etc	Settlement/overtopping	**16**	**3=**		**8**	**2=**		**2**	**3=**		Regular levelling to check crest at uniform level
Dam etc	Internal erosion/piping	**16**	**3=**		**8**	**2=**		**2**	**3=**		Burrowing animals
Ancillary Structures	Pipes damaged/surface movement	**16**	**3=**		**8**	**2=**		**2**	**3=**		Culverts beneath dam could fracture

Appendix 2 Scoring Tables, Site 2

TABLE 3 – NEAR VALLEY IMPACT ASSESSMENT – SCORE JUSTIFICATION

Site: SITE 2 **Date:** AUG 2002
By: KHBR

Impact	Comment	Impact score (0-4)	PAR Score
1 Residential Property	Mainly properties between reservoir and Great Cambridge Road; estimate 75 properties : site visit required	3	500
2 Non Residential Property	Schools and retail park to south may be affected. Flooding rather than loss of life	2	500
3 Transportation Infrastructure	Main road may be affected	2	50
4 Recreational Sites	Recreation ground and water park	2	50
5 Industrial Sites	Assume light industrial	1	-
6 Utilities	Local loss of distribution	1	-
7 Agriculture / Habitats	No farming : open ground used for recreation	0	-

Table 5 – Reservoir Impact Assessment Summary Sheet **Date: AUG 2002**

Site: SITE 2 **By: KHBR**

NEAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
Impact 1	Residential Properties	3	0.15	0.45	500
Impact 2	Non Residential Properties	2	0.15	0.30	500
Impact 3	Transportation Infrastructure	2	0.10	0.20	50
Impact 4	Recreational Sites	2	0.05	0.10	50
Impact 5	Industrial Sites	1	0.25	0.25	---
Impact 6	Utilities	1	0.25	0.25	---
Impact 7	Agriculture / Habitats	0	0.05	0	---
		Total Near Valley Score[1] =		**1.55**	Total PAR = 1100
					Pot^n loss of life[2] = (0.5 x PAR) **550**

Table 5 (continued)

FAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
Impact 1	Residential Properties		0.15		
Impact 2	Non Residential Properties		0.15		
Impact 3	Transportation Infrastructure		0.10		
Impact 4	Recreational Sites		0.05		
Impact 5	Industrial Sites		0.25		
Impact 6	Utilities		0.25		
Impact 7	Agriculture / Habitats		0.05		
		Total Far Valley Score[3] =			

Total PAR =	
Pot^n loss of life[4] = (PAR$^{0.6}$)	

Combined Impact Score			
	Score	Factor	Total
Near Valley Score[1]	1.55	100	155
Near Valley Pot^n Loss of Life[2]	550	1	550
Far Valley score[3]	-	30	-
Far Valley Pot^n Loss of Life[4]	-	1	-
Reservoir Impact Score =			**705**

Table 6 – LCI Diagram Score Justification
Site: SITE 2
Sheet 1 of 2

Date: Aug 2002
By: KHBR

Element: Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dam body, foundations & abutments	Settlement	Not a significant problem due to age and height of dam. Monitoring suggests little movement.	3	1	1	3
	Instability	No obvious signs of instability from I/Eng and S/Eng observations.	2	1	2	4
	Internal erosion	No obvious signs of leakage through dam from I/Eng and S/Eng observations.	2	1	2	4
	External erosion / Damage to upstream face	Wave action slowly undermining tree roots etc : needs monitoring (I/Eng).	2	2	2	8
	External erosion / downstream face	History of rabbit/vole activity at the site.	2	2	2	8
Spillway	Inadequate capacity/overtopping	Freeboard is inadequate : I/Eng recommended improvements to safely pass design flood.	4	3	2	24

Table 6 – LCI Diagram Score Justification | **Date: Aug 2002**
Site: SITE 2
Sheet 2 of 2 | **By: KHBR**

Element:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Spillway	Deterioration of structures	Overflow brickwork in poor condition.	2	2	2	8
Spillway	Culverts under river	Culverts require regular inspection/maintenance to keep clear of debris: brickwork needs repairs.	2	2	2	8
Spillway	Leakage through structures	Some leakage through brickwork noted but this may not be from reservoir.	2	1	2	4
Outlet Works	Valves inoperable	Earlier concern over main draw-off valve, which is now operable. Confidence figure assumes regular operation/maintenance.	2	1	2	4
Inlet Works	Blockage	The inlet channel downstream of the weir tends to become obstructed with vegetation. This is inspected and cleared on a regular basis, including during floods.	2	1	2	4

Table 7 – Risk Summary Table

Site: **SITE 2** — **Date:** **AUG 2002**

Sheet 1 of 2 — **By:** **KHBR**

Element Ref. Location	Cause / Indicator	Criticality Score	Crit. Rank		Cons. X Like.	C x L Rank		Conf. Score	Conf. Rank		Impact Score = 705 Risk Score (Impact x Criticality)
Spillway	Inadequate capacity/overtopping	24			12			2			
Dam etc	External erosion/upstream face	8			4			2			
Dam etc	External erosion/downstream face	8			4			2			
Spillway	Deterioration of structures	8			4			2			
Spillway	Culverts under river	8			4			2			
Dam etc	Instability	4			2			2			
Dam etc	Internal erosion	4			2			2			
Spillway	Leakage through structures	4			2			2			
Outlet Works	Valves inoperable	4			2			2			
Inlet Works	Blockage	4			2			2			
Dam etc	Settlement	3			3			1			

Table 7 – Risk Summary Table

Site: SITE 2 **Date: August 2002**

Sheet 2 of 2 **By: KHBR**

Element Ref.		**Criticality Score**	**Crit. Rank**		**Cons. X Like.**	**C x L Rank**		**Conf. Score**	**Conf. Rank**		Impact Score = **Risk Score** (Impact x Criticality)
Location	Cause / Indicator										

Table 8 – Summary of Highest Risk Elements

Site: **SITE2** | **Date:** **August 2002**

Sheet 1 of 1 | **By:** **KHBR**

Element Ref.											
Location	***Cause / Indicator***	**Criticality Score**	**Crit. Rank**		**Cons. X Like.**	**C x S Rank**		**Conf. Score**	**Conf. Rank**		***Comment***
Spillway	Inadequate capacity/overtopping	**24**			**12**			**2**			
Dam etc	External erosion/upstream face	**8**			**4**			**2**			
Dam etc	External erosion/downstream face	**8**			**4**			**2**			
Spillway	Deterioration of structures	**8**			**4**			**2**			
Spillway	Culverts under river	**8**			**4**			**2**			

Appendix 3 Scoring Tables, Site 3

TABLE 3 – NEAR VALLEY IMPACT ASSESSMENT – SCORE JUSTIFICATION

Site: SITE 3 **Date:** AUGUST 2002

By: KHBR

Impact	Comment	Impact score (0-4)	PAR Score
1 Residential Property	None	0	0
2 Non Residential Property	Riding stables / car park	1	150
3 Transportation Infrastructure	Minor roads; flood should pass under railway viaduct	1	25
4 Recreational Sites	Fishing/walking along river, but unlikely during major flood event	1	10
5 Industrial Sites	None	0	-
6 Utilities	Unlikely to be affected	0	-
7 Agriculture / Habitats	Land in flood plain will be flooded	1	-

Table 4 – Far Valley Impact Assessment – Score Justification

Site: SITE 3 **Date:** AUGUST 2002

By: KHBR

Impact	Comment	Impact score (0-4)	PAR Score
1 Residential Property	Urban area around 25km	3	100
2 Non Residential Property	Shopping centres, trading estates, offices, schools, etc.	4	5000
3 Transportation Infrastructure	Various roads and railways	2	50
4 Recreational Sites	River-related recreational activities unlikely during flood	1	10
5 Industrial Sites	Numerous ‘Works’ on OS Plans	3	-
6 Utilities	Local loss of distribution assumed	2	-
7 Agriculture / Habitats	First few kilometres of far valley are agricultural	1	-

Table 5 – Reservoir Impact Assessment Summary Sheet **Date: AUGUST 2002**

Site: SITE 3 **By: KHBR**

NEAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
Impact 1	Residential Properties	0	0.15	0	0
Impact 2	Non Residential Properties	1	0.15	0.15	150
Impact 3	Transportation Infrastructure	1	0.10	0.10	25
Impact 4	Recreational Sites	1	0.05	0.05	10
Impact 5	Industrial Sites	0	0.25	0	---
Impact 6	Utilities	0	0.25	0	---
Impact 7	Agriculture / Habitats	1	0.05	0.05	---
		Total Near Valley Score[1] =		**0.35**	185Total PAR =
					Pot^{n} 193oss of life[2] = (0.5 x PAR)

Table 5 (continued)

FAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
Impact 1	Residential Properties	3	0.15	0.45	100
Impact 2	Non Residential Properties	4	0.15	0.60	5000
Impact 3	Transportation Infrastructure	2	0.10	0.20	50
Impact 4	Recreational Sites	1	0.05	0.05	10
Impact 5	Industrial Sites	3	0.25	0.75	---
Impact 6	Utilities	2	0.25	0.50	---
Impact 7	Agriculture / Habitats	1	0.05	0.05	---
		Total Far Valley Score[3] =		**2.60**	

Total PAR =	5160
Pot[n] loss of life[4] = ($PAR^{0.6}$)	**169**

Combined Impact Score

	Score	Factor	Total
Near Valley Score[1]	0.35	100	35
Near Valley Pot[n] Loss of Life[2]	93	1	93
Far Valley score[3]	2.60	30	78
Far Valley Pot[n] Loss of Life[4]	169	1	169
Reservoir Impact Score =			**375**

Table 6 – LCI Diagram Score Justification **Date: JULY 2002**
Site: SITE 3
Sheet 1 of 2 **By: KHBR**

Element:

Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dam body etc	Settlement/overtopping	Within zone of coal mining, but Coal Mining Report stated movement should have ceased; Pastures Road Embankment uneven before inspection in 1996: now addressed. S/Eng to watch for low areas.	2	2	2	8
Dam body etc	Settlement/damage to structures	Control structure regularly inspected by EA as part of routine maintenance.	2	1	2	4
Pastures Road Embankment	Instability/rapid drawdown	Not referred to in information available: dependent on material in dam and rate of drawdown: low confidence due to lack of information.	2	2	3	12
Dam body etc	Internal erosion	Watertightness in flood events unknown, however short duration of impounding means failure unlikely.	2	2	2	8
	External erosion/overtopping	The embankments can be overtopped in extreme events (>150 yr according to I/Eng). Bare patches on embankments could lead to rapid erosion. Bare patches identified by I/Eng have been seeded (S/Eng). Confidence value assumes ongoing maintenance to keep good cover.	3	2	1	6
Control structure	Gates not operable (mechanical or blockage causes)/overtopping	Four gates manually operable, inspected/tested monthly. One gate at most likely to be inoperable in flood.	1	2	1	2

Table 6 – LCI Diagram Score Justification
Site: SITE 3
Sheet 2 of 2

Date: JULY2002
By: KHBR

Element:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Control structure	Gates not operated correctly/overtopping	The EA has produced a detailed operating procedure for the site.	1	2	1	2
Railway embankment	Instability	Substantial structure which should withstand floods for an adequate period due to its width.	2	1	2	4

Table 7 – Risk Summary Table

Site: SITE 3 **Date: July 2002**

Sheet 1 of 1 **By:**

Element Ref. Location	Cause / Indicator	Criticality Score	Crit. Rank		Cons. X Like.	C x L Rank		Conf. Score	Conf. Rank		Impact Score = 2686 **Risk Score** (Impact x Criticality)
Pastures Road embankment	Instability/rapid drawdown	12	1		4	1=		3	1		
Dam etc	Settlement/overtopping	8	2=		4	1=		2	2=		
Dam etc	Internal erosion	8	2=		4	1=		2	2=		
Dam etc	External erosion/overtopping	6	4		6	4		1	6		
Dam etc	Settlement/damage to structures	4	5=		2	5=		2	2=		
Railway embankment	Instability	4	5=		2	5=		2	2=		
Control structure	Inoperable gates/overtopping	2	7=		2	5=		1	6=		
Control structure	Gates operated incorrectly	2	7=		2	5=		1	6=		

Table 8 – Summary of Highest Risk Elements

Site: SITE 3 **Date: JULY 2002**

Sheet 1 of 1 **By:**

Element Ref. *Location*	*Cause / Indicator*	Criticality Score	Crit. Rank		Cons. X Like.	C x S Rank		Conf. Score	Conf. Rank		*Comment*
Pastures Rd Embankment	Instability/rapid drawdown	12	1		4	1=		3	1		No information on speed of drawdown
Dam etc	Settlement/overtopping	8	2=		4	1=		2	2=		History of settlement
Dam etc	Internal erosion	8	2=		4	1=		2	2=		Watertightness unknown
Dam etc	External erosion/overtopping	6	4		6	4		1	6=		Confidence assumes ongoing maintenance
Dam etc	Settlement/damage to structures	4	5=		2	5=		2	2=		Structures regularly inspected
Railway embankment	Instability	4	5=		2	5=		2	2=		Robust structure

Appendix 4 Scoring Tables, Site 4

TABLE 3 – NEAR VALLEY IMPACT ASSESSMENT – SCORE JUSTIFICATION

Site: SITE 4 **Date:** AUG 2002

By: KHBR

Impact	Comment	Impact score (0-4)	PAR Score
1 Residential Property	None appear to be in flood plain	0	0
2 Non Residential Property	Industrial estates/business parks/shopping centre. No schools or hospitals apparent.	3	1000
3 Transportation Infrastructure	Local roads affected. Major roads and railways appear to be above flood plain	1	25
4 Recreational Sites	Footpath along river may be used for walking/fishing but unlikely during flood.	1	10
5 Industrial Sites	Light industrial assumed	1	-
6 Utilities	Some local loss of distribution	1	-
7 Agriculture / Habitats	Agricultural near reservoir	1	-

Table 5 – Reservoir Impact Assessment Summary Sheet **Date: AUG 2002**

Site: SITE 4 **By: KHBR**

NEAR VALLEY ASSESSMENT		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
		IMPACT			**PEOPLE AT RISK**
Impact 1	Residential Properties	0	0.15	0	0
Impact 2	Non Residential Properties	3	0.15	0.45	1000
Impact 3	Transportation Infrastructure	1	0.10	0.10	25
Impact 4	Recreational Sites	1	0.05	0.05	10
Impact 5	Industrial Sites	1	0.25	0.25	---
Impact 6	Utilities	1	0.25	0.25	---
Impact 7	Agriculture / Habitats	1	0.05	0.05	---
		Total Near Valley Score[1] =		**1015**	Total PAR = 1035
					Pot^n loss of life[2] = (0.5 x PAR) **518**

Table 5 (continued)

FAR VALLEY ASSESSMENT		IMPACT: Impact Score (0 – 4)	IMPACT: Weight	IMPACT: Score (Score x Weight)	PEOPLE AT RISK: PAR Value
Impact 1	Residential Properties		0.15		
Impact 2	Non Residential Properties		0.15		
Impact 3	Transportation Infrastructure		0.10		
Impact 4	Recreational Sites		0.05		
Impact 5	Industrial Sites		0.25		
Impact 6	Utilities		0.25		
Impact 7	Agriculture / Habitats		0.05		
		Total Far Valley Score[3] =			Total PAR =
					Pot^n loss of life[4] (PAR$^{0.6}$) =

Combined Impact Score	Score	Factor	Total
Near Valley Score[1]	1.15	100	115
Near Valley Pot^n Loss of Life[2]	518	1	518
Far Valley score[3]	-	30	-
Far Valley Pot^n Loss of Life[4]	-	1	-
Reservoir Impact Score =			**633**

TABLE 6 – LCI DIAGRAM SCORE JUSTIFICATION

Site: SITE 4

Sheet 1 of 2

Date: JULY 2002

By: KHBR

Element:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dams etc	Settlement/cracking of dam/structures	Only significant structures are pipes, which should have flexibility; Coal Mining Report states mining settlement should have ceased. Settlement of dams should be minimal bearing in mind their height and age.	2	1	2	4
	Settlement/overtopping	Low points on Canklow D/E have yet to be made up as recommended by I/Eng; S/Eng to watch for further settlement on all dams. Amount of settlement not significant in supply terms (I/Eng).	1	2	2	4
	Instability))) Overtopping External erosion)	Some shallow slips and bare patches identified by I/Eng; surface erosion may be caused by cattle. Remedial works proposed by I/Eng had not been carried out by April 2001.	3	2	2	12
	Instability/Rapid drawdown	Not referred to in information available: dependent on materials and rate of drawdown: low confidence due to lack of information.	2	2	3	12
	External erosion/waves	Maximum wave run-up of 0.43m calculated by I/Eng: could cause erosion of upstream face during flood event but unlikely to cause dam failure.	2	1	2	4
Motorway/ railway embankments	Instability	Embankments are wide and robust: unlikely to fail and even if they did, would not lead to release of water as they are well above flood level.	1	1	2	2

Table 6 – LCI Diagram Score Justification
Site: SITE 4
Sheet 2 of 2

Date: Aug 2002
By: KHBR

Element: Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dam etc	Internal erosion	Watertightness in flood events unknown, however short duration of impounding means failure unlikely.	2	2	2	8
Inlet spillways	Surface erosion/overtopping	I/Eng noted surface erosion on several spillways, notably Canklow A and recommended good grass cover be maintained: S/Eng (April 2001) stated this had not been carried out yet.	3	2	2	12
Outlet pipes	Blockage/overtopping	All reservoirs except Canklow C have more than one outlet, and multiple blockage unlikely.	2	1	2	4
Canklow Regulator	Operational failure	If Regulator cannot be operated from open position, reservoirs will have less impounding. If Regulator cannot be operated from closed or partially closed position then impounding would be greater. Most likely failure causes are (a) power failure: manual operation is possible and (b) vandalism: additional security measures recommended by I/Eng (not implemented by April 2001) would improve situation.	2	1	2	4

Table 7 – Risk Summary Table

Site: **SITE 4** **Date:** **JULY 2002** Sheet 1 of **By:** **KHBR**

Element Ref.		Criticality Score	Crit. Rank		Cons. X Like.	C x L Rank		Conf. Score	Conf. Rank		Impact Score = 705
Location	Cause / Indicator										**Risk Score** (Impact x Criticality)
Dams etc	Instability & external erosion/overtopping	12	1=		6	1=		2	2=		
Inlet spillways	Surface erosion/overtopping	12	1=		6	1=		2	2=		
Dam etc	Instability/rapid drawdown	12	1=		4	3=		3	1		
Dam etc	Internal erosion	8	4		4	3=		2	2=		
Dam etc	Settlement/cracking of dam/structures	4	5=		2	5=		2	2=		
Dam etc	Settlement/overtopping	4	5=		2	5=		2	2=		
Dam etc	External erosion/waves	4	5=		2	5=		2	2=		
Outlet pipes	Blockage/overtopping	4	5=		2	5=		2	2=		
Canklow Regulator	Operational failure	4	5=		2	5=		2	2=		
Motorway/ railway embankments	Instability	2	10		1	10		2	2=		

Table 8 – Summary of Highest Risk Elements

Site: SITE 4 — **Date: JULY 2002**

Sheet 1 of 1 — **By: KHBR**

Element Ref. Location	Cause / Indicator	Criticality Score	Crit. Rank		Cons. X Like.	C x S Rank		Conf. Score	Conf. Rank		Comment
Dams etc	Instability & External erosion/overtopping	12	1=		6	1=		2	2=		Slips/bare patches recc by I/Eng not repaired by 4/01
Inlet spillways	Surface erosion/overtopping	12	1=		6	1=		2	2=		I/Eng works not done by 4/01
Dam etc	Instability/rapid drawdown	12	1=		4	2=		3	1		No info on rapid drawdown
Dams etc	Internal erosion	8	4		4	3=		2	2=		Watertightness unknown

Appendix 5 Scoring Tables, Site 5

TABLE 3 – NEAR VALLEY IMPACT ASSESSMENT – SCORE JUSTIFICATION

Site: SITE 5 **Date:** JULY 2002

By: KHBR

Impact	Comment	Impact score (0-4)	PAR Score
1 Residential Property			
2 Non Residential Property			
3 Transportation Infrastructure			
4 Recreational Sites			
5 Industrial Sites			-
6 Utilities			-
7 Agriculture / Habitats			-

Table 5 – Reservoir Impact Assessment Summary Sheet **Date: JULY 2002**

Site: SITE 5 **By: KHBR**

NEAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
Impact 1	Residential Properties		0.15		
Impact 2	Non Residential Properties		0.15		
Impact 3	Transportation Infrastructure		0.10		
Impact 4	Recreational Sites		0.05		
Impact 5	Industrial Sites		0.25		---
Impact 6	Utilities		0.25		---
Impact 7	Agriculture / Habitats		0.05		---
		Total Near Valley Score[1] =			Total PAR =

Table 5 (continued)

FAR VALLEY ASSESSMENT		IMPACT			PEOPLE AT RISK
		Impact Score (0 – 4)	Weight	Score (Score x Weight)	PAR Value
Impact 1	Residential Properties		0.15		
Impact 2	Non Residential Properties		0.15		
Impact 3	Transportation Infrastructure		0.10		
Impact 4	Recreational Sites		0.05		
Impact 5	Industrial Sites		0.25		
Impact 6	Utilities		0.25		
Impact 7	Agriculture / Habitats		0.05		
		Total Far Valley Score[3] =			

PEOPLE AT RISK	
Total PAR =	
Pot^n loss of life[4] = ($PAR^{0.6}$)	

Combined Impact Score			
	Score	Factor	Total
Near Valley Score[1]		100	
Near Valley Pot^n Loss of Life[2]		1	
Far Valley score[3]	-	30	-
Far Valley Pot^n Loss of Life[4]	-	1	-
Reservoir Impact Score =			

Table 6 – LCI Diagram Score Justification

Site: SITE 5

Sheet 1 of 2

Date: JULY 2002

By: KHBR

Element Ref:						
Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
Dam body, foundations etc	Settlement	Cracking within dam/structures: structures regularly checked.	2	1	2	4
		Overtopping/breach: settlement has occurred to East Compartment (S/Eng): could concentrate flow during overtopping. Settlement being monitored.	3	2	2	12
	Instability - general	No stability problems identified by Inspecting Engineer.	3	1	1	3
	Instability/Rapid drawdown	Not commented on by Inspecting/Supervising Engineers; depends on time taken to fill/empty and type of material.	2	2	3	12
	Internal erosion – general	No knowledge of seepage/leakage: planned for S/Eng to visit during a flood event. Unlikely to be a major problem in short-duration impounding.	2	2	2	8
	External erosion/mole activity	Mole activity noted by S/Eng on W Compartment: action to be taken.	2	1	2	4

Table 6 – LCI Diagram Score Justification
Site: SITE 5
Sheet 2 of 2

Date: JULY 2002
By: H Hewlett

Element Ref:

Location	Cause / Indicator	Comment – source of information	Cons	Like	Conf	Crit
	External erosion/rutting	Noted in both compartments by S/Eng: could be weak points on d/s side if overtopping occurs.	2	2	2	8
	External erosion/cattle & humans	Cattle graze in the reservoirs and have potential to damage embankments; anglers also use area. EA visit to undertake maintenance.	2	2	2	8
Inlet spillways	Erosion by flow	Maintenance is carried out to keep spillways in an operable condition (S/Eng).	1	1	2	2
Outlet works	Obstruction of outlet pipes	There are several outlet pipes from each compartment and blockage of them all is most unlikely.	2	1	2	4

Table 7 – Risk Summary Table
Site: SITE 5 **Date: JULY 2002**
Sheet 1 of 1 **By: H Hewlett**

Element Ref. Location	Cause / Indicator	Criticality Score	Crit. Rank		Cons. X Like.	C x L Rank		Conf. Score	Conf. Rank		Impact Score = 705 Risk Score (Impact x Criticality)
Dam etc	Instability/rapid drawdown	12	1=		4	2=		3	1		
Dam etc	Overtopping/breach	12	1=		6	1		2	2=		
Dam etc	Internal erosion – general	8	3=		4	2=		2	2=		
Dam etc	External erosion/rutting	8	3=		4	2=		2	2=		
Dam etc	External erosion/cattle & human	8	3=		4	2=		2	2=		
Dam etc	External erosion/mole activity	4	6=		2	7=		2	2=		
Dam etc	Settlement/cracking	4	6=		2	7=		2	2=		
Outlet works	Obstruction	4	6=		2	7=		2	2=		
Dam etc	Instability – general	3	9		3	6		1	10		
Inlet spillways	Erosion	2	10		1	10		2	2=		

Table 8 – Summary of Highest Risk Elements

Site: **SITE 5**

Sheet 1 of 1

Date: **JULY 2002**

By: **H Hewlett**

Element Ref.		**Criticality Score**	**Crit. Rank**		**Cons. X Like.**	**C x S Rank**		**Conf. Score**	**Conf. Rank**		***Comment***
Location	***Cause / Indicator***										
Dam etc	Instability/rapid drawdown	**12**	**1=**		**4**	**2=**		**3**	**1**		**Lack of information**
Dam etc	Overtopping/breach	**12**	**1=**		**6**	**1**		**2**	**2=**		**History of settlement**
Dam etc	Internal erosion – general	**8**	**3=**		**4**	**2=**		**2**	**2=**		**S/Eng to check during flood**
Dam etc	External erosion – rutting	**8**	**3=**		**4**	**2=**		**2**	**2=**		**Noted in both compartments**
Dam etc	External erosion – cattle/human	**8**	**3=**		**4**	**2=**		**2**	**2=**		**Regular maintenance required**