Defra

RESEARCH CONTRACT
RESERVOIR SAFETY ADVICE

TASK B : EARLY DETECTION OF INTERNAL EROSION

FEASIBILITY REPORT
Volume 2 of 2 : Appendices

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KBR

VOLUME PLAN

Volume

1 Main Report

2 **Appendices A to H : Supporting Documentation**

A: Terms of Reference
B: Literature Review
C: Results of Questionnaire B
D: Detailed consideration of 6 cases
E: Expert Elicitation
F : Possible techniques for early detection of internal erosion
G: Options and costs for remote monitoring

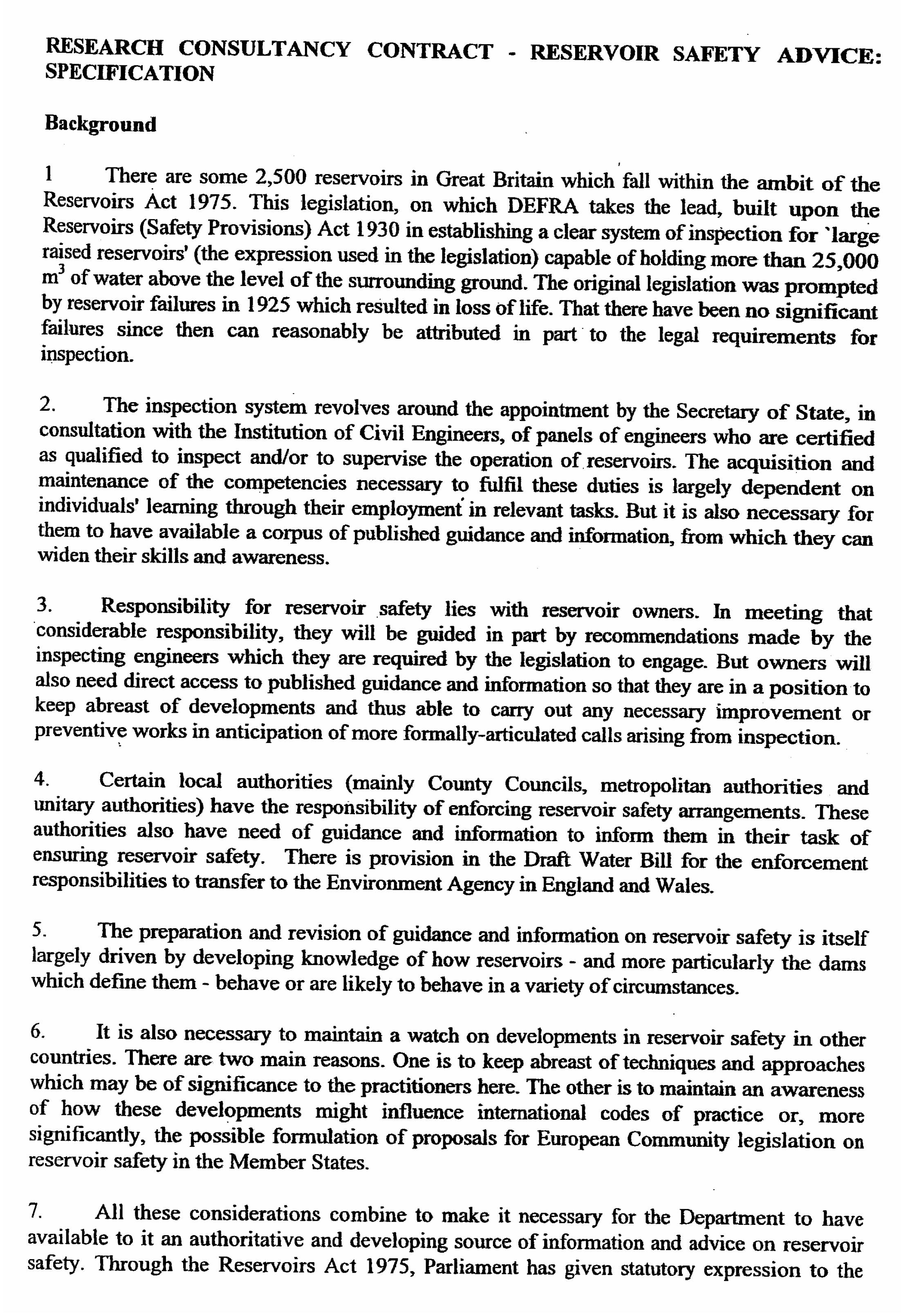
Annex Annex to Tasks A and B : Feasibility Reports

1: Bibliography
2: Questionnaire : Number returned and implied number of incidents / yr in UK
3: Package sent out as Questionnaire

CONTENTS

List of Tables

APPENDIX A : TERMS OF REFERENCE



RESEARCH CONSULTANCY CONTRACT - RESERVOIR SAFETY ADVICE: SPECIFICATION

Background

1 There are some 2,500 reservoirs in Great Britain which fall within the ambit of the Reservoirs Act 1975. This legislation, on which DEFRA takes the lead, built upon the Reservoirs (Safety Provisions) Act 1930 in establishing a clear system of inspection for `large raised reservoirs' (the expression used in the legislation) capable of holding more than 25,000 m^3 of water above the level of the surrounding ground. The original legislation was prompted by reservoir failures in 1925 which resulted in loss of life. That there have been no significant failures since then can reasonably be attributed in part to the legal requirements for inspection.

2. The inspection system revolves around the appointment by the Secretary of State, in consultation with the Institution of Civil Engineers, of panels of engineers who are certified as qualified to inspect and/or to supervise the operation of reservoirs. The acquisition and maintenance of the competencies necessary to fulfil these duties is largely dependent on individuals' learning through their employment in relevant tasks. But it is also necessary for them to have available a corpus of published guidance and information, from which they can widen their skills and awareness.

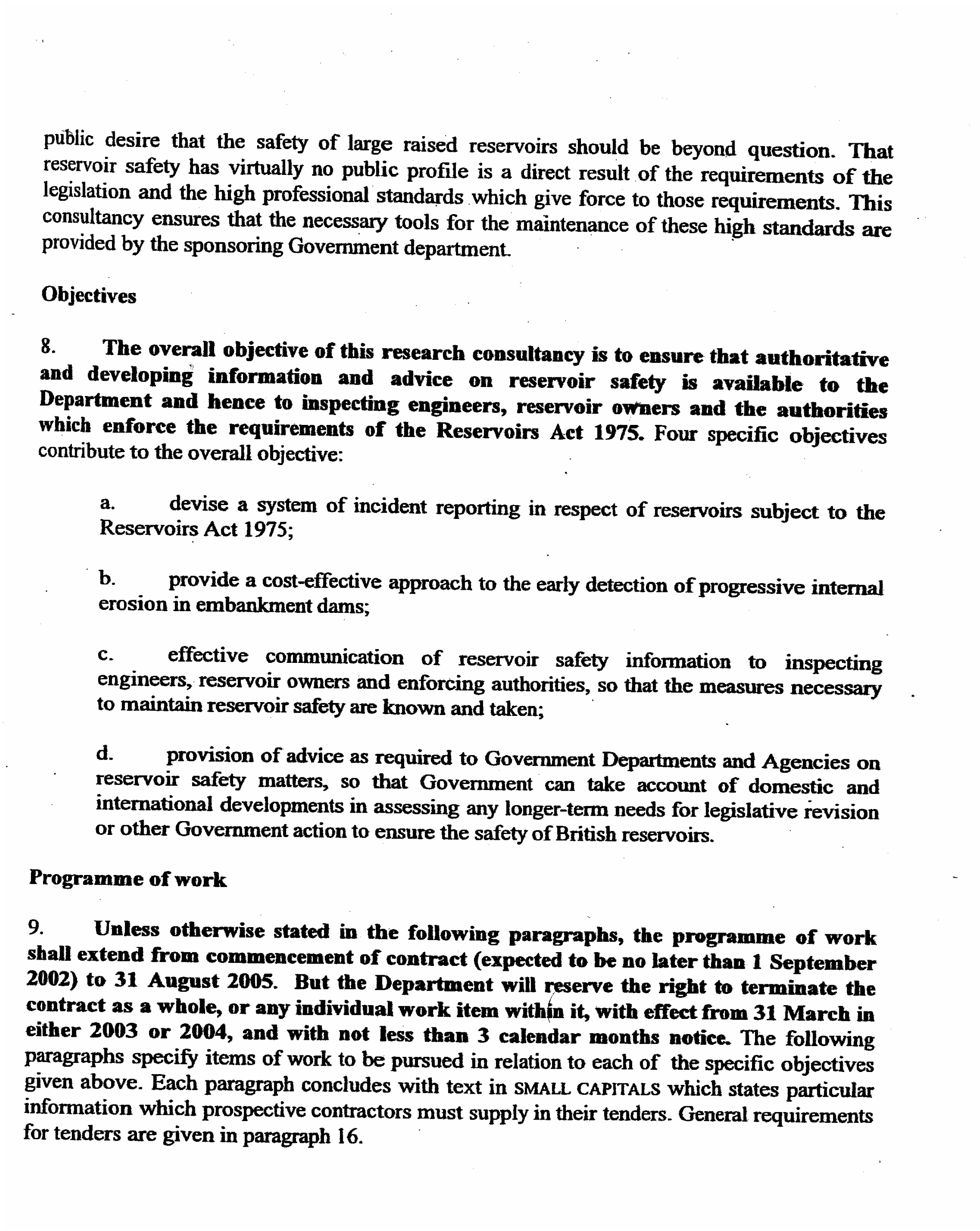
3. Responsibility for reservoir safety lies with reservoir owners. In meeting that considerable responsibility, they will be guided in part by recommendations made by the inspecting engineers which they are required by the legislation to engage. But owners will also need direct access to published guidance and information so that they are in a position to keep abreast of developments and thus able to carry out any necessary improvement or preventive works in anticipation of more formally-articulated calls arising from inspection.

4. Certain local authorities (mainly County Councils, metropolitan authorities and unitary authorities) have the responsibility of enforcing reservoir safety arrangements. These authorities also have need of guidance and information to inform them in their task of ensuring reservoir safety. There is provision in the Draft Water Bill for the enforcement responsibilities to transfer to the Environment Agency in England and Wales.

5. The preparation and revision of guidance and information on reservoir safety is itself largely driven by developing knowledge of how reservoirs - and more particularly the dams which define them - behave or are likely to behave in a variety of circumstances.

6. It is also necessary to maintain a watch on developments in reservoir safety in other countries. There are two main reasons. One is to keep abreast of techniques and approaches which may be of significance to the practitioners here. The other is to maintain an awareness of how these developments might influence international codes of practice or, more significantly, the possible formulation of proposals for European Community legislation on reservoir safety in the Member States.

7. All these considerations combine to make it necessary for the Department to have available to it an authoritative and developing source of information and advice on reservoir safety. Through the Reservoirs Act 1975, Parliament has given statutory expression to the



public desire that the safety of large raised reservoirs should be beyond question. That reservoir safety has virtually no public profile is a direct result of the requirements of the legislation and the high professional standards which give force to those requirements. This consultancy ensures that the necessary tools for the maintenance of these high standards are provided by the sponsoring Government department.

Objectives

8. **The overall objective of this research consultancy is to ensure that authoritative and developing information and advice on reservoir safety is available to the Department and hence to inspecting engineers, reservoir owners and the authorities which enforce the requirements of the Reservoirs Act 1975.** Four specific objectives contribute to the overall objective:

a. devise a system of incident reporting in respect of reservoirs subject to the Reservoirs Act 1975;

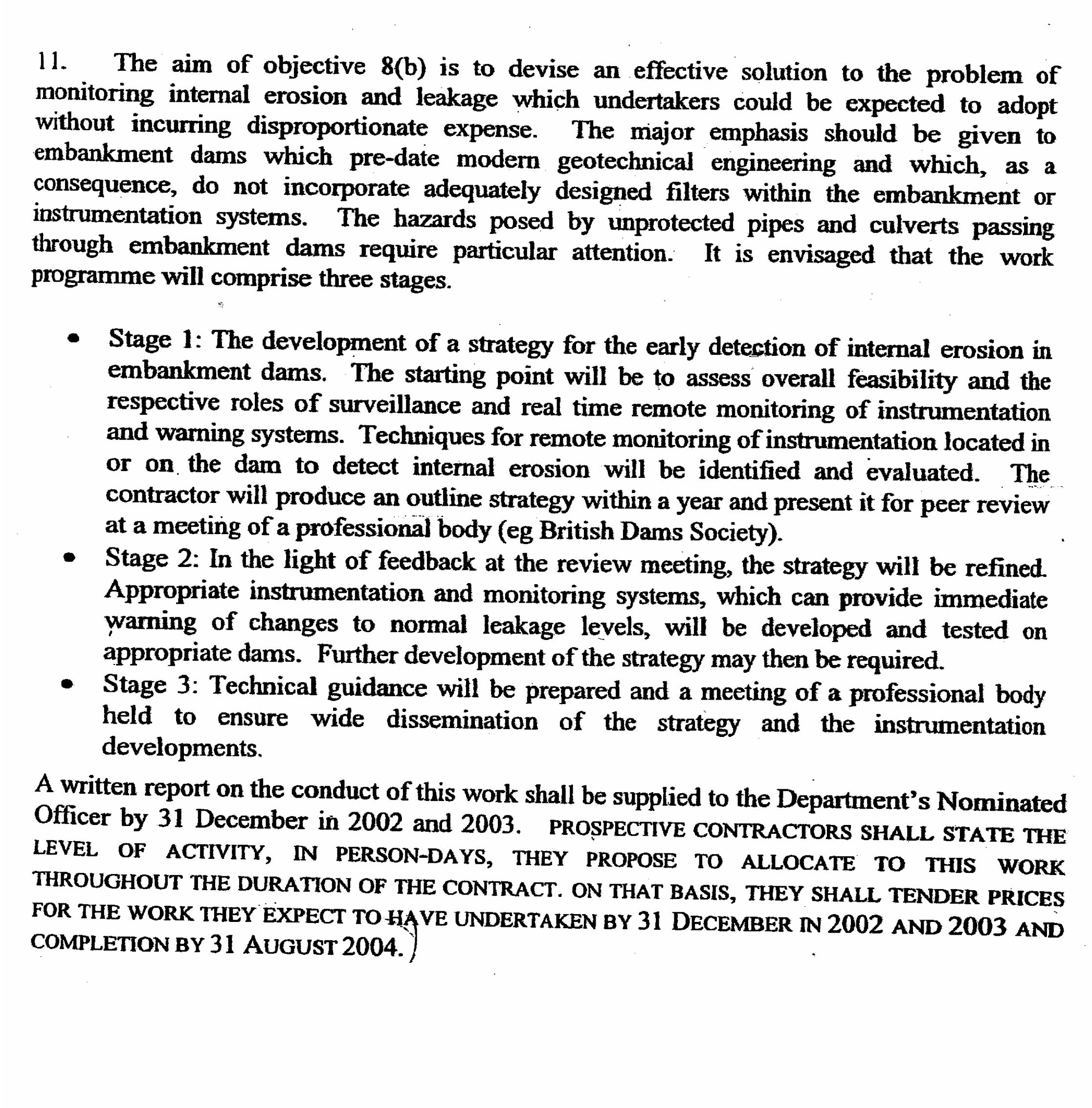
b. provide a cost-effective approach to the early detection of progressive internal erosion in embankment dams;

c. effective communication of reservoir safety information to inspecting engineers, reservoir owners and enforcing authorities, so that the measures necessary to maintain reservoir safety are known and taken;

d. provision of advice as required to Government Departments and Agencies on reservoir safety matters, so that Government can take account of domestic and international developments in assessing any longer-term needs for legislative revision or other Government action to ensure the safety of British reservoirs.

Programme of work

9. **Unless otherwise stated in the following paragraphs, the programme of work shall extend from commencement of contract (expected to be no later than 1 September 2002) to 31 August 2005. But the Department will reserve the right to terminate the contract as a whole, or any individual work item within it, with effect from 31 March in either 2003 or 2004, and with not less than 3 calendar months notice.** The following paragraphs specify items of work to be pursued in relation to each of the specific objectives given above. Each paragraph concludes with text in SMALL CAPITALS which states particular information which prospective contractors must supply in their tenders. General requirements for tenders are given in paragraph 16.



11. The aim of objective 8(b) is to devise an effective solution to the problem of monitoring internal erosion and leakage which undertakers could be expected to adopt without incurring disproportionate expense. The major emphasis should be given to embankment dams which pre-date modern geotechnical engineering and which, as a consequence, do not incorporate adequately designed filters within the embankment or instrumentation systems. The hazards posed by unprotected pipes and culverts passing through embankment dams require particular attention. It is envisaged that the work programme will comprise three stages.

- Stage 1: The development of a strategy for the early detection of internal erosion in embankment dams. The starting point will be to assess overall feasibility and the respective roles of surveillance and real time remote monitoring of instrumentation and warning systems. Techniques for remote monitoring of instrumentation located in or on the dam to detect internal erosion will be identified and evaluated. The contractor will produce an outline strategy within a year and present it for peer review at a meeting of a professional body (eg British Dams Society).
- Stage 2: In the light of feedback at the review meeting, the strategy will be refined. Appropriate instrumentation and monitoring systems, which can provide immediate warning of changes to normal leakage levels, will be developed and tested on appropriate dams. Further development of the strategy may then be required.
- Stage 3: Technical guidance will be prepared and a meeting of a professional body held to ensure wide dissemination of the strategy and the instrumentation developments.

A written report on the conduct of this work shall be supplied to the Department's Nominated Officer by 31 December in 2002 and 2003. PROSPECTIVE CONTRACTORS SHALL STATE THE LEVEL OF ACTIVITY, IN PERSON-DAYS, THEY PROPOSE TO ALLOCATE TO THIS WORK THROUGHOUT THE DURATION OF THE CONTRACT. ON THAT BASIS, THEY SHALL TENDER PRICES FOR THE WORK THEY EXPECT TO HAVE UNDERTAKEN BY 31 DECEMBER IN 2002 AND 2003 AND COMPLETION BY 31 AUGUST 2004.

APPENDIX B : LITERATURE REVIEW

B.1 Introduction

This section summarises the main points from the literature review carried out for this project. The individual references identified are given in full in the Bibliography, a separate volume accompanying this report, together with a short description of the content of each reference.

Relevant conferences include the following ICOLD Congress
- Q56 - Dam and foundation monitoring Lausanne, 1985
- Q75 – Incidents and failures at dams, Florence, 1997
- Q78 - Monitoring of dams and their foundations, Florence, 1997
- Q85 - dam and foundation monitoring, Beijing 2000

B.2 Fell et al (2001)

A research report of particular relevance to this research is the research report by Fell et al (2001) with a very similar title to this project. Fell et al differentiate stages in the internal erosion process (his Figure 1) as follows

Stage	Definition	Remarks
Initiation	Mechanism of deterioration (e.g. Concentrated leak, leakage exits at downstream side of dam) initiates internal erosion	
Continuation	Erosion either controlled/ terminated by a filter, or other protective feature, or continues	This is not really a separate stage, but a link between Initiation and progression
Progression	Backward erosion of "piping", or enlargement of concentrated leak	
Breach/ Failure	Breach mechanism forms	

This has provided useful background information in building up models adopted for this research.

Table B.1 : Summary of tables in Fell et al, 2001

<table>
<tr><th></th><th>Initiation</th><th>Continuation</th><th>Progression</th><th>Breach</th></tr>
<tr><td>Model</td><td>1. Means of initiation
2, 4. Time for development</td><td></td><td>5. Ability to support roof
6. Pipe enlargement
7. Upstream zone</td><td>8 Likelihood
9 Downstream zone</td></tr>
<tr><td>Case Histories</td><td colspan="4">12 Time for development; 13 Embankment; 14 Foundation; 15 Reservoir level</td></tr>
<tr><td>Prediction model - time</td><td></td><td></td><td colspan="2">10</td></tr>
<tr><td>Test model</td><td></td><td></td><td colspan="2">11 Embankment; 12 Foundation</td></tr>
<tr><td>Rate of detection and method of detection</td><td colspan="4">16 Embankment; 17 Foundation; 18 Conduit</td></tr>
</table>

Other reports and papers of relevance are

Wan and Fell	2002	Investigation of internal erosion and piping of soils in embankment dams by the slot erosion test and the hole erosion tests. UNICIV Report N0 R-412. July. ISBN 85841 379 5
Wan and Fell	2003	Experimental investigation of internal erosion by the process of suffusion in embankment dams and their foundations. ANCOLD Conf

The former has various plots of test results against the parameters given in Table 4.10 of the main report; however an indication of the range of results is given in Figure 5.1 and 5.2 of the Wan report, reproduced here on the next page. Attention is drawn to the results of samples of soil from Teton dam (third from right).

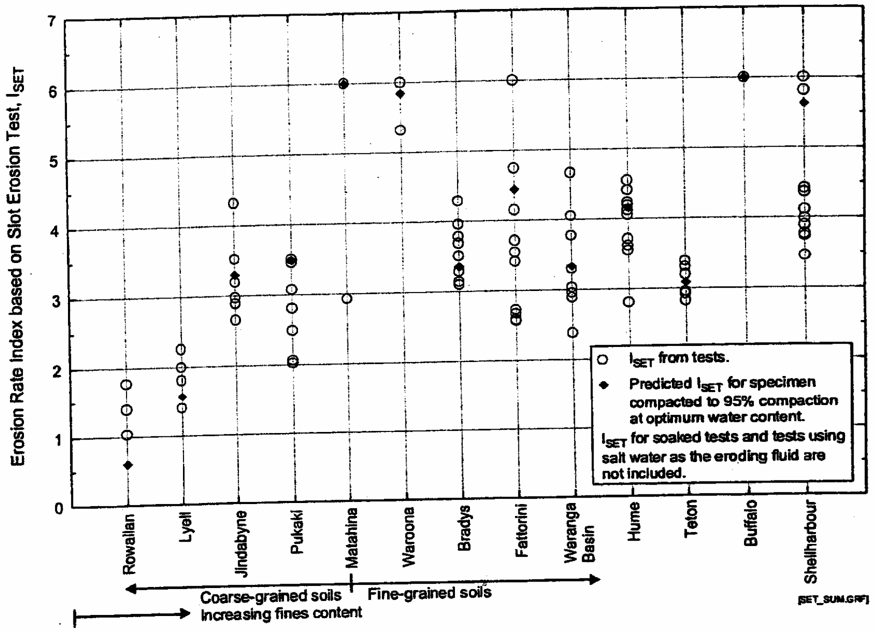


Figure 5.1 Summary of I_{SET} for all successful Slot Erosion Tests.

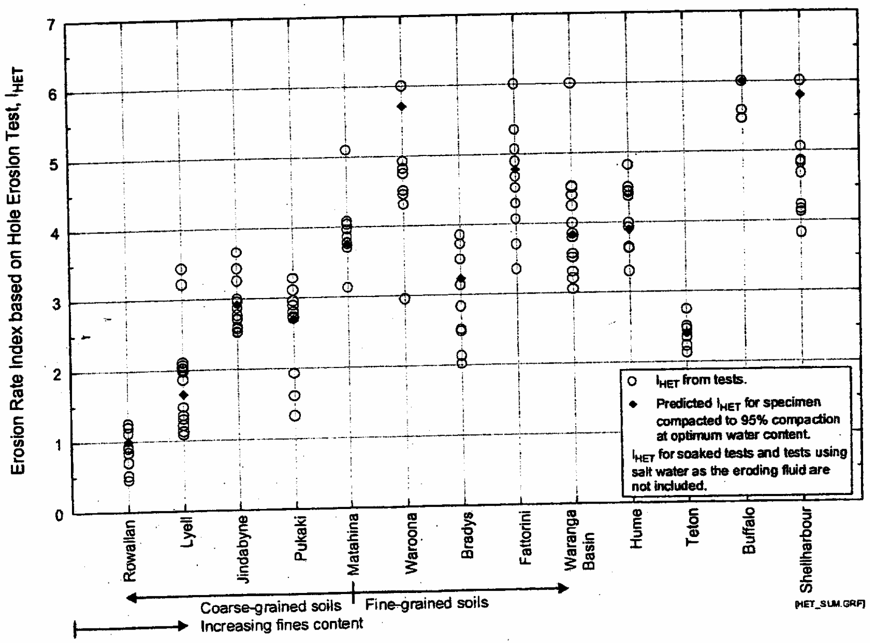


Figure 5.2 Summary of I_{HET} for all successful Hole Erosion Tests.

B.3 Case History data

A summary of case histories of internal erosion is given in

- Appendix I of Charles, 2002
- Fell et al (2001) Tables 2 and 13 to 15.

However there are a number of problems in using published case histories

- Many occur in the first five years of a dams life – this research project is more interested in incidents in service
- Many are failures – data is also requires on incidents, to understand what governs the rate of erosion
- The published information is often incomplete in respect of detailing all of the characteristics of a dam – this is the reason the questionnaire was developed; to identify case histories where additional information can be collected (if appropriate) from those involved in the incident.

Nevertheless for completeness published case histories of progressive internal erosion are given in Table B.2.

Table B.2 : Examples of dams where internal erosion resulted in surface settlement

Dam	Dimensions, Age	Remarks	Rate of progression	Actions taken to prevent failure
Occurrence on first filling				
Biberry	20m high. Impounded 1845. Failed 1852.	The downstream fill was coarse grained rubble, offering poor filter protection and little control of flow. The dam suffered severe internal erosion during the first years of operation and could not be kept to level. It settled so that the crest was lower than the spillway weir. The operators refused to lower the latter as they would lose storage. It rained and the dam overtopped and failed. After the washout two sinkholes were observed over the upstream boundary of the core in the unfailed part of the dam. The crest had settled right across at these locations (Binnie, 1981).		
Dale Dyke	Impounded 1864. Failed 1864.	The downstream fill was rockfill, offering poor filter protection and no control of flow. It failed on first impounding, which was rapid. It seems likely that a sinkhole developed on the upstream boundary of the core followed by settlement; rapid erosion and the development of the uncontrolled leak, which eventually resulted in local overtopping and catastrophic failure. (Binnie, 1978; Binnie, 1981)		
Balderhead.	A rolled till core. 48m high. Impounded 1967 (Vaughan et al 1970)	Two sink holes appeared above the upstream boundary of the core one year after first impounding. Excess leakage started when the reservoir was 1m below TWL. Leakage stopped when the reservoir was drawn down 10m, although the leak was 25m down. The dam had inadequate filter protection. However, the fill on both sides of the core controlled the magnitude of the leak and the rate at which damage could develop. New filter criteria were derived. The leak was cured by grouting plus a diaphragm wall over the affected length.	Over 10 weeks extended to 3m wide x 2.5m deep hole	Reservoir lowered 9m (which increased crest settlement), grouting and diaphragm wall in core
Warmwithens –	10m high dam built in 1860 (Wickham, 1992; Charles & Boden 1985, para 21; Moffat, 1975)	1.5m dia. outlet tunnel driven through embankment in 1965 to contain new outlet pipes Chart recorder shows increased leakage started 1700 on 23rd Nov 1970, with rapid increase at 0500 am on 24th Nov. Escape of water first noticed 0730 am on 24th	Maximum outflow 0900 on 24th Nov, with 115,000m^3 reservoir discharged by 13.30.	Dam failed by erosion along ‘new culvert’. Breaching sufficiently slow that two reservoirs in cascade downstream could cope with inflows with only minor damage
Occurrence in service				
Upper Roddlesworth	21m high. Built 1865.	A standard puddle core dam. Sink holes appeared over the upstream side of the core in 1904, 1905, 1908 (Binnie 1981, Charles & Boden, 1985). The second event occurred at the site of the first where the hole had been filled with puddle. The third event was at a new site, more over the upstream face. The hole was again backfilled. The dam did not fail. The damage was very delayed.		
Lluest Wen	24m high puddle clay core. Constructed in 1896 (Twort 1977)	Horse fell into 2m deep hole on 23 Dec 1969	Inspected on 7th Jan when suspended clay present in cracked drain pipe	Temporary evacuation of people downstream 12th Jan; grouting of tower and cut through spillway started 19th Jan; reservoir had been lowered 9m by 29th Jan
Green Booth	35m high Pennine dam (Flemming et al 1985)	Depression on crest noticed by public in 1983, some 20 years after construction	Over 3 days extended to 3m x 1m in plan, 0.04m settlement	Reservoir lowered from 1.65m below TWL by further 9.3m over 8 days. Core grouted, 4% by volume
Withens Clough	As Charles, 2002			
Winscar	As Charles, 2002			

B.4 Fault trees

Recent literature reviews of the use of fault trees to estimate the annual probability of failure include:-

			Remarks
Foster & Fell	1999	UNICIV report (Draft) A framework for estimating the probability of failure of embankment dams by piping using event tree methods	a) Plus paper at ICOLD Beijing b) Includes review of previous studies using event tree methods (4 number) c) Includes 18 tables of influence of particular factors on the likelihood of each step in process
Dise	1998	Risk analysis by US BOR of a seepage/piping dam safety issue	

The Foster and Fell report provides a useful summary of published work. It considers that the important factors governing the likelihood of failure are

a) the fines content (passing 0.075mm) which determines the ability to hold a roof
b) the degree of saturation of the clay core

However, the report confuses steps in the process with contributory factors.

B.5 Intrinsic condition (including contributory factors)

Various studies have attempted to identify those features of a dam which make it more vulnerable to internal erosion, namely:-

			Number of features
Foster et al	1999	Analysis of US and Australian data on dam failures and incidents	Embankment -8, Foundation - 6, Emb into fdn -12
Babtie group	2002	Assessment system in Stability Upgrades to Older Embankment Dams	170
This project	2003	Questionnaire on experience of Category 1 to 3 incidents	26

B.6 ANCOLD Guidelines on monitoring

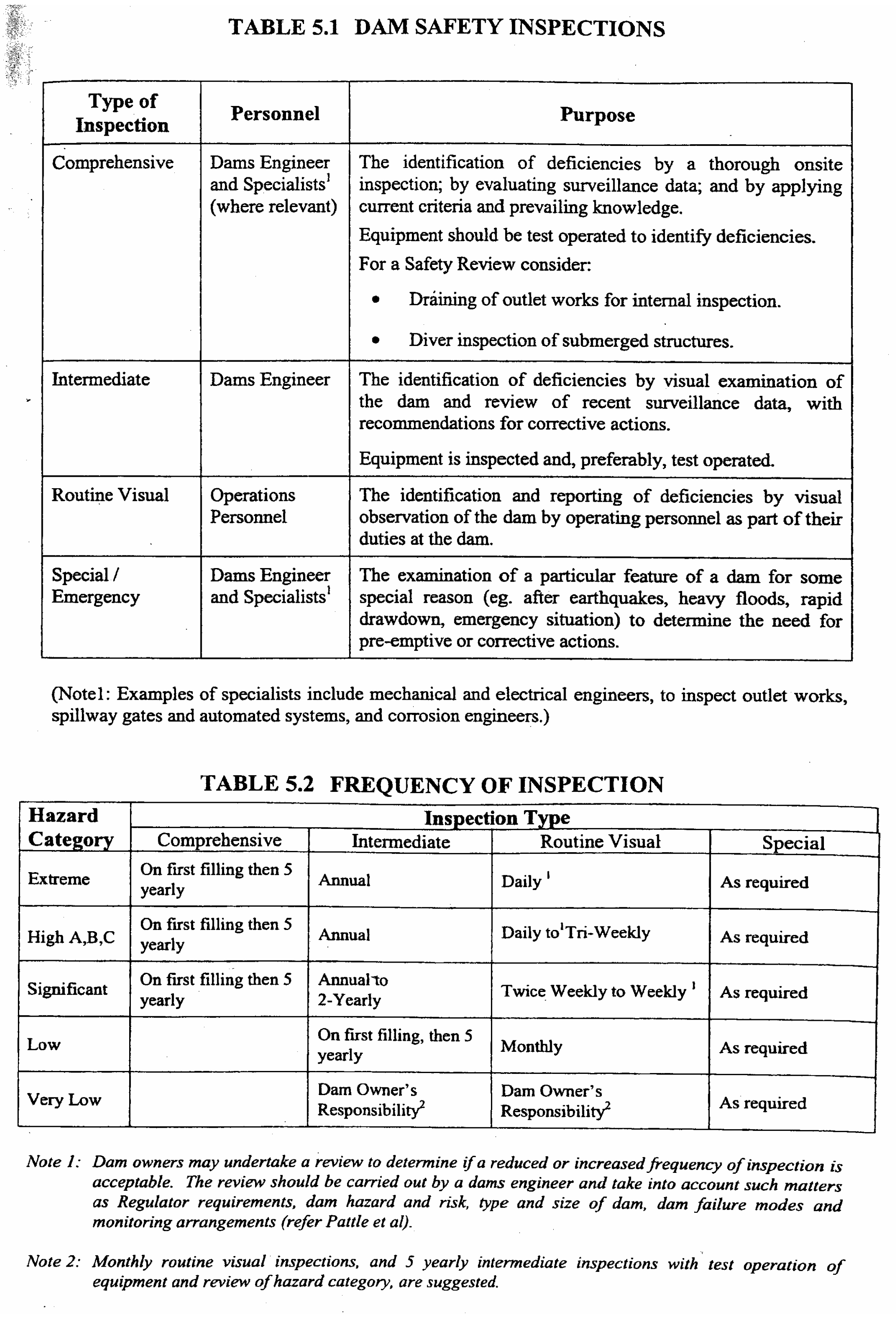


TABLE 5.1 DAM SAFETY INSPECTIONS

Type of Inspection	Personnel	Purpose
Comprehensive	Dams Engineer and Specialists[1] (where relevant)	The identification of deficiencies by a thorough onsite inspection; by evaluating surveillance data; and by applying current criteria and prevailing knowledge. Equipment should be test operated to identify deficiencies. For a Safety Review consider: • Draining of outlet works for internal inspection. • Diver inspection of submerged structures.
Intermediate	Dams Engineer	The identification of deficiencies by visual examination of the dam and review of recent surveillance data, with recommendations for corrective actions. Equipment is inspected and, preferably, test operated.
Routine Visual	Operations Personnel	The identification and reporting of deficiencies by visual observation of the dam by operating personnel as part of their duties at the dam.
Special / Emergency	Dams Engineer and Specialists[1]	The examination of a particular feature of a dam for some special reason (eg. after earthquakes, heavy floods, rapid drawdown, emergency situation) to determine the need for pre-emptive or corrective actions.

(Note1: Examples of specialists include mechanical and electrical engineers, to inspect outlet works, spillway gates and automated systems, and corrosion engineers.)

TABLE 5.2 FREQUENCY OF INSPECTION

Hazard Category	Inspection Type			
	Comprehensive	Intermediate	Routine Visual	Special
Extreme	On first filling then 5 yearly	Annual	Daily [1]	As required
High A,B,C	On first filling then 5 yearly	Annual	Daily to[1]Tri-Weekly	As required
Significant	On first filling then 5 yearly	Annual to 2-Yearly	Twice Weekly to Weekly [1]	As required
Low		On first filling, then 5 yearly	Monthly	As required
Very Low		Dam Owner's Responsibility[2]	Dam Owner's Responsibility[2]	As required

Note 1: Dam owners may undertake a review to determine if a reduced or increased frequency of inspection is acceptable. The review should be carried out by a dams engineer and take into account such matters as Regulator requirements, dam hazard and risk, type and size of dam, dam failure modes and monitoring arrangements (refer Pattle et al).

Note 2: Monthly routine visual inspections, and 5 yearly intermediate inspections with test operation of equipment and review of hazard category, are suggested.

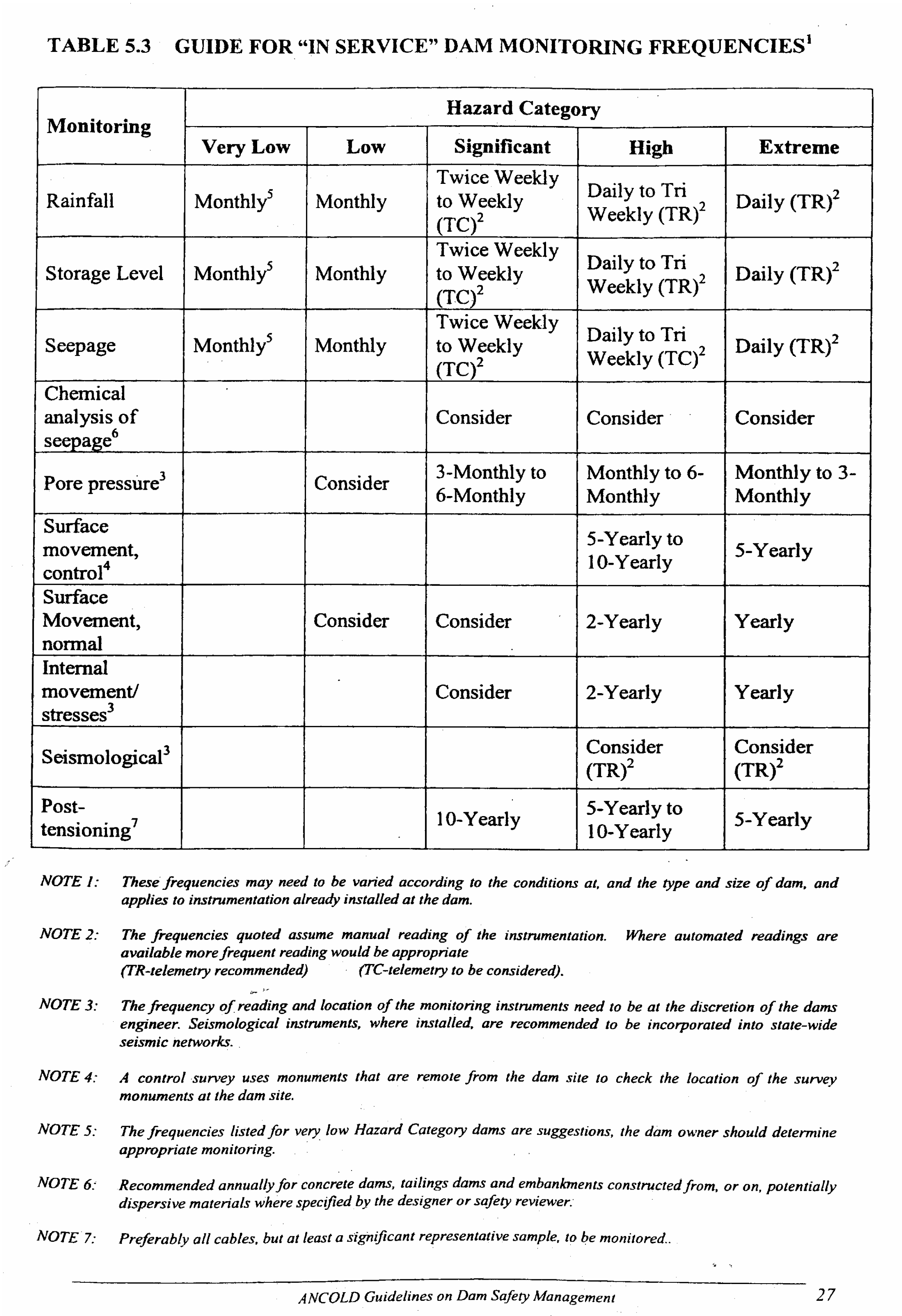


TABLE 5.3 GUIDE FOR "IN SERVICE" DAM MONITORING FREQUENCIES[1]

Monitoring	Hazard Category				
	Very Low	Low	Significant	High	Extreme
Rainfall	Monthly[5]	Monthly	Twice Weekly to Weekly (TC)[2]	Daily to Tri Weekly (TR)[2]	Daily (TR)[2]
Storage Level	Monthly[5]	Monthly	Twice Weekly to Weekly (TC)[2]	Daily to Tri Weekly (TR)[2]	Daily (TR)[2]
Seepage	Monthly[5]	Monthly	Twice Weekly to Weekly (TC)[2]	Daily to Tri Weekly (TC)[2]	Daily (TR)[2]
Chemical analysis of seepage[6]			Consider	Consider	Consider
Pore pressure[3]		Consider	3-Monthly to 6-Monthly	Monthly to 6-Monthly	Monthly to 3-Monthly
Surface movement, control[4]				5-Yearly to 10-Yearly	5-Yearly
Surface Movement, normal		Consider	Consider	2-Yearly	Yearly
Internal movement/ stresses[3]			Consider	2-Yearly	Yearly
Seismological[3]				Consider (TR)[2]	Consider (TR)[2]
Post-tensioning[7]			10-Yearly	5-Yearly to 10-Yearly	5-Yearly

NOTE 1: *These frequencies may need to be varied according to the conditions at, and the type and size of dam, and applies to instrumentation already installed at the dam.*

NOTE 2: *The frequencies quoted assume manual reading of the instrumentation. Where automated readings are available more frequent reading would be appropriate*
(TR-telemetry recommended) (TC-telemetry to be considered).

NOTE 3: *The frequency of reading and location of the monitoring instruments need to be at the discretion of the dams engineer. Seismological instruments, where installed, are recommended to be incorporated into state-wide seismic networks.*

NOTE 4: *A control survey uses monuments that are remote from the dam site to check the location of the survey monuments at the dam site.*

NOTE 5: *The frequencies listed for very low Hazard Category dams are suggestions, the dam owner should determine appropriate monitoring.*

NOTE 6: *Recommended annually for concrete dams, tailings dams and embankments constructed from, or on, potentially dispersive materials where specified by the designer or safety reviewer.*

NOTE 7: *Preferably all cables, but at least a significant representative sample, to be monitored..*

APPENDIX C : RESULTS OF QUESTIONNAIRE B

C.1 Introduction

This section provides the results of the questionnaire. It should be read in conjunction with the Annex Volume, which includes

- the summary of results common to both Tasks A and B
- the full package sent out to every recipient of the questionnaire.

There are 11 open questions out of the total of 115 boxes to be completed. Of the 40 responses to Questionnaire B, five included comments on the Word proforma file. The commentary includes a summary of the responses to the open questions.

The results are summarised as follows:-

This section
- Table C.1 – response broken down by respondent
- Table C.2 – response broken down by dam type
- a commentary on the results

Main text
- Table 1.3 Summary table
- Table 3.1
- Figures 3.1, 3.2 and at end of Section 4

Questions are only included in Table C2 where the response would be expected to vary significantly from the response by respondent

Where results are plotted as cumulative distributions, they are the percentage of non-blank answers (rather than of all respondents).

C.2 Verification and adjustments of responses

The following questions were clearly misunderstood by a few of the respondents. In order that an improved statistical analysis of the answers could be undertaken, these responses have been interpreted and adjustments made to the completed questionnaires. Details of the adjustments are listed below:

Question 7
One respondent showed the incident as Level 1. However, there was no uncontrolled release of water so it was actually a Level 2 incident

Question 7 to end
There was overlap of one incident, as described in the Annex Report. The data file has been adjusted by removing the versions of the incident given by the Panel Engineer from the analysis (although retaining it for cross checking information on the dam).

C.3 Summary of responses to Q1 – 6 (by respondent)

Your experience (Q1)
As might be expected the number of dams that respondents had been involved with in their career was generally between 51 and 100, although there were 20% of respondents who only had experience of less than 20 dams, and 25% who had been involved in more than 100.

Number of occurrences of internal erosion incidents over last 10 years (Q2)
The responses to this question are summarised in the Annex volume; including use of the data to provide independent estimates of the annual probability of each level of internal erosion event.

One panel engineer reported a Level 1 incident (failure). This was queried with the respondent and this is understood to be a small reservoir (probably not registered under the Act) which from its appearance with a breach along the line of a brick culvert through the dam is considered likely to have failed due to internal erosion. However, no details of the date of the failure are available; it is possible it was prior to 1992 and thus would not be eligible to be included under Q2. It is also understood the owner is unlikely to be prepared to co-operate with obtaining more information on the incident.

Views on surveillance (Q3-6)
Overall 35% of respondents suggested to be effective visual inspection is required every 2 days or more frequently, whilst 35% suggested weekly, with scatter around these values. The Panel AR engineers employed by consulting engineers had a greater proportion (45%) who considered every 2 days or more frequently was necessary.

In terms of the qualifications, experience and training of staff who carry out regular visual inspections the response closest to the median was

Q	Minimum	"Median" Response	
4a	Level of education	GCSE	60%
4b	Proportion of time on dam safety work	7.5 hours/ week or less	58%
4c	Experience of work on dams	two years or less	60%
5a	Training	in-house course	60%
		training by a supervisor	21%
5b	CPD per year	7.5 hours or less	56%

Overall views on the value of the different forms of instrumentation are summarised in Table 3.1 in the main text, with seepage quantity, turbidity and visual inspection considered to be of high value, settlement monitoring of medium value and piezometers of low value.

Open Question 4d
Are there any other features that should be used to define the experience and levels of staff carrying out routine surveillance duties.

Key issues	No of responses
Frequency should vary with hazard posed by dam	2
Understanding of hydraulics and soil mechanics	2
Good observational skills	5
Induction by panel engineer (e.g. accompany them on visit)	3
Communicative, sufficiently self-confident to seek advice when minor change	2
Enquiring mind, enthusiasm	2
Understand historical forms of construction of dams	1

C.4 Summary of responses to Q7 onwards (by respondent)

The analysis of the specific examples of internal erosion provided in response to the questionnaires are considered in relation to providing information on the following issues

a) How quickly did the internal erosion progress?
b) Is there any particular feature that makes the dam more vulnerable to internal erosion?
c) What was done to stop the internal erosion (and thus what could be done in advance to reduce the probability of occurrence of progressive internal erosion)?
d) How do the results compare with the output from the expert elicitation?

Ideally the characteristics of the dams experiencing internal erosion would be compared with those of the UK dam population as a whole; however this is not currently possible because the data for the UK dam population is not available.

Results are summarised below in one or more of the following ways

i) Tables C1 and C2 with the subdivision of responses to the questionnaire, by respondent and dam type respectively
ii) Figures in the main body of the text
iii) Where relevant on figures summarising the results of the elicitation (Figures E1 to E14)
iv) Table of the most common (typical) response
v) Table (or figure) summarising the range of overall responses to a particular question

Date of event and seriousness of event (Q7, 8)
The number of events a year is discussed in Annex 2; including a check on duplication of events between dam owners and panel engineers. Of the 37 events reported; 8 were either prior to 1993, or were in 2003. After correction for this and duplication there were 16 case histories provided over the last 10 years for Level 2 incidents and 11 for Level 3 incidents.

Characteristics of dam (Q9 -12)

Q		Most common response		Remarks
9	Flood category	Category A	67%	9% each of other classes
10	Year of construction	1800- 1850	30%	12% prior to 1800, From 1850: 24%, 12%, 15% in each succeeding 50 year period
11	Height of dam	4-10m	44%	12% less than this, 36% greater
12	Dam crest length	51-500	63%	

Information on incident (Q13-18)

Q		Most common response		Remarks
13	Reservoir level at time of incident	-0.1 to +0.1m (above TWL)	60%	
14	Initiating event	Gradual deterioration	39%	27% reported none noted
15	Location of problem	Embankment	42%	
16	Mechanism of deterioration	Piping	39%	33% selected concentrated leak
17	Elevation of erosion path	-1.0 to 0.0m (above TWL)	33%	33% considered -1 to -5m

Question 18
Any further comments on the incident

Key issues	**No of responses**
Additional information on incident	7
Overtopping over top of core was cause in 2 case histories	1
Decay of tree roots	1
Excavation at base of d/s shoulder by adjacent land owner	1
Along interface of original and raised section of dam	1
Occurred as dam started overtopping	1
Second incident in 10 years	2
Old scour pipe	1

Event Detection (Q19-22d)

Q		Most common response		Remarks
19	Who detected incident	Staff on routine visit	42%	Supervising Engineer detected 21%
20	Level of training of detecting personnel	On the job	30%	
21	Would improved training affect reliability of detection	No	70%	15% felt it would have improved
22	Indicators of internal erosion	See Table C2		

Rate of deterioration (Q23-28)

Q		Most common response		Remarks
23	Time from detection to			
a	First physical action	0-6 hours	39%	
b	Maximum flow	≤ 2 hours	27%	39% left blank
c	The incident being controlled	13-24 hours	24%	
24	Magnitude of flow			
a	When detected	<0.1 litre/sec	15%	36% left blank
b	At its maximum	0.1 to 1 litre/sec	21%	48% left blank
c	When incident controlled	<0.1 litre/sec	30%	42% left blank
25	Elapsed time between last surveillance visit and detection	Even spread from same day to over a week		
26	Total volume of fill eroded	<0.5m^3	55%	Ignoring the failure, one (3%) reports as > 10m^3
27a	If no action, how long before dam would have failed?	>180 days	27%	15% considered < 5 days; 36% blank
27b	Leakage rate which would have been uncontrollable	3 to 5 l/sec	9%	82% left blank

Question 28
Do you have any further comments on the rate of deterioration

Key issues	No of responses
Time to fail is a guess (one respondent suggested may have been years)	5
Leak self heals, then restarts (or was an old leak which restarted after 6, 25 years)	4
Would have failed by overtopping first	1
Failure rate of seepage = 2.5 x leakage rate (but leakage rate not given)	1

Intrinsic condition (Q29-39)

For many of these questions the majority of responses were blank, presumably because the value of the parameter was not known (or not readily available to the person completing the questionnaire)

Q		Most common response		Remarks
29	Embankment type	Puddle clay	48%	
30	Dam foundation	Weathered rock	30%	
31	For fill forming watertight element			
a	Geological origin	Glacial	36%	
b	Liquid limit	41-50	9%	
c	Plasticity Index	11-20	18%	
32	For fill downstream of impervious element			
a	Form of construction	Random	30%	
b	Geological origin	Glacial	33%	
c	Does it satisfy modern filter criteria?	Don't know	33%	
d	D_{15}			88% blank
33	For fill upstream of impervious element			
a	Form of construction	Random	39%	
b	Geological origin	Glacial	27%	
c	Does it act as a crack filler?	Don't know	36%	
d	Soil type	Clay PI <22	27%	
34	For impervious element at ground level			
a	Width	Even spread from		

		1 to >20m		
b	Head across it	3-5m		
35	If incident involved conduit			
a	External diameter of conduit	0.25-0.5m	12%	
b	Pipe laid within fill	15%		
c	Spacing of movement joints			88% blank
36	Geometry of steepest abutment	<30 degrees	42%	
37	Characteristics of reservoir water			
a	pH			82% blank
b	Total dissolved solids			97% blank
c	Conductivity			94% blank

Question 35d
Was there any special treatment of the interface between the fill and conduit

Key issues	No of responses
No	8
Puddle clay surround	2
Don’t know	2
Concrete surround	1

Question 37d
Any other data that might be relevant?

Key issues	No of responses
Fish stocked	2

Question 38
Have any of the embankment or foundation soils been subjected to any form of dispersion or erodibility testing

Key issues	No of responses
No	17
Don’t know	1
Yes – 4 crumb and 4 double hydrometer show mildly dispersive	1
Test results no longer available	1

Question 39
Are there any unusual features? E.g. narrow crest, steep downstream slope; filters retrofitted to downstream face

Key issues	No of responses
Yes – details provided	10
No	9
Near vertical cliff by culvert	2

Surveillance (Q40-44d, 49)

Q		Most common response		Remarks
40	Frequency of visits to dam before incident	weekly	33%	
41	Number of instruments at dam	See Table C3		
42	Elapsed time from last reading to incident	See Table C3		
43	Process to asses surveillance data			
	Trigger values	No review but operator would flag unusual values	36%	
	Formal review by other	Supervising Engineer	42%	
44	Frequency of reviews			
	By engineer	26-52 weeks	30%	
	By Supervising Engineer	26-52 weeks	61%	
	Written report	26-52 weeks	70%	
	External consultant	Note 1		
49	Was the frequency of any of the following changed as a result of the incident?			
a	Surveillance visit	No	58%	
b	Reading piezometers			Blank 60%
c	Readings seepage measurement devices	No	24%	
d	Reading settlement measurement devices	No	35%	

Notes
1. Question ambiguous, some entered 0 or 999 to show no external consultant

Prior warning (Q45-48)

Q		Most common response		Remarks
45	Is it likely that internal erosion was occurring prior to the incident?	Yes	51%	
46	Indicators of internal erosion	See Table C3		
47	For each incident which parameter was the most useful as an indicator of internal erosion	Quantity of seepage	48%	33% indicated some form of deformation

Question 48
Please expand the above (prior warning), or provide any further comments on what prior warning there was (in retrospect) e.g. quantify the settlement rate, seepage flows

Key issues	**No of responses**
Further site specific detail provided	20
The dam was too small to come under the Reservoirs Act	3
The only surveillance was the periodic Supervising Engineer visits	1

Actions taken to control (Q50-55)

Q		Most common response		Remarks
50	What action was taken immediately on detection	Lower reservoir	67%	9% reported this as having no effect
51	What physical works were then carried out?	Other Grouting	33% 27%	
52	Were the works effective	Yes	61%	In 15% of cases action was only partially effective, with further action required
53	If supplementary physical measures were taken, what were they?	Other Diaphragm wall	18% 12%	Blank 51%
54	Was site investigation carried out, and if so how many boreholes	11 to 20	21%	Blank 58%

Question 50d
What action was taken immediately on detection, and in your opinion how effective was it? (other than lower reservoir, filter on downstream face, dump material into reservoir)

Key issues	No of responses
Further dam specific information	12
Dam demolished	1

Question 55
Please provide any further information e.g. key findings of any investigations/ reports into the cause

Key issues	No of responses
Further dam specific information	24
Site investigation inconclusive	1
Thermal sensing used	2
Lowering and raising water level used to pinpoint source of leak	1

Drawdown capacity (Q56-57)

Q		Most common response		Remarks
56	What was the drawdown capacity prior to the incident?	0.5-1.0m/day	15%	18% less than this; 45% blank
57	Has the drawdown capacity been modified since the event?			94% blank

Question 58
Please add any other comments you may have, either in the text box or as an attached Word document

Key issues	No of responses
Further dam specific information	10
No Incidents more serious than level 4 have been experienced by the company	2
Outside Act	1
The Questionnaire does not accept fractions for some questions	1

C.5 Table C1 : Summary of responses, broken down by respondent type

Table C.1 : Analysis of Questionnaire B by type of respondent

	QUESTION	Increments	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
		Possible		Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE
		Responses		NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							(Incl correction for blanks)
1	Please enter the number of dams in UK that you have been involved with in a professional capacity over the course of your career.																	
		Fewer than 10		1	1	0	0	1	1	4	9%	100%	0%	0%	50%	33%	10%	
		11 to 20		1	0	1	0	0	1	3	9%	0%	9%	0%	0%	33%	8%	
		21 to 50		5	0	2	1	0	0	8	45%	0%	18%	8%	0%	0%	20%	
		51 to 100		1	0	4	7	0	1	13	9%	0%	36%	58%	0%	33%	33%	
		More than 100		2	0	3	4	1	0	10	18%	0%	27%	33%	50%	0%	25%	
		Blank		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	
2	In the last 10 years, have you been involved with (or have an intimate knowledge of) any occurrences of internal erosion within a dam? If yes, indicate the number of each level of incident (see Guidance Notes for definitions of Level of incident)																	
a	Level 1 (Failure)	0 to 0		6	1	5	8	2	2	24	55%	100%	45%	67%	100%	67%	60%	
		1 to 1		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	
		2 to 2		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		3 to 3		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		4 to 4		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		5 to 5		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		6 to 6		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		>6		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		5	0	5	4	0	1	15	45%	0%	45%	33%	0%	33%	38%	
b	Level 2 (Emergency drawdown/ works)																	
		0 to 0		3	1	2	3	1	2	12	27%	100%	18%	25%	50%	67%	30%	
		1 to 1		2	0	1	4	1	0	8	18%	0%	9%	33%	50%	0%	20%	
		2 to 2		1	0	3	2	0	0	6	9%	0%	27%	17%	0%	0%	15%	
		3 to 3		1	0	1	0	0	0	2	9%	0%	9%	0%	0%	0%	5%	
		4 to 4		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		5 to 5		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		6 to 6		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	
		>6		1	0	0	0	0	0	1	9%	0%	0%	0%	0%	0%	3%	
		Blank		3	0	3	3	0	1	10	27%	0%	27%	25%	0%	33%	25%	
c	Level 3 (Unplanned visit/ precautionary drawdown)																	
		0 to 0		2	1	1	4	1	1	10	18%	100%	9%	33%	50%	33%	25%	
		1 to 1		0	0	3	1	0	1	5	0%	0%	27%	8%	0%	33%	13%	
		2 to 2		0	0	1	3	0	0	4	0%	0%	9%	25%	0%	0%	10%	
		3 to 3		0	0	1	0	1	0	2	0%	0%	9%	0%	50%	0%	5%	
		4 to 4		1	0	1	0	0	0	2	9%	0%	9%	0%	0%	0%	5%	
		5 to 5		1	0	0	0	0	0	1	9%	0%	0%	0%	0%	0%	3%	
		6 to 6		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		>6		2	0	0	0	0	0	2	18%	0%	0%	0%	0%	0%	5%	
		Blank		5	0	4	4	0	1	14	45%	0%	36%	33%	0%	33%	35%	
d	Level 4 (Works from periodic safety review)																	
		0 to 0		1	1	2	3	2	1	10	9%	100%	18%	25%	100%	33%	25%	
		1 to 5		3	0	0	3	0	1	7	27%	0%	0%	25%	0%	33%	18%	
		6 to 10		4	0	3	2	0	0	9	36%	0%	27%	17%	0%	0%	23%	
		11 to 20		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION	Increments	Possible Responses	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							CUMULATIVE (Incl correction for blanks)
				Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		21 to 40		2	0	1	0	0	0	3	18%	0%	9%	0%	0%	0%	8%	
		41 to 60		0	0	0	1	0	0	1	0%	0%	0%	8%	0%	0%	3%	
		61 to 100		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		>100		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		1	0	4	3	0	1	9	9%	0%	36%	25%	0%	33%	23%	
e Level 5 (unplanned visit by Supervising Engineer/ Investigation)																		
		0 to 0		1	1	2	5	1	1	11	9%	100%	18%	42%	50%	33%	28%	
		1 to 2		1	0	1	2	0	1	5	9%	0%	9%	17%	0%	33%	13%	
		3 to 4		1	0	0	0	1	0	2	9%	0%	0%	0%	50%	0%	5%	
		5 to 6		1	0	0	0	0	0	1	9%	0%	0%	0%	0%	0%	3%	
		7 to 8		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		9 to 10		5	0	1	0	0	0	6	45%	0%	9%	0%	0%	0%	15%	
		11 to 15		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		>15		1	0	1	0	0	0	2	9%	0%	9%	0%	0%	0%	5%	
		Blank		1	0	6	5	0	1	13	9%	0%	55%	42%	0%	33%	33%	
Q3 To be able to have a reasonable reliability of detecting internal erosion in time to forestall a Level 2 incident, in your personal opinion: What frequency of visual inspection is required (use fractions of a day if necessary)																		
		0 to 0.5		2	0	0	0	0	0	2	18%	0%	0%	0%	0%	0%	5%	
	0.01	0.51 to 1		1	0	1	0	0	0	2	9%	0%	9%	0%	0%	0%	5%	6%
	0.01	1.01 to 2		3	0	4	1	1	1	10	27%	0%	36%	8%	50%	33%	25%	36%
	0.01	2.01 to 3		1	0	0	2	0	1	4	9%	0%	0%	17%	0%	33%	10%	48%
	0.01	3.01 to 4		1	0	2	0	0	0	3	9%	0%	18%	0%	0%	0%	8%	58%
	0.01	4.01 to 5		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	58%
	0.01	5.01 to 7		2	0	3	8	1	0	14	18%	0%	27%	67%	50%	0%	35%	100%
		>7		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	100%
		Blank		1	1	1	1	0	1	5	9%	100%	9%	8%	0%	33%	13%	
4 a What minimum level of education attainment should they have achieved																		
		GCSE		6	1	7	9	1	0	24	55%	100%	64%	75%	50%	0%	60%	
		A levels		1	0	2	2	0	0	5	9%	0%	18%	17%	0%	0%	13%	
		HNC		3	0	1	1	1	2	8	27%	0%	9%	8%	50%	67%	20%	
		Degree		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		1	0	1	0	0	1	3	9%	0%	9%	0%	0%	33%	8%	
b What is the minimum proportion of time that they should spend on dam safety related work																		
		0 to 0		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		0.01 to 0		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		0.01 to 4		4	1	2	4	2	0	13	36%	100%	18%	33%	100%	0%	33%	
		4.01 to 7.5		3	0	4	2	0	1	10	27%	0%	36%	17%	0%	33%	25%	
		7.51 to 15		2	0	2	3	0	1	8	18%	0%	18%	25%	0%	33%	20%	
		15.01 to 22.5		2	0	2	0	0	0	4	18%	0%	18%	0%	0%	0%	10%	
		22.51 to 30		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		>30		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		0	0	1	3	0	1	5	0%	0%	9%	25%	0%	33%	13%	

Table C.1 : Analysis of Questionnaire B by type of respondent

	QUESTION	Increments	Possible Responses	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
					Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
					NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
c	What is the minimum number of years experience of work on dams they should have had (express as equivalent full time years so 50% of time for 10 years is 5 year equivalent)																		
			0 to 0		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			1 to 1		5	1	4	6	2	0	18	45%	100%	36%	50%	100%	0%	45%	
			2 to 2		4	0	2	3	0	1	10	36%	0%	18%	25%	0%	33%	25%	
			3 to 3		1	0	0	0	0	0	1	9%	0%	0%	0%	0%	0%	3%	
			4 to 4		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			5 to 5		1	0	4	2	0	1	8	9%	0%	36%	17%	0%	33%	20%	
			6 to 10		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			>10		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			Blank		0	0	1	1	0	1	3	0%	0%	9%	8%	0%	33%	8%	
d	(Not subject to analysis)																		
5	What training should the staff carrying out the visual inspections have?																		
a	Type of training		None		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			Verbal by Supervisor		0	1	1	2	0	1	5	0%	100%	9%	17%	0%	33%	13%	
			Written by Supervisor		0	0	1	2	0	0	3	0%	0%	9%	17%	0%	0%	8%	
			In House Course		10	0	6	6	2	0	24	91%	0%	55%	50%	100%	0%	60%	
			External Course		1	0	2	1	0	2	6	9%	0%	18%	8%	0%	67%	15%	
			Blank		0	0	1	1	0	0	2	0%	0%	9%	8%	0%	0%	5%	
b	Number of hours CPD on dam safety issues per year?																		
			0 to 0		0	0	1	1	0	0	2	0%	0%	9%	8%	0%	0%	5%	
			1 to 4		3	0	3	0	0	3	9	27%	0%	27%	0%	0%	100%	23%	
			5 to 7.5		3	1	2	5	0	0	11	27%	100%	18%	42%	0%	0%	28%	
			8.5 to 15		2	0	3	3	2	0	10	18%	0%	27%	25%	100%	0%	25%	
			16 to 22.5		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			23.5 to 30		1	0	0	0	0	0	1	9%	0%	0%	0%	0%	0%	3%	
			31 to 37.5		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
			>37.5		0	0	1	1	0	0	2	0%	0%	9%	8%	0%	0%	5%	
			Blank		2	0	1	2	0	0	5	18%	0%	9%	17%	0%	0%	13%	
6	Which of the following instrumentation do you consider is of value in detecting and monitoring progression of internal erosion																		
a	Standpipe piezometer		High		1	0	0	4	0	1	6	9%	0%	0%	33%	0%	33%	15%	
			Medium		3	0	3	1	1	0	8	27%	0%	27%	8%	50%	0%	20%	
			Low		5	0	5	6	1	2	19	45%	0%	45%	50%	50%	67%	48%	
			None		2	1	2	0	0	0	5	18%	100%	18%	0%	0%	0%	13%	
			Blank		0	0	1	1	0	0	2	0%	0%	9%	8%	0%	0%	5%	
b	Other piezometer																		
			High		1	0	0	2	0	1	4	9%	0%	0%	17%	0%	33%	10%	
			Medium		4	0	2	2	1	1	10	36%	0%	18%	17%	50%	33%	25%	
			Low		4	0	6	6	1	1	18	36%	0%	55%	50%	50%	33%	45%	
			None		2	1	2	1	0	0	6	18%	100%	18%	8%	0%	0%	15%	
			Blank		0	0	1	1	0	0	2	0%	0%	9%	8%	0%	0%	5%	
c	Settlement monitoring																		
			High		1	0	1	4	1	2	9	9%	0%	9%	33%	50%	67%	23%	
			Medium		6	0	5	4	1	1	17	55%	0%	45%	33%	50%	33%	43%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION	Increments	Possible	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
				Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
		Responses		NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		Low		4	1	4	3	0	0	12	36%	100%	36%	25%	0%	0%	30%	
		None		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		0	0	1	1	0	0	2	0%	0%	9%	8%	0%	0%	5%	
d Seepage quantity																		
		High		10	0	7	9	2	3	31	91%	0%	64%	75%	100%	100%	78%	
		Medium		1	0	3	3	0	0	7	9%	0%	27%	25%	0%	0%	18%	
		Low		0	1	0	0	0	0	1	0%	100%	0%	0%	0%	0%	3%	
		None		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	
e Seepage turbidity																		
		High		10	0	7	10	2	2	31	91%	0%	64%	83%	100%	67%	78%	
		Medium		0	0	3	2	0	1	6	0%	0%	27%	17%	0%	33%	15%	
		Low		1	1	0	0	0	0	2	9%	100%	0%	0%	0%	0%	5%	
		None		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	
f Visual inspection																		
		High		6	1	9	9	2	2	29	55%	100%	82%	75%	100%	67%	73%	
		Medium		4	0	0	3	0	1	8	36%	0%	0%	25%	0%	33%	20%	
		Low		1	0	1	0	0	0	2	9%	0%	9%	0%	0%	0%	5%	
		None		0	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%	0%	
		Blank		0	0	1	0	0	0	1	0%	0%	9%	0%	0%	0%	3%	
g Other (give details in 6h)																		
		High		1	0	0	1	0	0	2	9%	0%	0%	8%	0%	0%	5%	
		Medium		0	0	1	0	1	0	2	0%	0%	9%	0%	50%	0%	5%	
		Low		1	0	1	0	0	0	2	9%	0%	9%	0%	0%	0%	5%	
		None		1	0	0	1	0	0	2	9%	0%	0%	8%	0%	0%	5%	
		Blank		8	1	9	10	1	3	32	73%	100%	82%	83%	50%	100%	80%	
h (Not subject to analysis)																		
7 What was the seriousness of the incident (use the definitions provided in the Guidance Note)																		
		Level 1		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Level 2		5		7	5	1	0	18	71%	#DIV/0!	50%	26%	50%	0%	53%	
		Level 3		2		7	6	0	1	16	29%	#DIV/0!	50%	32%	0%	33%	47%	
		Blank		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
8 Year of the event?																		
		0 to 1970		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1971 to 1980		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		1981 to 1992		0		1	1	0	1	3	0%	#DIV/0!	7%	5%	0%	33%	9%	
		1993 to 1995		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		1996 to 1998		1		2	3	0	0	6	14%	#DIV/0!	14%	16%	0%	0%	18%	
		1999 to 2000		1		5	3	0	0	9	14%	#DIV/0!	36%	16%	0%	0%	26%	
		2001 to 2002		4		2	1	0	0	7	57%	#DIV/0!	14%	5%	0%	0%	21%	
		>2002		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		Blank		0		0	0	1	0	1	0%	#DIV/0!	0%	0%	50%	0%	3%	
9 Flood Category of the dam (using the Floods and Reservoir Safety Guidelines)																		
		A		7		6	8	1	0	22	100%	#DIV/0!	43%	42%	50%	0%	65%	
		B		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		C		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		D		0		1	1	0	1	3	0%	#DIV/0!	7%	5%	0%	33%	9%	
		Blank		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION		Increments Possible Responses	Units	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
10	Year of construction of the dam (approx if not known exactly)																	
		0 to 1700		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		1701 to 1750		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1751 to 1800		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		1801 to 1850		4		1	4	0	1	10	57%	#DIV/0!	7%	21%	0%	33%	29%	
		1851 to 1900		1		4	3	0	0	8	14%	#DIV/0!	29%	16%	0%	0%	24%	
		1901 to 1950		0		2	2	0	0	4	0%	#DIV/0!	14%	11%	0%	0%	12%	
		1951 to 1980		1		4	1	0	0	6	14%	#DIV/0!	29%	5%	0%	0%	18%	
		>1980		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Blank		0		0	0	1	0	1	0%	#DIV/0!	0%	0%	50%	0%	3%	
11	Height of the dam (m)																	
		0 to 2		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		3 to 3		1		1	0	0	1	3	14%	#DIV/0!	7%	0%	0%	33%	9%	
		4 to 5		0		4	4	0	0	8	0%	#DIV/0!	29%	21%	0%	0%	24%	
		6 to 10		2		3	3	0	0	8	29%	#DIV/0!	21%	16%	0%	0%	24%	
		11 to 15		2		1	0	0	0	3	29%	#DIV/0!	7%	0%	0%	0%	9%	
		16 to 20		1		3	3	0	0	7	14%	#DIV/0!	21%	16%	0%	0%	21%	
		21 to 30		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		>30		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		0		1	0	1	0	2	0%	#DIV/0!	7%	0%	50%	0%	6%	
12	Dam Crest Length (m)																	
		0 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		21 to 50		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		51 to 100		0		2	4	0	1	7	0%	#DIV/0!	14%	21%	0%	33%	21%	
		101 to 200		2		1	4	0	0	7	29%	#DIV/0!	7%	21%	0%	0%	21%	
		201 to 500		3		3	1	0	0	7	43%	#DIV/0!	21%	5%	0%	0%	21%	
		501 to 1000		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		1001 to 1500		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		>1500		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Blank		0		4	0	1	0	5	0%	#DIV/0!	29%	0%	50%	0%	15%	
13	What was the reservoir level at the time the incident was detected, expressed as height above (+) or below (-) the spillway overflow																	
		< -2		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		-1.99 to -1		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		-0.99 to -0.3		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		-0.29 to -0.1		1		0	1	0	1	3	14%	#DIV/0!	0%	5%	0%	33%	9%	
		-0.09 to 0		1		3	6	0	0	10	14%	#DIV/0!	21%	32%	0%	0%	29%	
		0.01 to 0.1		2		4	2	1	0	9	29%	#DIV/0!	29%	11%	50%	0%	26%	
		0.11 to 0.5		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		>0.5		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Blank		0		5	0	0	0	5	0%	#DIV/0!	36%	0%	0%	0%	15%	
14	What was the initiating event? i.e. was there a trigger?																	
		None noted		0		4	3	1	1	9	0%	#DIV/0!	29%	16%	50%	33%	26%	
		Gradual deterioration		6		5	2	0	0	13	86%	#DIV/0!	36%	11%	0%	0%	38%	
		Rise in reservoir level		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		Previous drawdown of reservoir		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Other		0		1	6	0	0	7	0%	#DIV/0!	7%	32%	0%	0%	21%	
		Blank		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	

Table C.1 : Analysis of Questionnaire B by type of respondent

				CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
QUESTION		Increments Possible Responses	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
15	Where at the damsite did the problem occur? (Choose the most appropriate response)																	
		Embankment		2		4	7	0	0	13	29%	#DIV/0!	29%	37%	0%	0%	38%	
		Foundation		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Embankment/foundation interface		0		2	3	0	0	5	0%	#DIV/0!	14%	16%	0%	0%	15%	
		Embankment-abutment interface		0		1	0	1	1	3	0%	#DIV/0!	7%	0%	50%	33%	9%	
		Along a pipe or culvert		1		4	0	0	0	5	14%	#DIV/0!	29%	0%	0%	0%	15%	
		Into a pipe or culvert		2		0	1	0	0	3	29%	#DIV/0!	0%	5%	0%	0%	9%	
		Along a spillway wall		2		3	0	0	0	5	29%	#DIV/0!	21%	0%	0%	0%	15%	
		Other		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
16	What was the mechanism of deterioration? (please make your best estimate; definitions of terms are given in Section 10 of the Guidance Note)																	
		Concentrated leak		3		8	2	0	1	14	43%	#DIV/0!	57%	11%	0%	33%	41%	
		Suffusion		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		Piping		1		3	8	1	0	13	14%	#DIV/0!	21%	42%	50%	0%	38%	
		Dispersive clays		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Other		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Don't know		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
		Blank		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
17	At what elevation was the intake to the erosion path? (expressed as height above (+) or below (-) the spillway overflow). Provide your best estimate if not known precisely																	
		< -20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		-19.9 to -10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		-9.9 to -5		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		-4.9 to -2		1		2	3	1	0	7	14%	#DIV/0!	14%	16%	50%	0%	21%	
		-1.9 to -1		1		2	1	0	0	4	14%	#DIV/0!	14%	5%	0%	0%	12%	
		-0.9 to 0		3		3	4	0	1	11	43%	#DIV/0!	21%	21%	0%	33%	32%	
		0.01 to 1		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
		>1		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
		Blank		1		3	0	0	0	4	14%	#DIV/0!	21%	0%	0%	0%	12%	
18	(Not subject to analysis)																	
19	Who detected the incident?																	
		Public		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
		Staff on a routine visit		3		5	6	1	0	15	43%	#DIV/0!	36%	32%	50%	0%	44%	
		Staff passing the dam on an incidental visit		3		1	1	0	1	6	43%	#DIV/0!	7%	5%	0%	33%	18%	
		Supervising Engineer		1		4	2	0	0	7	14%	#DIV/0!	29%	11%	0%	0%	21%	
		Inspecting Engineer		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		Blank		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
20	What was the level of training of the detecting personnel in looking for unusual behaviour and thus when specialist advice should be sought																	
		None		2		4	1	0	0	7	29%	#DIV/0!	29%	5%	0%	0%	21%	
		On the job		1		5	3	0	1	10	14%	#DIV/0!	36%	16%	0%	33%	29%	
		Verbal instructions by supervisor		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		Written instructions by supervisor		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION	Increments	Possible Responses	Units	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		In-house course		2		0	2	1	0	5	29%	#DIV/0!	0%	11%	50%	0%	15%	
		External Course		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Blank		1		3	3	0	0	7	14%	#DIV/0!	21%	16%	0%	0%	21%	
21 Would improved training of staff undertaking routine visits have affected the reliability of detection?																		
		Yes		2		2	1	0	0	5	29%	#DIV/0!	14%	5%	0%	0%	15%	
		No		5		7	9	1	1	23	71%	#DIV/0!	50%	47%	50%	33%	68%	
		Unsure		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		Blank		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
22 To what extent did each of the following indicate internal erosion was occurring at the time the incident was detected?																		
a Seepage: Quantity		Strong		3		9	3	1	1	17	43%	#DIV/0!	64%	16%	50%	33%	50%	
		Medium		0		2	3	0	0	5	0%	#DIV/0!	14%	16%	0%	0%	15%	
		Low		4		0	4	0	0	8	57%	#DIV/0!	0%	21%	0%	0%	24%	
		No Indication		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Blank		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
b Seepage: Turbidity or other characteristic																		
		Strong		1		5	1	0	0	7	14%	#DIV/0!	36%	5%	0%	0%	21%	
		Medium		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Low		2		0	3	1	1	7	29%	#DIV/0!	0%	16%	50%	33%	21%	
		No Indication		4		5	6	0	0	15	57%	#DIV/0!	36%	32%	0%	0%	44%	
		Blank		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
c Settlement																		
		Strong		0		2	4	0	0	6	0%	#DIV/0!	14%	21%	0%	0%	18%	
		Medium		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Low		0		1	3	0	0	4	0%	#DIV/0!	7%	16%	0%	0%	12%	
		No Indication		6		5	2	1	1	15	86%	#DIV/0!	36%	11%	50%	33%	44%	
		No Instruments		1		4	2	0	0	7	14%	#DIV/0!	29%	11%	0%	0%	21%	
		Blank		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
d Piezometer readings																		
		Strong		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Medium		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
		Low		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		No Indication		0		4	3	0	0	7	0%	#DIV/0!	29%	16%	0%	0%	21%	
		No Instruments		7		7	6	1	1	22	100%	#DIV/0!	50%	32%	50%	33%	65%	
		Blank		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
23 What was the time between the incident being detected and (give your best estimate)																		
a the first physical action taken on site which would reduce the risk of failure?		0 to 6		2		7	4	0	0	13	29%	#DIV/0!	50%	21%	0%	0%	38%	43%
		7 to 12		1		1	2	0	0	4	14%	#DIV/0!	7%	11%	0%	0%	12%	57%
		13 to 24		2		1	3	0	0	6	29%	#DIV/0!	7%	16%	0%	0%	18%	77%
		25 to 36		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	77%
		37 to 48		1		1	0	0	1	3	14%	#DIV/0!	7%	0%	0%	33%	9%	87%
		49 to 72		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	90%
		73 to 168		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	90%
		>168		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	100%
		Blank		0		3	0	1	0	4	0%	#DIV/0!	21%	0%	50%	0%	12%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION		Increments		CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
		Possible Responses	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
b	the maximum flow rate from the leak (or other symptom of internal erosion)																	
		0 to 2		3		4	1	0	1	9	43%	#DIV/0!	29%	5%	0%	33%	26%	45%
		3 to 4		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	55%
		5 to 6		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	55%
		7 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	55%
		9 to 12		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	65%
		13 to 24		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	80%
		25 to 36		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	80%
		>36		1		0	3	0	0	4	14%	#DIV/0!	0%	16%	0%	0%	12%	100%
		Blank		2		7	4	1	0	14	29%	#DIV/0!	50%	21%	50%	0%	41%	
c	the incident was controlled (e.g. reservoir drawn down and leak had stopped)																	
		0 to 12		0		2	2	0	0	4	0%	#DIV/0!	14%	11%	0%	0%	12%	15%
		13 to 24		1		3	4	0	0	8	14%	#DIV/0!	21%	21%	0%	0%	24%	46%
		25 to 36		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	50%
		37 to 48		1		4	0	0	1	6	14%	#DIV/0!	29%	0%	0%	33%	18%	73%
		49 to 72		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	77%
		73 to 96		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	81%
		97 to 168		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	88%
		>168		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	100%
		Blank		2		3	2	1	0	8	29%	#DIV/0!	21%	11%	50%	0%	24%	
24	Assuming that there was some form of leakage flow, what was the magnitude of this flow - please make your best estimate (leave blank if no seepage flow, but please comment in Q27)																	
a	when the event was detected	<0.1		1		3	1	0	0	5	14%	#DIV/0!	21%	5%	0%	0%	15%	
		0.11 to 0.5		1		1	2	0	0	4	14%	#DIV/0!	7%	11%	0%	0%	12%	
		0.51 to 1		0		0	1	0	1	2	0%	#DIV/0!	0%	5%	0%	33%	6%	
		1.01 to 2		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		2.01 to 5		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		5.01 to 10		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
		10.01 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>20		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		Blank		3		5	4	1	0	13	43%	#DIV/0!	36%	21%	50%	0%	38%	
b	at its maximum																	
		0 to 0.1		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		0.11 to 1		1		2	3	0	1	7	14%	#DIV/0!	14%	16%	0%	33%	21%	
		1.01 to 5		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
		5.01 to 10		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		11 to 50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		51 to 100		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		101 to 1000		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		>1000		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Blank		4		8	4	1	0	17	57%	#DIV/0!	57%	21%	50%	0%	50%	
c	when the incident was controlled?																	
		<0.1		2		4	4	0	0	10	29%	#DIV/0!	29%	21%	0%	0%	29%	
		0.11 to 0.5		0		1	0	0	1	2	0%	#DIV/0!	7%	0%	0%	33%	6%	
		0.51 to 1		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		1.01 to 2		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION		Increments	Possible Responses	Units	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
					NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
			2.01 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			5.01 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			10.01 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>20		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
			Blank		3		7	4	1	0	15	43%	#DIV/0!	50%	21%	50%	0%	44%	
Q25	What was the elapsed time between the last surveillance visit of the dam and the event being detected?																		
			< 0		2		0	2	0	0	4	29%	#DIV/0!	0%	11%	0%	0%	12%	
		0.01	0.01 to 0.5		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	6%
		0.01	0.51 to 1		2		2	0	0	0	4	29%	#DIV/0!	14%	0%	0%	0%	12%	29%
		0.01	1.01 to 2		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	41%
		0.01	2.01 to 3		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	53%
		0.01	3.01 to 4		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	53%
		0.01	4.01 to 7		1		0	2	0	0	3	14%	#DIV/0!	0%	11%	0%	0%	9%	71%
			>7		0		4	1	0	0	5	0%	#DIV/0!	29%	5%	0%	0%	15%	100%
			Blank		1		5	5	1	1	13	14%	#DIV/0!	36%	26%	50%	33%	38%	
26	What was the total volume of fill eroded from the dam (please make your best estimate)																		
			<0.5 cubic metres		4		8	5	0	1	18	57%	#DIV/0!	57%	26%	0%	33%	53%	
			0.5 to 2 cubic metres		2		1	3	0	0	6	29%	#DIV/0!	7%	16%	0%	0%	18%	
			2.1 to 10 cubic metres		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
			greater than 10 cubic metres		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
			Blank		0		3	2	1	0	6	0%	#DIV/0!	21%	11%	50%	0%	18%	
27	Assuming that no action was taken following detection, can you please estimate																		
a	when the dam would have failed? This is the time between detection and failure.		0 to 1		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
			2 to 2		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
			3 to 5		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			6 to 10		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
			11 to 30		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
			31 to 90		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
			91 to 180		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>180		2		4	3	0	0	9	29%	#DIV/0!	29%	16%	0%	0%	26%	
			Blank		2		3	6	1	1	13	29%	#DIV/0!	21%	32%	50%	33%	38%	
b	the leakage rate when the situation would have become uncontrollable?																		
			0 to 0		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			1 to 2		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
			3 to 5		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
			6 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			11 to 50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			51 to 100		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			101 to 1000		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>1000		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			Blank		7		11	8	1	1	28	100%	#DIV/0!	79%	42%	50%	33%	82%	
28	(Not subject to analysis)																		
29	What is the type of embankment?																		
			Puddle Clay		4		4	8	0	0	16	57%	#DIV/0!	29%	42%	0%	0%	47%	
			Homogeneous		1		2	2	0	0	5	14%	#DIV/0!	14%	11%	0%	0%	15%	

Table C.1 : Analysis of Questionnaire B by type of respondent

				CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
QUESTION		Increments Possible Responses	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		Rolled Clay		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Concrete core wall		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		Upstream membrane		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Other		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		Unknown		1		2	0	0	1	4	14%	#DIV/0!	14%	0%	0%	33%	12%	
						3		1	0									
		Blank		0		3	0	1	0	4	0%	#DIV/0!	21%	0%	50%	0%	12%	
30	What is the dam foundation? Please select one of the predefined options																	
		Gravel		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
		Sand		2		1	0	0	0	3	29%	#DIV/0!	7%	0%	0%	0%	9%	
		Silt		0		0	3	0	0	3	0%	#DIV/0!	0%	16%	0%	0%	9%	
		Clay Plasticity Index >22		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		Clay Plasticity Index 22 or less		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Weathered rock		1		5	4	0	0	10	14%	#DIV/0!	36%	21%	0%	0%	29%	
		Rock with many gouge filled discontinuities		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Sound Rock		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		Blank		2		4	1	1	1	9	29%	#DIV/0!	29%	5%	50%	33%	26%	
31	For the fill forming the watertight element:-																	
a	What is the geological origin?	Alluvial		0		2	7	0	0	9	0%	#DIV/0!	14%	37%	0%	0%	26%	
		Glacial		5		3	4	0	0	12	71%	#DIV/0!	21%	21%	0%	0%	35%	
		Lacustrine		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Marine		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Weathered rock		0		4	0	0	0	4	0%	#DIV/0!	29%	0%	0%	0%	12%	
		Other		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Blank		1		3	0	1	1	6	14%	#DIV/0!	21%	0%	50%	33%	18%	
b	What is its Liquid Limit?																	🟨
		0 to 10		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		11 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		21 to 30		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		31 to 40		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		41 to 50		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
		51 to 60		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		61 to 70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		6		9	10	1	1	27	86%	#DIV/0!	64%	53%	50%	33%	79%	
c	What is its Plasticity Index?																	🟨
		0 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		6 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		11 to 15		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		16 to 20		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
		21 to 30		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		31 to 40		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		41 to 50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		5		9	10	1	1	26	71%	#DIV/0!	64%	53%	50%	33%	76%	
32	For the fill material immediately downstream of the impervious element:-																	
a	What would you describe its form of construction?	Random		1		3	6	0	0	10	14%	#DIV/0!	21%	32%	0%	0%	29%	
		Zoned		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Selected		1		3	3	0	0	7	14%	#DIV/0!	21%	16%	0%	0%	21%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION	Increments	Possible	Units	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
		Responses		NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		Homogenous		3		2	2	0	0	7	43%	#DIV/0!	14%	11%	0%	0%	21%	
		Blank		2		5	0	1	1	9	29%	#DIV/0!	36%	0%	50%	33%	26%	
b What is its geological origin?																		
		Alluvial		0		1	7	0	0	8	0%	#DIV/0!	7%	37%	0%	0%	24%	
		Glacial		5		2	4	0	0	11	71%	#DIV/0!	14%	21%	0%	0%	32%	
		Lacustrine		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Marine		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Weathered rock		0		4	0	0	0	4	0%	#DIV/0!	29%	0%	0%	0%	12%	
		Other		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Blank		1		5	0	1	1	8	14%	#DIV/0!	36%	0%	50%	33%	24%	
c Does it satisfy modern filter criteria against the core?																		
		Yes		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
		No		4		2	4	0	0	10	57%	#DIV/0!	14%	21%	0%	0%	29%	
		Marginal		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Homogenous dam		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
		Don't know		3		3	5	0	0	11	43%	#DIV/0!	21%	26%	0%	0%	32%	
		Blank		0		5	0	1	1	7	0%	#DIV/0!	36%	0%	50%	33%	21%	
d What is the D15 of its particle size distribution (i.e. particle size for which 15% is finer)?																		
		<0.01		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		0.01 to 0.06		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		0.07 to 0.1		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		0.11 to 1		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		1.1 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		6 to 10		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		11 to 70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		6		12	10	1	1	30	86%	#DIV/0!	86%	53%	50%	33%	88%	
33 For the fill material immediately upstream of the impervious element:-																		
a What would you describe its form of construction?																		
		Random		2		3	7	0	0	12	29%	#DIV/0!	21%	37%	0%	0%	35%	
		Zoned		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Selected		0		3	1	0	0	4	0%	#DIV/0!	21%	5%	0%	0%	12%	
		Homogenous		2		2	2	0	0	6	29%	#DIV/0!	14%	11%	0%	0%	18%	
		Blank		3		5	1	1	1	11	43%	#DIV/0!	36%	5%	50%	33%	32%	
b What is its geological origin?																		
		Alluvial		0		1	7	0	0	8	0%	#DIV/0!	7%	37%	0%	0%	24%	
		Glacial		3		2	4	0	0	9	43%	#DIV/0!	14%	21%	0%	0%	26%	
		Lacustrine		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Marine		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Weathered rock		0		4	0	0	0	4	0%	#DIV/0!	29%	0%	0%	0%	12%	
		Other		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		4		5	0	1	1	11	57%	#DIV/0!	36%	0%	50%	33%	32%	
c Does it act as a crack filler, in that fines could be washed into a crack in the core and seal it?																		
		Yes		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
		No		2		2	2	0	0	6	29%	#DIV/0!	14%	11%	0%	0%	18%	
		Marginal		0		0	3	0	0	3	0%	#DIV/0!	0%	16%	0%	0%	9%	
		Don't know		2		6	4	0	0	12	29%	#DIV/0!	43%	21%	0%	0%	35%	
		Blank		3		5	0	1	1	10	43%	#DIV/0!	36%	0%	50%	33%	29%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION		Increments Possible Responses	Units	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
d	What is the soil type?																	
		Gravel		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Sand		2		0	0	0	0	2	29%	#DIV/0!	0%	0%	0%	0%	6%	
		Silt		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
		Clay Plasticity Index >22		0		1	3	0	0	4	0%	#DIV/0!	7%	16%	0%	0%	12%	
		Clay Plasticity Index 22 or less		2		2	5	0	0	9	29%	#DIV/0!	14%	26%	0%	0%	26%	
		Weathered (soft) rockfill		0		4	1	0	0	5	0%	#DIV/0!	29%	5%	0%	0%	15%	
		Sound Rockfill		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		2		6	0	1	1	10	29%	#DIV/0!	43%	0%	50%	33%	29%	
34	For the impervious element at original ground level																	
a	What is its width?	0 to 1		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		2 to 2		2		1	0	0	0	3	29%	#DIV/0!	7%	0%	0%	0%	9%	
		3 to 3		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		4 to 5		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
		6 to 10		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		11 to 15		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
		16 to 20		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		>20		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Blank		3		8	5	1	1	18	43%	#DIV/0!	57%	26%	50%	33%	53%	
b	What is the head across it?																	
		0 to 2		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		3 to 5		0		2	4	0	0	6	0%	#DIV/0!	14%	21%	0%	0%	18%	
		6 to 10		2		1	3	0	0	6	29%	#DIV/0!	7%	16%	0%	0%	18%	
		11 to 15		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
		16 to 20		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
		21 to 30		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		31 to 50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		3		6	2	1	1	13	43%	#DIV/0!	43%	11%	50%	33%	38%	
35	If the incident involved a conduit (pipe or culvert) through the embankment fill																	
a	what is the external diameter of this conduit?	<0.25 metres		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		0.25 to 0.5 metres		1		2	1	0	0	4	14%	#DIV/0!	14%	5%	0%	0%	12%	
		0.51 to 1 metre		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		1.01 to 2 metres		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		Greater than 2 metres		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Blank		4		10	9	1	1	25	57%	#DIV/0!	71%	47%	50%	33%	74%	
b	What was the type of construction of pipe or culvert																	
		Masonry culvert		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		Brick culvert		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		Concrete culvert		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Pipe laid in concrete		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Pipe laid within fill		1		3	1	0	0	5	14%	#DIV/0!	21%	5%	0%	0%	15%	
		Other		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		Blank		4		9	9	1	1	24	57%	#DIV/0!	64%	47%	50%	33%	71%	
c	What is the spacing of movement joints (or any other feature through which fill cold be eroded)																	
		0 to 1		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		2 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION	Increments	Possible Responses	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
				Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		3 to 4		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		5 to 7		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		8 to 10		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		11 to 15		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		16 to 20		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		>20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		5		13	10	1	1	30	71%	#DIV/0!	93%	53%	50%	33%	88%	
d (Not subject to analysis)																		
36																		
		>80 degrees		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		60 to 80 degrees		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		45 to 60 degrees		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		30 to 45 degrees		3		2	3	0	0	8	43%	#DIV/0!	14%	16%	0%	0%	24%	
		< 30 degrees		1		7	6	0	0	14	14%	#DIV/0!	50%	32%	0%	0%	41%	
		Blank		2		4	2	1	1	10	29%	#DIV/0!	29%	11%	50%	33%	29%	
37 What are the characteristics of the reservoir water?																		
a pH		0 to 3		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		4 to 4		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		5 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		6 to 6		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		7 to 7		2		1	0	0	0	3	29%	#DIV/0!	7%	0%	0%	0%	9%	
		8 to 8		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		9 to 9		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>9		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		4		11	11	1	1	28	57%	#DIV/0!	79%	58%	50%	33%	82%	
b Total dissolved solids																		
		0 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		11 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		21 to 30		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		31 to 40		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		41 to 50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		51 to 60		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		61 to 70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		7		13	11	1	1	33	100%	#DIV/0!	93%	58%	50%	33%	97%	
c Conductivity																		
		0 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		11 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		21 to 30		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		31 to 40		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		41 to 50		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		51 to 60		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		61 to 70		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>70		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		Blank		7		12	11	1	1	32	100%	#DIV/0!	86%	58%	50%	33%	94%	
d (Not subject to analysis)																		
38 (Not subject to analysis)																		
39 (Not subject to analysis)																		
Q40 What was the frequency of visits to the dam before the incident?																		
		Daily (or more frequent)		1		1	2	0	0	4	14%		7%	11%	0%	0%	12%	13%
		3 times/ week		4		2	1	1	0	8	57%		14%	5%	50%	0%	24%	39%
		2 times/ week		0		1	1	0	0	2	0%		7%	5%	0%	0%	6%	45%

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION			Increments Possible Responses	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							CUMULATIVE (Incl correction for blanks)
					Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	
					NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
			Weekly		1		3	6	0	1	11	14%		21%	32%	0%	33%	32%	81%
			Fortnightly		0		1	0	0	0	1	0%		7%	0%	0%	0%	3%	84%
			Monthly		1		1	0	0	0	2	14%		7%	0%	0%	0%	6%	90%
			Less frequent than monthly		0		2	1	0	0	3	0%		14%	5%	0%	0%	9%	100%
			Blank		0		3	0	0	0	3	0%		21%	0%	0%	0%	9%	
41		How many of the following instruments does the dam have (in functioning order; approximate numbers acceptable)																	
	a	Standpipe piezometers	0 to 0		7		5	6	1	1	20	100%	#DIV/0!	36%	32%	50%	33%	59%	
			1 to 1		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			2 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			3 to 5		0		2	3	0	0	5	0%	#DIV/0!	14%	16%	0%	0%	15%	
			6 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			11 to 15		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
			16 to 20		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
			>20		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			Blank		0		4	0	0	0	4	0%	#DIV/0!	29%	0%	0%	0%	12%	
	b	Other forms of piezometer																	
			0 to 0		7		6	5	1	1	20	100%	#DIV/0!	43%	26%	50%	33%	59%	
			1 to 1		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			2 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			3 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			6 to 10		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			11 to 15		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			16 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			Blank		0		7	6	0	0	13	0%	#DIV/0!	50%	32%	0%	0%	38%	
	c	Settlement monitoring points																	
			0 to 0		1		6	5	0	1	13	14%	#DIV/0!	43%	26%	0%	33%	38%	
			1 to 1		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			2 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			3 to 5		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
			6 to 10		3		0	4	1	0	8	43%	#DIV/0!	0%	21%	50%	0%	24%	
			11 to 15		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			16 to 20		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
			>20		2		2	0	0	0	4	29%	#DIV/0!	14%	0%	0%	0%	12%	
			Blank		0		4	0	0	0	4	0%	#DIV/0!	29%	0%	0%	0%	12%	
	d	V notch or other quantification of seepage																	
			0 to 0		5		6	6	1	1	19	71%	#DIV/0!	43%	32%	50%	33%	56%	
			1 to 1		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
			2 to 2		2		0	2	0	0	4	29%	#DIV/0!	0%	11%	0%	0%	12%	
			3 to 3		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
			4 to 4		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			5 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			6 to 6		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>6		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			Blank		0		4	1	0	0	5	0%	#DIV/0!	29%	5%	0%	0%	15%	
42		What was the elapsed time between readings of these instruments prior to the incident?																	
	a	Standpipe piezometers	0 to 0.5		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
			1.5 to 1		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	

Table C.1 : Analysis of Questionnaire B by type of respondent

					CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							
QUESTION		Increments	Possible	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE
			Responses		NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							(Incl correction for blanks)
			2 to 2		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			3 to 4		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			13 to 25		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
			>25		0		2	2	0	0	4	0%	#DIV/0!	14%	11%	0%	0%	12%	
			Blank		6		9	7	1	1	24	86%	#DIV/0!	64%	37%	50%	33%	71%	
b	Other forms of piezometer																		
			0 to 0.5		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
			1.5 to 1		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			2 to 2		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			3 to 4		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			13 to 25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			Blank		6		12	11	1	1	31	86%	#DIV/0!	86%	58%	50%	33%	91%	
c	Settlement monitoring points																		
			0 to 4		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			13 to 16		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
			17 to 20		0		0	0	1	0	1	0%	#DIV/0!	0%	0%	50%	0%	3%	
			21 to 25		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
			26 to 52		2		2	4	0	0	8	29%	#DIV/0!	14%	21%	0%	0%	24%	
			>52		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
			Blank		3		10	6	0	1	20	43%	#DIV/0!	71%	32%	0%	33%	59%	
d	V notch or other quantification of seepage																		
			0 to 0.5		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
			1.5 to 1		2		1	1	0	0	4	29%	#DIV/0!	7%	5%	0%	0%	12%	
			2 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			3 to 4		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			13 to 25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>25		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
			Blank		4		10	8	1	1	24	57%	#DIV/0!	71%	42%	50%	33%	71%	
43	What was the process used to assess surveillance data before the event? e.g. reviewed by trained personnel to look for unusual readings and new trends?																		
a	Technician taking readings given formal trigger values, which if the readings then exceeded he would immediately seek further advice		No review		1		6	3	0	0	10	14%	#DIV/0!	43%	16%	0%	0%	29%	
			No review, but operator would flag unusual reading		3		3	5	1	0	12	43%	#DIV/0!	21%	26%	50%	0%	35%	
			Yes - trigger values defined		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
			Blank		2		4	3	0	1	10	29%	#DIV/0!	29%	16%	0%	33%	29%	
b	Formal review by others																		
			Line supervisor		2		1	0	0	0	3	29%	#DIV/0!	7%	0%	0%	0%	9%	
			Supervising engineer		2		5	6	1	0	14	29%	#DIV/0!	36%	32%	50%	0%	41%	
			External consultant		0		0	3	0	0	3	0%	#DIV/0!	0%	16%	0%	0%	9%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION			Increments		CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT						
			Possible Responses	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall
					NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED						
			Blank		3		8	2	0	1	14	43%	#DIV/0!	57%	11%	0%	33%	41%
44		What was the frequency between																
	a	Reviews by an engineer	0 to 4		4		2	0	0	0	6	57%	#DIV/0!	14%	0%	0%	0%	18%
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			13 to 16		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			17 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			21 to 25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			26 to 52		2		5	3	0	0	10	29%	#DIV/0!	36%	16%	0%	0%	29%
			>52		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			Blank		1		7	8	1	1	18	14%	#DIV/0!	50%	42%	50%	33%	53%
	b	Reviews by the Supervising Engineer																
			0 to 4		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			13 to 16		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			17 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			21 to 25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			26 to 52		4		7	8	1	0	20	57%	#DIV/0!	50%	42%	50%	0%	59%
			>52		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%
			Blank		2		7	2	0	1	12	29%	#DIV/0!	50%	11%	0%	33%	35%
	c	Written report on readings (including Supervising Engineer's annul statement)																
			0 to 4		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			9 to 12		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			13 to 16		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			17 to 20		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			21 to 25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			26 to 52		4		8	9	1	1	23	57%	#DIV/0!	57%	47%	50%	33%	68%
			>52		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			Blank		3		6	2	0	0	11	43%	#DIV/0!	43%	11%	0%	0%	32%
	d	Written reports by External consultant																
			0 to 4		2		4	0	0	0	6	29%	#DIV/0!	29%	0%	0%	0%	18%
			5 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			9 to 25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			26 to 52		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%
			53 to 104		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			105 to 260		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%
			261 to 520		2		0	2	0	0	4	29%	#DIV/0!	0%	11%	0%	0%	12%
			>520		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%
			Blank		3		8	8	1	1	21	43%	#DIV/0!	57%	42%	50%	33%	62%
45		Is it likely that internal erosion was occurring prior to the incident?																
			Yes		6		5	7	0	0	18	86%	#DIV/0!	36%	37%	0%	0%	53%
			No		1		2	1	0	0	4	14%	#DIV/0!	14%	5%	0%	0%	12%
			Maybe		0		5	3	1	1	10	0%	#DIV/0!	36%	16%	50%	33%	29%
			Blank		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%
46		Did any of the following indicators give prior warning of the incident?																
	a	Seepage: Quantity	Strong		0		4	2	0	0	6	0%	#DIV/0!	29%	11%	0%	0%	18%
			Medium		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%

CUMULATIVE
(Incl correction for blanks)

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION		Increments Possible Responses	Units	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CATEGORY OF RESPONDENT Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		Low		2		2	4	0	0	8	29%	#DIV/0!	14%	21%	0%	0%	24%	
		No Indication		4		4	5	1	1	15	57%	#DIV/0!	29%	26%	50%	33%	44%	
		Blank		0		4	0	0	0	4	0%	#DIV/0!	29%	0%	0%	0%	12%	
b	Seepage: Turbidity or other characteristic																	
		Strong		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Medium		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		Low		0		4	2	0	0	6	0%	#DIV/0!	29%	11%	0%	0%	18%	
		No Indication		5		5	8	1	1	20	71%	#DIV/0!	36%	42%	50%	33%	59%	
		Blank		2		5	0	0	0	7	29%	#DIV/0!	36%	0%	0%	0%	21%	
c	Settlement																	
		Strong		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		Medium		1		1	1	0	0	3	14%	#DIV/0!	7%	5%	0%	0%	9%	
		Low		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		No Indication		5		4	6	1	0	16	71%	#DIV/0!	29%	32%	50%	0%	47%	
		No Instrument		0		4	2	0	1	7	0%	#DIV/0!	29%	11%	0%	33%	21%	
		Blank		1		5	0	0	0	6	14%	#DIV/0!	36%	0%	0%	0%	18%	
d	Piezometer readings																	
		Strong		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Medium		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
		Low		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		No Indication		0		5	3	0	0	8	0%	#DIV/0!	36%	16%	0%	0%	24%	
		No Instrument		5		4	6	1	1	17	71%	#DIV/0!	29%	32%	50%	33%	50%	
		Blank		2		5	0	0	0	7	29%	#DIV/0!	36%	0%	0%	0%	21%	
47	For each incident which parameter was the most useful as an indicator of internal erosion																	
		Suspended Fines		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		Quantity of Seepage		2		7	5	1	1	16	29%	#DIV/0!	50%	26%	50%	33%	47%	
		Piezometer Readings		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		Embankment Crest Deformation		1		3	1	0	0	5	14%	#DIV/0!	21%	5%	0%	0%	15%	
		Other Deformation		2		1	4	0	0	7	29%	#DIV/0!	7%	21%	0%	0%	21%	
		Blank		1		2	0	0	0	3	14%	#DIV/0!	14%	0%	0%	0%	9%	
48	(Not subject to analysis)																	
49	Was the frequency of any of the following changed as a result of the incident (give relative increase i.e. 2 = twice as often; if no change enter 1; consider frequency one year after completion of physical works)																	
a	Surveillance visit	<=1		2		8	8	1	0	19	29%	#DIV/0!	57%	42%	50%	0%	56%	
		1.01 to 1.25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.26 to 1.5		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		1.51 to 1.75		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.76 to 2		2		1	2	0	1	6	29%	#DIV/0!	7%	11%	0%	33%	18%	
		2.01 to 2.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		2.51 to 5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		>5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Blank		3		5	0	0	0	8	43%	#DIV/0!	36%	0%	0%	0%	24%	
b	Frequency of reading piezometers																	
		<=1		1		3	2	0	0	6	14%	#DIV/0!	21%	11%	0%	0%	18%	
		1.01 to 1.25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.26 to 1.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.51 to 1.75		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	

Table C.1 : Analysis of Questionnaire B by type of respondent

CATEGORY OF RESPONDENT | CATEGORY OF RESPONDENT

QUESTION	Increments	Possible Responses	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	CUMULATIVE (Incl correction for blanks)
				NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
		1.76 to 2		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
		2.01 to 2.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		2.51 to 5		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		>5		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
		Blank		6		7	6	1	1	21	86%	#DIV/0!	50%	32%	50%	33%	62%	
c Frequency of reading seepage measurement devices																		
		<=1		2		2	4	0	0	8	29%	#DIV/0!	14%	21%	0%	0%	24%	
		1.01 to 1.25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.26 to 1.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.51 to 1.75		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.76 to 2		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
		2.01 to 2.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		2.51 to 5		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
		>5		1		4	0	0	0	5	14%	#DIV/0!	29%	0%	0%	0%	15%	
		Blank		4		6	5	1	1	17	57%	#DIV/0!	43%	26%	50%	33%	50%	
d Frequency of reading settlement measurement devices																		
		<= 1		2		5	4	1	0	12	29%	#DIV/0!	36%	21%	50%	0%	35%	
		1.01 to 1.25		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.26 to 1.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.51 to 1.75		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		1.76 to 2		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
		2.01 to 2.5		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		2.51 to 5		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
		>5		0		3	0	0	0	3	0%	#DIV/0!	21%	0%	0%	0%	9%	
		Blank		4		6	6	0	1	17	57%	#DIV/0!	43%	32%	0%	33%	50%	
50 What action was taken immediately on detection, and in your opinion how effective was it?																		
a Lower reservoir		Effective		6		8	7	1	0	22	86%	#DIV/0!	57%	37%	50%	0%	65%	
		Minor		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		No Effect		1		0	2	0	0	3	14%	#DIV/0!	0%	11%	0%	0%	9%	
		Not Undertaken		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
		Blank		0		5	0	0	1	6	0%	#DIV/0!	36%	0%	0%	33%	18%	
b Filter downstream																		
		Effective		0		1	2	0	0	3	0%	#DIV/0!	7%	11%	0%	0%	9%	
		Minor		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
		No Effect		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Not Undertaken		4		7	9	1	0	21	57%	#DIV/0!	50%	47%	50%	0%	62%	
		Blank		3		5	0	0	1	9	43%	#DIV/0!	36%	0%	0%	33%	26%	
c Dump material into reservoir																		
		Effective		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
		Minor		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		No Effect		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		Not Undertaken		4		7	10	1	0	22	57%	#DIV/0!	50%	53%	50%	0%	65%	
		Blank		3		6	0	0	1	10	43%	#DIV/0!	43%	0%	0%	33%	29%	
d (Not subject to analysis)																		
51 What physical works were then carried out to deal with the incident?																		
		Diaphragm wall		1		2	2	0	0	5	14%	#DIV/0!	14%	11%	0%	0%	15%	
		Sheetpiling		1		1	0	0	0	2	14%	#DIV/0!	7%	0%	0%	0%	6%	
		Grouting		2		3	3	1	0	9	29%	#DIV/0!	21%	16%	50%	0%	26%	
		Reline conduit		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	

Table C.1 : Analysis of Questionnaire B by type of respondent

QUESTION		Increments	Possible	Units	CATEGORY OF RESPONDENT							CATEGORY OF RESPONDENT							CUMULATIVE (Incl correction for blanks)
					Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall	
			Responses		NUMBER OF EACH RESPONSE FROM EACH CATEGORY							NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED							
			Add filters		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
			Other		2		4	5	0	1	12	29%	#DIV/0!	29%	26%	0%	33%	35%	
			Blank		1		4	0	0	0	5	14%	#DIV/0!	29%	0%	0%	0%	15%	
52	Were the physical works effective?																		
			Yes		3		8	8	1	1	21	43%	#DIV/0!	57%	42%	50%	33%	62%	
			Partially, no further action		2		0	0	0	0	2	29%	#DIV/0!	0%	0%	0%	0%	6%	
			Partially, further action required		1		0	2	0	0	3	14%	#DIV/0!	0%	11%	0%	0%	9%	
			No		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
			Blank		1		5	0	0	0	6	14%	#DIV/0!	36%	0%	0%	0%	18%	
53	If supplementary physical measures were taken, what were they?																		
			Diaphragm wall		1		0	3	0	0	4	14%	#DIV/0!	0%	16%	0%	0%	12%	
			Sheetpiling		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			Grouting		0		1	1	0	0	2	0%	#DIV/0!	7%	5%	0%	0%	6%	
			Reline pipe		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			Add filters		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			Other		2		2	2	0	0	6	29%	#DIV/0!	14%	11%	0%	0%	18%	
			Not Applicable		0		2	2	0	0	4	0%	#DIV/0!	14%	11%	0%	0%	12%	
			Blank		4		9	3	1	1	18	57%	#DIV/0!	64%	16%	50%	33%	53%	
54	Was site investigation carried out to assist in understanding the cause? If so, please give the number of exploratory holes (of any type) (leave blank if no site investigation done)																		
			0 to 1		0		1	0	0	0	1	0%	#DIV/0!	7%	0%	0%	0%	3%	
			2 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			3 to 4		1		0	1	0	0	2	14%	#DIV/0!	0%	5%	0%	0%	6%	
			5 to 6		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			7 to 8		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			9 to 10		2		1	0	0	0	3	29%	#DIV/0!	7%	0%	0%	0%	9%	
			11 to 20		0		2	4	1	0	7	0%	#DIV/0!	14%	21%	50%	0%	21%	
			>20		1		0	0	0	0	1	14%	#DIV/0!	0%	0%	0%	0%	3%	
			Blank		3		10	6	0	1	20	43%	#DIV/0!	71%	32%	0%	33%	59%	
55	(Not subject to analysis)																		
56	What was the drawdown capacity prior to the incident (over the upper third of the reservoir)?																		
			0 to 0		0		2	1	0	0	3	0%	#DIV/0!	14%	5%	0%	0%	9%	
			0.01 to 0.1		0		2	0	0	0	2	0%	#DIV/0!	14%	0%	0%	0%	6%	
			0.11 to 0.3		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
			0.31 to 0.5		0		0	2	1	0	3	0%	#DIV/0!	0%	11%	50%	0%	9%	
			0.51 to 1		2		1	2	0	0	5	29%	#DIV/0!	7%	11%	0%	0%	15%	
			1.01 to 1.5		0		0	1	0	0	1	0%	#DIV/0!	0%	5%	0%	0%	3%	
			1.51 to 2		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
			>2		0		0	2	0	0	2	0%	#DIV/0!	0%	11%	0%	0%	6%	
			Blank		5		9	1	0	1	16	71%	#DIV/0!	64%	5%	0%	33%	47%	
57	Has the drawdown capacity been modified since the event (or is it planned to be)? If so, please indicate the drawdown capability after these modifications (leave blank if no change)																		
			0 to 0		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	
		0.01	0.01 to 0.1		0		0	0	0	0	0	0%	#DIV/0!	0%	0%	0%	0%	0%	

Table C.1 : Analysis of Questionnaire B by type of respondent

CATEGORY OF RESPONDENT — NUMBER OF EACH RESPONSE FROM EACH CATEGORY

QUESTION	Increments	Possible Responses	Units	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall
	0.01	0.11 to 0.3		0		0	1	0	0	1
	0.01	0.31 to 0.5		0		1	0	0	0	1
	0.01	0.51 to 1		0		0	0	0	0	0
	0.01	1.01 to 1.5		0		0	0	0	0	0
	0.01	1.51 to 2		0		0	0	0	0	0
		>2		0		0	0	0	0	0
		Blank		7		13	10	1	1	32

CATEGORY OF RESPONDENT — NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED

CUMULATIVE (Incl correction for blanks)

Possible Responses	Dam Owners >15	Dam Owners 1, 2	Panel AR Employee	Panel AR Other	Sup. Engineer Dam Owner	Sup. Engineer Consultant	Overall
0.11 to 0.3	0%	#DIV/0!	0%	5%	0%	0%	3%
0.31 to 0.5	0%	#DIV/0!	7%	0%	0%	0%	3%
0.51 to 1	0%	#DIV/0!	0%	0%	0%	0%	0%
1.01 to 1.5	0%	#DIV/0!	0%	0%	0%	0%	0%
1.51 to 2	0%	#DIV/0!	0%	0%	0%	0%	0%
>2	0%	#DIV/0!	0%	0%	0%	0%	0%
Blank	100%	#DIV/0!	93%	53%	50%	33%	94%

58 (Not subject to analysis)

C.6 Table C2 : Summary of responses, broken down by dam type/ appurtenant works

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
What was the seriousness of the incident (use the definitions provided in the Guidance Note)																
	Level 1	0	0	0	0	0	0%	0%	0%	0%	0%					
	Level 2	10	2	1	5	18	83%	17%	50%	63%	53%					
	Level 3	2	10	1	3	16	17%	83%	50%	38%	47%					
	Blank	0	0	0	0	0	0%	0%	0%	0%	0%					
8 Year of the event?																
	1970	0	0	0	0	0	0%	0%	0%	0%	0%					
	1980	1	1	0	0	2	8%	8%	0%	0%	6%					
	1992	0	0	0	3	3	0%	0%	0%	38%	9%					
	1995	2	1	0	0	3	17%	8%	0%	0%	9%					
	1998	2	3	0	1	6	17%	25%	0%	13%	18%					
	2000	2	4	1	2	9	17%	33%	50%	25%	26%					
	2002	4	3	0	0	7	33%	25%	0%	0%	21%					
	>2002	1	0	1	1	3	8%	0%	50%	13%	9%					
	Blank	0	0	0	1	1	0%	0%	0%	13%	3%					
9 Flood Category of the dam (using the Floods and Reservoir Safety Guidelines)																
	A	8	10	1	3	22	67%	83%	50%	38%	65%					
	B	1	2	0	0	3	8%	17%	0%	0%	9%					
	C	2	0	0	1	3	17%	0%	0%	13%	9%					
	D	0	0	1	2	3	0%	0%	50%	25%	9%					
	Blank	1	0	0	2	3	8%	0%	0%	25%	9%					
10 Year of construction of the dam (approx if not known exactly)																
	1700	1	0	0	0	1	8%	0%	0%	0%	3%					
	1750	0	0	0	0	0	0%	0%	0%	0%	0%					
	1800	1	1	0	1	3	8%	8%	0%	13%	9%					
	1850	5	3	1	1	10	42%	25%	50%	13%	29%					
	1900	3	5	0	0	8	25%	42%	0%	0%	24%					
	1950	0	3	0	1	4	0%	25%	0%	13%	12%					
	1980	1	0	1	4	6	8%	0%	50%	50%	18%					
	>1980	1	0	0	0	1	8%	0%	0%	0%	3%					
	Blank	0	0	0	1	1	0%	0%	0%	13%	3%					
11 Height of the dam (m)																
	2	1	0	0	0	1	8%	0%	0%	0%	3%					
	3	2	0	0	1	3	17%	0%	0%	13%	9%					
	5	1	2	2	3	8	8%	17%	100%	38%	24%					
	10	4	2	0	2	8	33%	17%	0%	25%	24%					
	15	2	1	0	0	3	17%	8%	0%	0%	9%					
	20	1	6	0	0	7	8%	50%	0%	0%	21%					
	30	1	1	0	0	2	8%	8%	0%	0%	6%					
	>30	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	0	0	0	2	2	0%	0%	0%	25%	6%					

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
12 Dam Crest Length (m)																
	20	0	0	0	0	0	0%	0%	0%	0%	0%					
	50	2	0	1	0	3	17%	0%	50%	0%	9%					
	100	1	3	1	2	7	8%	25%	50%	25%	21%					
	200	3	3	0	1	7	25%	25%	0%	13%	21%					
	500	4	3	0	0	7	33%	25%	0%	0%	21%					
	1000	0	2	0	0	2	0%	17%	0%	0%	6%					
	1500	1	0	0	1	2	8%	0%	0%	13%	6%					
	>1500	0	1	0	0	1	0%	8%	0%	0%	3%					
	Blank	1	0	0	4	5	8%	0%	0%	50%	15%					
Information on incident																
13 What was the reservoir level at the time the incident was detected, expressed as height above (+) or below (-) the spillway overflow																
	-2	1	1	0	0	2	8%	8%	0%	0%	6%					
	-1	1	0	0	1	2	8%	0%	0%	13%	6%					
	-0.3	1	0	0	0	1	8%	0%	0%	0%	3%					
	-0.1	1	0	1	1	3	8%	0%	50%	13%	9%					
	0	3	9	0	3	15	25%	75%	0%	38%	44%					
	0.1	4	2	1	2	9	33%	17%	50%	25%	26%					
	0.5	0	0	0	1	1	0%	0%	0%	13%	3%					
	>0.5	1	0	0	0	1	8%	0%	0%	0%	3%					
	Blank	3	9	0	3	15	25%	75%	0%	38%	44%					
14 What was the initiating event? i.e. was there a trigger?																
	None noted	2	3	1	3	9	17%	25%	50%	38%	26%					
	Gradual deterioration	5	6	0	2	13	42%	50%	0%	25%	38%					
	Rise in reservoir level	2	0	0	0	2	17%	0%	0%	0%	6%					
	Previous drawdown of reservoir	0	0	0	0	0	0%	0%	0%	0%	0%					
	Other	2	3	1	1	7	17%	25%	50%	13%	21%					
	Blank	1	0	0	2	3	8%	0%	0%	25%	9%					
15 Where at the damsite did the problem occur? (Choose the most appropriate response)																
	Embankment	0	10	1	2	13	0%	83%	50%	25%	38%					
	Foundation	0	0	0	0	0	0%	0%	0%	0%	0%					
	Embankment/foundation interface	0	1	1	3	5	0%	8%	50%	38%	15%					
	Embankment-abutment interface	0	1	0	2	3	0%	8%	0%	25%	9%					
	Along a pipe or culvert	5	0	0	0	5	42%	0%	0%	0%	15%					
	Into a pipe or culvert	3	0	0	0	3	25%	0%	0%	0%	9%					
	Along a spillway wall	4	0	0	1	5	33%	0%	0%	13%	15%					
	Other	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	0	0	0	0	0	0%	0%	0%	0%	0%					

Table C2 : Analysis of Questionnaire B by dam type

			CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
	Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
16	What as the mechanism of deterioration? (please make your best estimate; definitions of terms are given in Section 10 of the Guidance Note)																
		Concentrated leak	6	4	0	4	14	50%	33%	0%	50%	41%					
		Suffusion	1	1	0	1	3	8%	8%	0%	13%	9%					
		Piping	3	7	2	1	13	25%	58%	100%	13%	38%					
		Dispersive clays	0	0	0	0	0	0%	0%	0%	0%	0%					
		Other	1	0	0	0	1	8%	0%	0%	0%	3%					
		Don't know	1	0	0	2	3	8%	0%	0%	25%	9%					
		Blank	0	0	0	0	0	0%	0%	0%	0%	0%					
17	At what elevation was the intake to the erosion path? (expressed as height above (+) or below (-) the spillway overflow). Provide your best estimate if not known precisely																
		less than -5	3	1	0	1	5	25%	8%	0%	13%	15%					
		from -4.99 to -2	2	4	0	1	7	17%	33%	0%	13%	21%					
		from -1.99 to 0	2	6	2	2	12	17%	50%	100%	25%	35%					
		from 0.01 to 1	2	0	0	0	2	17%	0%	0%	0%	6%					
		more than 1	0	1	0	1	2	0%	8%	0%	13%	6%					
		Blank	3	0	0	3	6	25%	0%	0%	38%	18%					
18	Do you have any further comments on the incident, including expanding any response where "other" was given																
	Event Detection																
19	Who detected the incident?																
		Public	2	0	0	1	3	17%	0%	0%	13%	9%					
		Staff on a routine visit	3	8	1	3	15	25%	67%	50%	38%	44%					
		Staff passing the dam on an incidental visit	3	2	0	1	6	25%	17%	0%	13%	18%					
		Supervising Engineer	2	2	1	2	7	17%	17%	50%	25%	21%					
		Inspecting Engineer	1	0	0	0	1	8%	0%	0%	0%	3%					
		Blank	1	0	0	1	2	8%	0%	0%	13%	6%					
20	What was the level of training of the detecting personnel in looking for unusual behaviour and thus when specialist advice should be sought																
		None	4	1	0	2	7	33%	8%	0%	25%	21%					
		On the job	3	3	1	3	10	25%	25%	50%	38%	29%					

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	Verbal instructions by supervisor	1	0	1	0	2	8%	0%	50%	0%	6%					
	Written instructions by supervisor	0	1	0	0	1	0%	8%	0%	0%	3%					
	In-house course	1	3	0	1	5	8%	25%	0%	13%	15%					
	External Course	0	2	0	0	2	0%	17%	0%	0%	6%					
	Blank	3	2	0	2	7	25%	17%	0%	25%	21%					
21 Would improved training of staff undertaking routine visits have affected the reliability of detection?																
	Yes	2	0	1	2	5	17%	0%	50%	25%	15%					
	No	9	10	1	3	23	75%	83%	50%	38%	68%					
	Unsure	0	2	0	1	3	0%	17%	0%	13%	9%					
	Blank	1	0	0	2	3	8%	0%	0%	25%	9%					
22 To what extent did each of the following indicate internal erosion was occurring at the time the incident was detected? a Seepage: Quantity																
	Strong	10	3	2	2	17	83%	25%	100%	25%	50%					
	Medium	0	4	0	1	5	0%	33%	0%	13%	15%					
	Low	2	4	0	2	8	17%	33%	0%	25%	24%					
	No Indication	0	1	0	1	2	0%	8%	0%	13%	6%					
	Blank	0	0	0	2	2	0%	0%	0%	25%	6%					
b Seepage: Turbidity or other characteristic																
	Strong	2	4	0	1	7	17%	33%	0%	13%	21%					
	Medium	1	0	1	0	2	8%	0%	50%	0%	6%					
	Low	2	1	1	3	7	17%	8%	50%	38%	21%					
	No Indication	6	7	0	2	15	50%	58%	0%	25%	44%					
	Blank	1	0	0	2	3	8%	0%	0%	25%	9%					
c Settlement																
	Strong	2	3	0	1	6	17%	25%	0%	13%	18%					
	Medium	0	0	0	0	0	0%	0%	0%	0%	0%					
	Low	1	2	0	1	4	8%	17%	0%	13%	12%					
	No Indication	6	6	0	3	15	50%	50%	0%	38%	44%					
	No Instruments	2	1	2	2	7	17%	8%	100%	25%	21%					
	Blank	1	0	0	1	2	8%	0%	0%	13%	6%					
d Piezometer readings																
	Strong	0	0	0	0	0	0%	0%	0%	0%	0%					
	Medium	0	2	0	0	2	0%	17%	0%	0%	6%					

Table C2 : Analysis of Questionnaire B by dam type

			CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
	Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
		Low	0	0	0	0	0	0%	0%	0%	0%	0%					
		No Indication	1	4	0	2	7	8%	33%	0%	25%	21%					
		No Instruments	10	6	2	4	22	83%	50%	100%	50%	65%					
		Rate of deterioration	0	0	0	0	0	0%	0%	0%	0%	0%					
		Blank	1	0	0	2	3	8%	0%	0%	25%	9%					
23	What was the time between the incident being detected and (give your best estimate)																
a	a) the first physical action taken on site which would reduce the risk of failure?																
		less than 5 hours	3	5	1	3	12	25%	42%	50%	38%	35%					
		5.1 to 24 hours	3	5	1	1	10	25%	42%	50%	13%	29%					
		24.1 to 48 hours	2	0	0	1	3	17%	0%	0%	13%	9%					
		48.1 to 72 hours	0	1	0	0	1	0%	8%	0%	0%	3%					
		more than 72.1 hours	2	1	0	0	3	17%	8%	0%	0%	9%					
		Blank	2	0	0	3	5	17%	0%	0%	38%	15%					
b	b) the maximum flow rate from the leak (or other symptom of internal erosion)																
		less than 5 hours	2	0	0	1	3	17%	0%	0%	13%	9%					
		5.1 to 24 hours	1	2	2	0	5	8%	17%	100%	0%	15%					
		24.1 to 48 hours	0	0	0	1	1	0%	0%	0%	13%	3%					
		48.1 to 72 hours	0	1	0	0	1	0%	8%	0%	0%	3%					
		more than 72.1 hours	0	1	0	1	2	0%	8%	0%	13%	6%					
		Blank	9	8	0	5	22	75%	67%	0%	63%	65%					
c	c) the incident was controlled (e.g. reservoir drawn down and leak had stopped)																
		12	1	1	0	2	4	8%	8%	0%	25%	12%					
		24	2	4	2	0	8	17%	33%	100%	0%	24%					
		36	0	1	0	0	1	0%	8%	0%	0%	3%					
		48	1	3	0	2	6	8%	25%	0%	25%	18%					
		72	0	1	0	0	1	0%	8%	0%	0%	3%					
		96	0	0	0	1	1	0%	0%	0%	13%	3%					
		168	1	0	0	1	2	8%	0%	0%	13%	6%					
		>168	2	1	0	0	3	17%	8%	0%	0%	9%					
		Blank	5	1	0	2	8	42%	8%	0%	25%	24%					
24	Assuming that there was some form of leakage flow, what was the magnitude of this flow - please make your best estimate (leave blank if no seepage flow, but please comment in Q27)																
a	when the event was detected																
		0.1	2	2	0	1	5	17%	17%	0%	13%	15%					
		0.5	1	3	0	0	4	8%	25%	0%	0%	12%	10%	30%	0%	0%	14%
		1	1	0	0	1	2	8%	0%	0%	13%	6%	20%	30%	0%	14%	21%

Table C2 : Analysis of Questionnaire B by dam type

			CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
	Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
		2	2	0	1	0	3	17%	0%	50%	0%	9%	40%	30%	50%	14%	31%
		5	0	0	1	0	1	0%	0%	50%	0%	3%	40%	30%	100%	14%	34%
		10	2	0	0	1	3	17%	0%	0%	13%	9%	60%	30%	100%	29%	45%
		20	0	0	0	0	0	0%	0%	0%	0%	0%	60%	30%	100%	29%	45%
		>20	2	1	0	0	3	17%	8%	0%	0%	9%	80%	40%	100%	29%	55%
		Blank			0	5	13	17%	50%	0%	63%	38%	100%	100%	100%	100%	100%
b	at its maximum																
		0.1	0	2	0	0	2	0%	17%	0%	0%	6%					
		1	2	4	0	1	7	17%	33%	0%	13%	21%	17%	40%	0%	13%	22%
		5	1	0	2	0	3	8%	0%	100%	0%	9%	25%	40%	100%	13%	31%
		10	1	0	0	1	2	8%	0%	0%	13%	6%	33%	40%	100%	25%	38%
		50	0	0	0	0	0	0%	0%	0%	0%	0%	33%	40%	100%	25%	38%
		100	0	0	0	0	0	0%	0%	0%	0%	0%	33%	40%	100%	25%	38%
		1000	1	0	0	0	1	8%	0%	0%	0%	3%	42%	40%	100%	25%	41%
		>1000	1	1	0	0	2	8%	8%	0%	0%	6%	50%	50%	100%	25%	47%
		Blank	6	5	0	6	17	50%	42%	0%	75%	50%	100%	100%	100%	100%	100%
c	when the incident was controlled?																
		0.1	1	0	0	0	1	8%	0%	0%	0%	3%					
		0.5	0	1	0	1	2	0%	8%	0%	13%	6%	0%	8%	0%	13%	6%
		1	2	0	0	0	2	17%	0%	0%	0%	6%	18%	8%	0%	13%	12%
		2	1	0	1	1	3	8%	0%	50%	13%	9%	27%	8%	50%	25%	21%
		5	0	0	0	0	0	0%	0%	0%	0%	0%	27%	8%	50%	25%	21%
		10	1	0	0	0	1	8%	0%	0%	0%	3%	36%	8%	50%	25%	24%
		20	0	0	0	0	0	0%	0%	0%	0%	0%	36%	8%	50%	25%	24%
		>20	1	1	0	0	2	8%	8%	0%	0%	6%	45%	17%	50%	25%	30%
		Blank	6	10	1	6	23	50%	83%	50%	75%	68%	100%	100%	100%	100%	100%
25	What was the elapsed time between the last surveillance visit of the dam and the event being detected?																
		0	0	0	0	0	0	0%	0%	0%	0%	0%					
		0.5	0	1	0	0	1	0%	8%	0%	0%	3%					
		1	3	1	0	0	4	25%	8%	0%	0%	12%					
		2	0	1	0	1	2	0%	8%	0%	13%	6%					
		3	1	1	0	0	2	8%	8%	0%	0%	6%					
		4	0	0	0	0	0	0%	0%	0%	0%	0%					
		7	2	1	0	0	3	17%	8%	0%	0%	9%					
		>7	1	3	0	1	5	8%	25%	0%	13%	15%					
		Blank	5	4	2	6	17	42%	33%	100%	75%	50%					
26	What was the total volume of fill eroded from the dam (please make your best estimate)																
		<0.5 cubic metres	7	6	1	4	18	58%	50%	50%	50%	53%					
		0.5 to 2 cubic metres	3	2	1	0	6	25%	17%	50%	0%	18%					

Table C2 : Analysis of Questionnaire B by dam type

Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE						CATEGORY OF DAM TYPE				
		Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall		Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED						CUMULATIVE				
	2.1 to 10 cubic metres	0	2	0	0	2	0%	17%	0%	0%	6%						
	greater than 10 cubic metres	1	0	0	1	2	8%	0%	0%	13%	6%						
	Blank	1	2	0	3	6	8%	17%	0%	38%	18%						
27 Assuming that no action was taken following detection, can you please estimate a when the dam would have failed? This is the time between detection and failure.																	
	1	2	0	0	0	2	17%	0%	0%	0%	6%	1	25%	0%	#DIV/0!	0%	10%
	2	1	0	0	1	2	8%	0%	0%	13%	6%	2	38%	0%	#DIV/0!	25%	19%
	5	1	0	0	0	1	8%	0%	0%	0%	3%	5	50%	0%	#DIV/0!	25%	24%
	10	0	0	0	1	1	0%	0%	0%	13%	3%	10	50%	0%	#DIV/0!	50%	29%
	30	2	1	0	0	3	17%	8%	0%	0%	9%	30	75%	11%	#DIV/0!	50%	43%
	90	1	1	0	1	3	8%	8%	0%	13%	9%	90	88%	22%	#DIV/0!	75%	57%
	180	0	0	0	0	0	0%	0%	0%	0%	0%	180	88%	22%	#DIV/0!	75%	57%
	360	0	2	0	0	2	0%	17%	0%	0%	6%	360	88%	44%	#DIV/0!	75%	67%
	>360	1	5	0	1	7	8%	42%	0%	13%	21%		100%	100%	#DIV/0!	100%	100%
	Blank	4	3	2	4	13	33%	25%	100%	50%	38%						
b the leakage rate when the situation would have become uncontrollable?																	
	0	0	0	0	0	0	0%	0%	0%	0%	0%						
	2	0	1	0	0	1	0%	8%	0%	0%	3%						
	5	0	3	0	0	3	0%	25%	0%	0%	9%						
	10	0	0	0	1	1	0%	0%	0%	13%	3%						
	50	0	0	0	0	0	0%	0%	0%	0%	0%						
	100	0	0	0	0	0	0%	0%	0%	0%	0%						
	1000	0	0	0	0	0	0%	0%	0%	0%	0%						
	>1000	1	0	0	0	1	8%	0%	0%	0%	3%						
	Blank	11	8	2	7	28	92%	67%	100%	88%	82%						
28 Do you have any further comments on the rate of deterioration. Useful data would include the magnitude of flow versus time prior to intervention; whether the flow naturally self healed (even if only																	
Characteristics of the dam at the location of the Internal erosion incident (leave blank if not applicable)																	
29 What is the type of embankment?																	
	Puddle Clay	4	12	0	0	16	33%	100%	0%	0%	47%						
	Homogeneous	3	0	2	0	5	25%	0%	100%	0%	15%						

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	Rolled Clay	0	0	0	1	1	0%	0%	0%	13%	3%					
	Concrete core wall	0	0	0	1	1	0%	0%	0%	13%	3%					
	Upstream membrane	1	0	0	0	1	8%	0%	0%	0%	3%					
	Other	2	0	0	0	2	17%	0%	0%	0%	6%					
	Unknown	1	0	0	3	4	8%	0%	0%	38%	12%					
	Blank	1	0	0	3	4	8%	0%	0%	38%	12%					
30 What is the dam foundation? Please select one of the predefined options																
	Gravel	1	0	0	1	2	8%	0%	0%	13%	6%					
	Sand	3	0	0	0	3	25%	0%	0%	0%	9%					
	Silt	1	0	1	1	3	8%	0%	50%	13%	9%					
	Clay Plasticity Index >22	0	1	1	0	2	0%	8%	50%	0%	6%					
	Clay Plasticity Index 22 or less	1	1	0	0	2	8%	8%	0%	0%	6%					
	Weathered rock	2	7	0	1	10	17%	58%	0%	13%	29%					
	Rock with many gouge filled discontinuities	0	0	0	0	0	0%	0%	0%	0%	0%					
	Sound Rock	2	1	0	0	3	17%	8%	0%	0%	9%					
	Blank	2	2	0	5	9	17%	17%	0%	63%	26%					
31 For the fill forming the watertight element:- a What is the geological origin?																
	Alluvial	2	3	2	2	9	17%	25%	100%	25%	26%					
	Glacial	5	6	0	1	12	42%	50%	0%	13%	35%					
	Lacustrine	1	0	0	0	1	8%	0%	0%	0%	3%					
	Marine	1	0	0	0	1	8%	0%	0%	0%	3%					
	Weathered rock	1	3	0	0	4	8%	25%	0%	0%	12%					
	Other	1	0	0	0	1	8%	0%	0%	0%	3%					
	Blank	1	0	0	5	6	8%	0%	0%	63%	18%					
b What is its Liquid Limit?																
	10	0	0	0	0	0	0%	0%	0%	0%	0%					
	20	0	0	0	0	0	0%	0%	0%	0%	0%					
	30	1	0	0	0	1	8%	0%	0%	0%	3%					
	40	1	1	0	0	2	8%	8%	0%	0%	6%					
	50	1	2	0	0	3	8%	17%	0%	0%	9%					
	60	0	1	0	0	1	0%	8%	0%	0%	3%					
	70	0	0	0	0	0	0%	0%	0%	0%	0%					
	>70	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	9	8	2	8	27	75%	67%	100%	100%	79%					
c What is its Plasticity Index?																
	5	0	0	0	0	0	0%	0%	0%	0%	0%					
	10	1	0	0	0	1	8%	0%	0%	0%	3%					
	15	2	1	0	0	3	17%	8%	0%	0%	9%					
	20	1	2	0	0	3	8%	17%	0%	0%	9%					
	30	0	0	0	0	0	0%	0%	0%	0%	0%					
	40	0	1	0	0	1	0%	8%	0%	0%	3%					

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	50	0	0	0	0	0	0%	0%	0%	0%	0%					
	>50	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	8	8	2	8	26	67%	67%	100%	100%	76%					
32 For the fill material immediately downstream of the impervious element:- a What would you describe its form of construction?																
	Random	2	6	0	2	10	17%	50%	0%	25%	29%					
	Zoned	0	0	0	1	1	0%	0%	0%	13%	3%					
	Selected	1	6	0	0	7	8%	50%	0%	0%	21%					
	Homogenous	4	0	2	1	7	33%	0%	100%	13%	21%					
	Blank	5	0	0	4	9	42%	0%	0%	50%	26%					
b What is its geological origin?																
	Alluvial	1	3	2	2	8	8%	25%	100%	25%	24%					
	Glacial	4	6	0	1	11	33%	50%	0%	13%	32%					
	Lacustrine	1	0	0	0	1	8%	0%	0%	0%	3%					
	Marine	1	0	0	0	1	8%	0%	0%	0%	3%					
	Weathered rock	1	3	0	0	4	8%	25%	0%	0%	12%					
	Other	1	0	0	0	1	8%	0%	0%	0%	3%					
	Blank	3	0	0	5	8	25%	0%	0%	63%	24%					
c Does it satisfy modern filter criteria against the core?																
	Yes	0	3	0	0	3	0%	25%	0%	0%	9%					
	No	5	2	0	3	10	42%	17%	0%	38%	29%					
	Marginal	0	0	0	0	0	0%	0%	0%	0%	0%					
	Homogenous dam	1	0	2	0	3	8%	0%	100%	0%	9%					
	Don't know	3	7	0	1	11	25%	58%	0%	13%	32%					
	Blank	3	0	0	4	7	25%	0%	0%	50%	21%					
d What is the D15 of its particle size distribution (i.e. particle size for which 15% is finer)?																
	0.01	1	1	0	0	2	8%	8%	0%	0%	6%					
	0.06	0	0	0	0	0	0%	0%	0%	0%	0%					
	0.1	1	0	0	0	1	8%	0%	0%	0%	3%					
	1	1	0	0	0	1	8%	0%	0%	0%	3%					
	5	0	0	0	0	0	0%	0%	0%	0%	0%					
	10	0	0	0	0	0	0%	0%	0%	0%	0%					
	70	0	0	0	0	0	0%	0%	0%	0%	0%					
	>70	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	9	11	2	8	30	75%	92%	100%	100%	88%					
33 For the fill material immediately upstream of the impervious element:- a What would you describe its form of construction?																

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	Random	2	7	0	3	12	17%	58%	0%	38%	35%					
	Zoned	0	0	0	1	1	0%	0%	0%	13%	3%					
	Selected	0	4	0	0	4	0%	33%	0%	0%	12%					
	Homogenous	4	0	2	0	6	33%	0%	100%	0%	18%					
	Blank	6	1	0	4	11	50%	8%	0%	50%	32%					
b What is its geological origin?																
	Lacustrine	1	0	0	0	1	8%	0%	0%	0%	3%					
	Marine	1	0	0	0	1	8%	0%	0%	0%	3%					
	Weathered rock	1	3	0	0	4	8%	25%	0%	0%	12%					
	Alluvial	1	3	2	2	8	8%	25%	100%	25%	24%					
	Glacial	3	5	0	1	9	25%	42%	0%	13%	26%					
	Blank	5	1	0	5	11	42%	8%	0%	63%	32%					
c Does it act as a crack filler, in that fines could be washed into a crack in the core and seal it?																
	Yes	1	0	2	0	3	8%	0%	100%	0%	9%					
	No	3	1	0	2	6	25%	8%	0%	25%	18%					
	Marginal	0	3	0	0	3	0%	25%	0%	0%	9%					
	Don't know	2	8	0	2	12	17%	67%	0%	25%	35%					
	Blank	6	0	0	4	10	50%	0%	0%	50%	29%					
d What is the soil type?																
	Gravel	1	0	0	0	1	8%	0%	0%	0%	3%					
	Sand	2	0	0	0	2	17%	0%	0%	0%	6%					
	Silt	0	0	1	2	3	0%	0%	50%	25%	9%					
	Clay Plasticity Index >22	1	3	0	0	4	8%	25%	0%	0%	12%					
	Clay Plasticity Index 22 or less	3	5	1	0	9	25%	42%	50%	0%	26%					
	Weathered (soft) rockfill	0	4	0	1	5	0%	33%	0%	13%	15%					
	Sound Rockfill	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	5	0	0	5	10	42%	0%	0%	63%	29%					
34 For the impervious element at original ground level a What is its width?																
	1	0	0	0	1	1	0%	0%	0%	13%	3%					
	2	1	1	0	1	3	8%	8%	0%	13%	9%					
	3	0	2	0	0	2	0%	17%	0%	0%	6%					
	5	1	1	0	0	2	8%	8%	0%	0%	6%					
	10	0	1	0	1	2	0%	8%	0%	13%	6%					
	15	3	0	0	0	3	25%	0%	0%	0%	9%					
	20	0	0	1	0	1	0%	0%	50%	0%	3%					
	>20	1	0	1	0	2	8%	0%	50%	0%	6%					
	Blank	6	7	0	5	18	50%	58%	0%	63%	53%					

Table C2 : Analysis of Questionnaire B by dam type

	Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
			Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
b	What is the head across it?																
		2	1	0	0	1	2	8%	0%	0%	13%	6%					
		5	2	2	2	0	6	17%	17%	100%	0%	18%					
		10	3	2	0	1	6	25%	17%	0%	13%	18%					
		15	0	3	0	0	3	0%	25%	0%	0%	9%					
		20	1	1	0	1	3	8%	8%	0%	13%	9%					
		30	0	1	0	0	1	0%	8%	0%	0%	3%					
		50	0	0	0	0	0	0%	0%	0%	0%	0%					
		>50	0	0	0	0	0	0%	0%	0%	0%	0%					
		Blank	5	3	0	5	13	42%	25%	0%	63%	38%					
e	Gradient																
		0.5	4	0	2	1	7	33%	0%	100%	13%	21%					
		1	0	0	0	0	0	0%	0%	0%	0%	0%					
		2	0	0	0	0	0	0%	0%	0%	0%	0%					
		5	2	4	0	0	6	17%	33%	0%	0%	18%					
		10	0	0	0	1	1	0%	0%	0%	13%	3%					
		>10	0	0	0	0	0	0%	0%	0%	0%	0%					
		Blank	12	12	2	8	34	100%	100%	100%	100%	100%					
35 a	If the incident involved a conduit (pipe or culvert) through the embankment fill what is the external diameter of this conduit?																
		<0.25 metres	1	0	0	0	1	8%	0%	0%	0%	3%					
		0.25 to 0.5 metres	3	1	0	0	4	25%	8%	0%	0%	12%					
		0.51 to 1 metre	1	0	0	0	1	8%	0%	0%	0%	3%					
		1.01 to 2 metres	2	0	0	0	2	17%	0%	0%	0%	6%					
		Greater than 2 metres	1	0	0	0	1	8%	0%	0%	0%	3%					
		Blank	4	11	2	8	25	33%	92%	100%	100%	74%					
b	What was the type of construction of pipe or culvert																
		Masonry culvert	2	0	0	0	2	17%	0%	0%	0%	6%					
		Brick culvert	1	0	0	0	1	8%	0%	0%	0%	3%					
		Concrete culvert	0	0	0	0	0	0%	0%	0%	0%	0%					
		Pipe laid in concrete	0	0	0	1	1	0%	0%	0%	13%	3%					
		Pipe laid within fill	4	1	0	0	5	33%	8%	0%	0%	15%					
		Other	1	0	0	0	1	8%	0%	0%	0%	3%					
		Blank	4	11	2	7	24	33%	92%	100%	88%	71%					
c	What is the spacing of movement joints (or any other feature through which fill cold be eroded)																
		1	2	0	0	0	2	17%	0%	0%	0%	6%					
		2	0	0	0	0	0	0%	0%	0%	0%	0%					
		4	0	0	0	0	0	0%	0%	0%	0%	0%					

Table C2 : Analysis of Questionnaire B by dam type

Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
		Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	7	1	0	0	0	1	8%	0%	0%	0%	3%					
	10	0	0	0	0	0	0%	0%	0%	0%	0%					
	15	0	0	0	0	0	0%	0%	0%	0%	0%					
	20	0	0	0	1	1	0%	0%	0%	13%	3%					
	>20	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	9	12	2	7	30	75%	100%	100%	88%	88%					
d Was there any special treatment of the interface between the fill and conduit? E.g. None, shaped concrete, cut-off collars, filter wraparound?																
36 Geometry of (steepest) abutment																
	>80 degrees	1	0	0	0	1	8%	0%	0%	0%	3%					
	60 to 80 degrees	0	0	0	0	0	0%	0%	0%	0%	0%					
	45 to 60 degrees	1	0	0	0	1	8%	0%	0%	0%	3%					
	30 to 45 degrees	4	3	1	0	8	33%	25%	50%	0%	24%					
	< 30 degrees	4	7	1	2	14	33%	58%	50%	25%	41%					
	Blank	2	2	0	6	10	17%	17%	0%	75%	29%					
37 What are the characteristics of the reservoir water?																
a pH																
	3	0	0	0	0	0	0%	0%	0%	0%	0%					
	4	0	0	0	0	0	0%	0%	0%	0%	0%					
	5	0	0	0	0	0	0%	0%	0%	0%	0%					
	6	1	0	0	0	1	8%	0%	0%	0%	3%					
	7	3	0	0	0	3	25%	0%	0%	0%	9%					
	8	0	1	0	0	1	0%	8%	0%	0%	3%					
	9	0	0	0	0	0	0%	0%	0%	0%	0%					
	>9	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	8	11	2	8	29	67%	92%	100%	100%	85%					
b Total dissolved solids																
	10	0	0	0	0	0	0%	0%	0%	0%	0%					
	20	0	0	0	0	0	0%	0%	0%	0%	0%					
	30	0	0	0	0	0	0%	0%	0%	0%	0%					
	40	0	0	0	0	0	0%	0%	0%	0%	0%					
	50	0	0	0	0	0	0%	0%	0%	0%	0%					
	60	0	0	0	0	0	0%	0%	0%	0%	0%					
	70	0	0	0	0	0	0%	0%	0%	0%	0%					
	>70	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank															
c Conductivity																
	10	0	0	0	0	0	0%	0%	0%	0%	0%					
	20	0	0	0	0	0	0%	0%	0%	0%	0%					

Table C2 : Analysis of Questionnaire B by dam type

			CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
	Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
		30	0	0	0	0	0	0%	0%	0%	0%	0%					
		40	0	0	0	0	0	0%	0%	0%	0%	0%					
		50	0	0	0	0	0	0%	0%	0%	0%	0%					
		60	0	0	0	0	0	0%	0%	0%	0%	0%					
		70	0	0	0	0	0	0%	0%	0%	0%	0%					
		>70	1	0	0	0	1	8%	0%	0%	0%	3%					
		Blank															
d	Any other data that might be relevant?																
38	Have any of the embankment or foundation soils been subjected to any form of dispersion or erodibility testing (e.g. pinhole test, crumb test, double hydrometer) and if so which test(s), what were the results																
39	Are there any unusual features? E.g. narrow crest, steep downstream slope; filters retrofitted to downstream face																
	Surveillance Before the Event		0	0	0	0	0	0%	0%	0%	0%	0%					
40	What was the frequency of visits to the dam before the incident?																
		Daily (or more frequent)	1	1	1	1	4	8%	8%	50%	13%	12%					
		3 times/ week	4	2	0	2	8	33%	17%	0%	25%	24%					
		2 times/ week	0	2	0	0	2	0%	17%	0%	0%	6%					
		Weekly	3	7	0	1	11	25%	58%	0%	13%	32%					
		Fortnightly	1	0	0	0	1	8%	0%	0%	0%	3%					
		Monthly	0	0	0	2	2	0%	0%	0%	25%	6%					
		Less frequent than monthly	2	0	1	0	3	17%	0%	50%	0%	9%					
		Blank	1	0	0	2	3	8%	0%	0%	25%	9%					
41	How many of the following instruments does the dam have (in functioning order; approximate numbers acceptable)																
a	Standpipe piezometers																
		0	0	0	0	0	0	0%	0%	0%	0%	0%					
		1	0	0	0	0	0	0%	0%	0%	0%	0%					
		2	0	0	0	0	0	0%	0%	0%	0%	0%					
		5	2	1	0	2	5	17%	8%	0%	25%	15%					
		10	0	1	0	0	1	0%	8%	0%	0%	3%					
		15	0	2	0	0	2	0%	17%	0%	0%	6%					
		20	0	1	0	0	1	0%	8%	0%	0%	3%					

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	>20	0	1	0	0	1	0%	8%	0%	0%	3%					
	Blank	10	6	2	6	24	83%	50%	100%	75%	71%					
b Other forms of piezometer																
	0	0	0	0	0	0	0%	0%	0%	0%	0%					
	1	0	0	0	0	0	0%	0%	0%	0%	0%					
	2	0	0	0	0	0	0%	0%	0%	0%	0%					
	5	0	0	0	0	0	0%	0%	0%	0%	0%					
	10	0	0	0	1	1	0%	0%	0%	13%	3%					
	15	0	0	0	0	0	0%	0%	0%	0%	0%					
	20	0	0	0	0	0	0%	0%	0%	0%	0%					
	>20	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	12	12	2	7	33	100%	100%	100%	88%	97%					
c Settlement monitoring points																
	0	0	0	0	0	0	0%	0%	0%	0%	0%					
	1	0	0	0	0	0	0%	0%	0%	0%	0%					
	2	0	0	0	0	0	0%	0%	0%	0%	0%					
	5	1	1	0	0	2	8%	8%	0%	0%	6%					
	10	4	2	0	2	8	33%	17%	0%	25%	24%					
	15	0	0	0	1	1	0%	0%	0%	13%	3%					
	20	0	2	0	0	2	0%	17%	0%	0%	6%					
	>20	1	3	0	0	4	8%	25%	0%	0%	12%					
	Blank	6	4	2	5	17	50%	33%	100%	63%	50%					
d V notch or other quantification of seepage																
42 What was the elapsed time between readings of these instruments prior to the incident? a Standpipe piezometers																
	0.5	0	0	0	0	0	0%	0%	0%	0%	0%					
	1	1	0	0	0	1	8%	0%	0%	0%	3%					
	2	0	0	0	1	1	0%	0%	0%	13%	3%					
	4	1	0	0	0	1	8%	0%	0%	0%	3%					
	8	0	0	0	0	0	0%	0%	0%	0%	0%					
	12	0	0	0	0	0	0%	0%	0%	0%	0%					
	25	0	1	0	0	1	0%	8%	0%	0%	3%					
	>25	0	4	0	0	4	0%	33%	0%	0%	12%					
	Blank	10	7	2	7	26	83%	58%	100%	88%	76%					
b Other forms of piezometer																
	0.5	0	0	0	0	0	0%	0%	0%	0%	0%					
	1	0	0	0	0	0	0%	0%	0%	0%	0%					
	2	0	0	0	1	1	0%	0%	0%	13%	3%					
	4	0	0	0	0	0	0%	0%	0%	0%	0%					
	8	0	0	0	0	0	0%	0%	0%	0%	0%					
	12	0	0	0	0	0	0%	0%	0%	0%	0%					
	25	0	0	0	0	0	0%	0%	0%	0%	0%					
	>25	0	0	0	0	0	0%	0%	0%	0%	0%					
	Blank	12	12	2	7	33	100%	100%	100%	88%	97%					

Table C2 : Analysis of Questionnaire B by dam type

			CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
	Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
c	Settlement monitoring points																
		4	0	0	0	0	0	0%	0%	0%	0%	0%					
		8	0	0	0	0	0	0%	0%	0%	0%	0%					
		12	0	0	0	0	0	0%	0%	0%	0%	0%					
		16	1	0	0	0	1	8%	0%	0%	0%	3%					
		20	0	0	0	1	1	0%	0%	0%	13%	3%					
		25	1	0	0	1	2	8%	0%	0%	13%	6%					
		52	1	6	0	1	8	8%	50%	0%	13%	24%					
		>52	1	0	0	0	1	8%	0%	0%	0%	3%					
		Blank	8	6	2	5	21	67%	50%	100%	63%	62%					
d	V notch or other quantification of seepage																
43	What was the process used to assess surveillance data before the event? e.g. reviewed by trained personnel to look for unusual readings and new trends?																
a	Technician taking readings given formal trigger values, which if the readings then exceeded he would immediately seek further advice																
		No review	5	1	1	3	10	42%	8%	50%	38%	29%					
		No review, but operator would flag unusual reading	3	7	1	1	12	25%	58%	50%	13%	35%					
		Yes - trigger values defined	1	0	0	1	2	8%	0%	0%	13%	6%					
		Blank	3	4	0	3	10	25%	33%	0%	38%	29%					
b	Formal review by others																
		Line supervisor	1	2	0	0	3	8%	17%	0%	0%	9%					
		Supervising engineer	5	5	2	2	14	42%	42%	100%	25%	41%					
		External consultant	0	2	0	1	3	0%	17%	0%	13%	9%					
		Blank	6	3	0	5	14	50%	25%	0%	63%	41%					
44	What was the frequency between																
a	Reviews by an engineer																
		4	3	1	0	0	4	25%	8%	0%	0%	12%					
		8	0	0	0	0	0	0%	0%	0%	0%	0%					
		12	0	0	0	0	0	0%	0%	0%	0%	0%					
		16	0	0	0	0	0	0%	0%	0%	0%	0%					
		20	0	0	0	0	0	0%	0%	0%	0%	0%					
		25	0	0	0	0	0	0%	0%	0%	0%	0%					
		52	3	5	0	2	10	25%	42%	0%	25%	29%					
		>52	0	0	0	0	0	0%	0%	0%	0%	0%					
		Blank	6	6	2	6	20	50%	50%	100%	75%	59%					

Table C2 : Analysis of Questionnaire B by dam type

	Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
			Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
b	Reviews by the Supervising Engineer																
		4	0	0	0	0	0	0%	0%	0%	0%	0%					
		8	0	0	0	0	0	0%	0%	0%	0%	0%					
		12	0	0	0	0	0	0%	0%	0%	0%	0%					
		16	0	0	0	0	0	0%	0%	0%	0%	0%					
		20	0	0	0	0	0	0%	0%	0%	0%	0%					
		25	0	0	0	0	0	0%	0%	0%	0%	0%					
		52	7	8	2	3	20	58%	67%	100%	38%	59%					
		>52	0	1	0	0	1	0%	8%	0%	0%	3%					
		Blank	5	3	0	5	13	42%	25%	0%	63%	38%					
c	Written report on readings (including Supervising Engineer's annul statement)																
		4	0	0	0	0	0	0%	0%	0%	0%	0%					
		8	0	0	0	0	0	0%	0%	0%	0%	0%					
		12	0	0	0	0	0	0%	0%	0%	0%	0%					
		16	0	0	0	0	0	0%	0%	0%	0%	0%					
		20	0	0	0	0	0	0%	0%	0%	0%	0%					
		25	0	0	0	0	0	0%	0%	0%	0%	0%					
		52	7	9	2	5	23	58%	75%	100%	63%	68%					
		>52	0	0	0	0	0	0%	0%	0%	0%	0%					
		Blank	5	3	0	3	11	42%	25%	0%	38%	32%					
d	Written reports by External consultant																
		4	0	0	0	0	0	0%	0%	0%	0%	0%					
		8	0	0	0	0	0	0%	0%	0%	0%	0%					
		25	0	0	0	0	0	0%	0%	0%	0%	0%					
		52	0	0	0	1	1	0%	0%	0%	13%	3%					
		104	0	0	0	0	0	0%	0%	0%	0%	0%					
		260	0	0	0	0	0	0%	0%	0%	0%	0%					
		520	1	3	0	0	4	8%	25%	0%	0%	12%					
		>520	1	0	0	1	2	8%	0%	0%	13%	6%					
		Blank	10	9	2	6	27	83%	75%	100%	75%	79%					
	Prior warning/ Previous manifestations																
45	Is it likely that internal erosion was occurring prior to the incident?																
		Yes	7	7	1	3	18	58%	58%	50%	38%	53%					
		No	3	1	0	0	4	25%	8%	0%	0%	12%					
		Maybe	1	4	1	4	10	8%	33%	50%	50%	29%					
		Blank	1	0	0	1	2	8%	0%	0%	13%	6%					
46	Did any of the following indicators give prior warning of the incident?																

Table C2 : Analysis of Questionnaire B by dam type

	Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
			Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
a	Seepage: Quantity																
		Strong	0	3	2	1	6	0%	25%	100%	13%	18%					
		Medium	1	0	0	0	1	8%	0%	0%	0%	3%					
		Low	3	3	0	2	8	25%	25%	0%	25%	24%					
		No Indication	5	6	0	4	15	42%	50%	0%	50%	44%					
		Blank	3	0	0	1	4	25%	0%	0%	13%	12%					
b	Seepage: Turbidity or other characteristic																
		Strong	0	0	0	0	0	0%	0%	0%	0%	0%					
		Medium	0	0	1	0	1	0%	0%	50%	0%	3%					
		Low	0	4	1	1	6	0%	33%	50%	13%	18%					
		No Indication	7	8	0	5	20	58%	67%	0%	63%	59%					
		Blank	5	0	0	2	7	42%	0%	0%	25%	21%					
c	Settlement																
		Strong	0	1	0	0	1	0%	8%	0%	0%	3%					
		Medium	2	1	0	0	3	17%	8%	0%	0%	9%					
		Low	0	1	0	0	1	0%	8%	0%	0%	3%					
		No Indication	4	8	0	4	16	33%	67%	0%	50%	47%					
		No Instrument	2	1	2	2	7	17%	8%	100%	25%	21%					
		Blank	4	0	0	2	6	33%	0%	0%	25%	18%					
d	Piezometer readings																
		Strong	0	0	0	0	0	0%	0%	0%	0%	0%					
		Medium	0	2	0	0	2	0%	17%	0%	0%	6%					
		Low	0	0	0	0	0	0%	0%	0%	0%	0%					
		No Indication	2	4	0	2	8	17%	33%	0%	25%	24%					
		No Instrument	5	6	2	4	17	42%	50%	100%	50%	50%					
		Blank	5	0	0	2	7	42%	0%	0%	25%	21%					
47	For each incident which parameter was the most useful as an indicator of internal erosion																
		Suspended Fines	2	0	0	0	2	17%	0%	0%	0%	6%					
		Quantity of Seepage	4	7	2	3	16	33%	58%	100%	38%	47%					
		Piezometer Readings	0	1	0	0	1	0%	8%	0%	0%	3%					
		Embankment Crest Deformation	2	0	0	3	5	17%	0%	0%	38%	15%					
		Other Deformation	2	4	0	1	7	17%	33%	0%	13%	21%					
		Blank	2	0	0	1	3	17%	0%	0%	13%	9%					

Table C2 : Analysis of Questionnaire B by dam type

	Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
			Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
48	Please expand the above, or provide any further comments on what prior warning there was (in retrospect) e.g. quantify the settlement rate, seepage flows																
	Surveillance After the Event		0	0	0	0	0	0%	0%	0%	0%	0%					
49	Was the frequency of any of the following changed as a result of the incident (give relative increase i.e. 2 = twice as often; if no change enter 1; consider frequency one year after completion of physical works)																
a	Surveillance visit																
		1	6	8	0	3	17	50%	67%	0%	38%	50%					
		1.25	0	0	0	0	0	0%	0%	0%	0%	0%					
		1.5	0	1	0	0	1	0%	8%	0%	0%	3%					
		1.75	0	0	0	0	0	0%	0%	0%	0%	0%					
		2	1	2	0	3	6	8%	17%	0%	38%	18%					
		2.5	0	0	0	0	0	0%	0%	0%	0%	0%					
		5	0	0	0	0	0	0%	0%	0%	0%	0%					
		>5	0	0	0	0	0	0%	0%	0%	0%	0%					
		Blank	5	1	2	2	10	42%	8%	100%	25%	29%					
b	Frequency of reading piezometers																
		1	3	2	0	0	5	25%	17%	0%	0%	15%					
		1.25	0	0	0	0	0	0%	0%	0%	0%	0%					
		1.5	0	0	0	0	0	0%	0%	0%	0%	0%					
		1.75	0	0	0	0	0	0%	0%	0%	0%	0%					
		2	0	2	0	0	2	0%	17%	0%	0%	6%					
		2.5	0	0	0	0	0	0%	0%	0%	0%	0%					
		5	0	1	0	1	2	0%	8%	0%	13%	6%					
		>5	1	1	0	1	3	8%	8%	0%	13%	9%					
		Blank	8	6	2	6	22	67%	50%	100%	75%	65%					
c	Frequency of reading seepage measurement devices																
		1	3	2	0	2	7	25%	17%	0%	25%	21%					
		1.25	0	0	0	0	0	0%	0%	0%	0%	0%					
		1.5	0	0	0	0	0	0%	0%	0%	0%	0%					
		1.75	0	0	0	0	0	0%	0%	0%	0%	0%					
		2	0	2	0	0	2	0%	17%	0%	0%	6%					
		2.5	0	0	0	0	0	0%	0%	0%	0%	0%					
		5	0	2	0	0	2	0%	17%	0%	0%	6%					
		>5	3	1	0	1	5	25%	8%	0%	13%	15%					
		Blank	6	5	2	5	18	50%	42%	100%	63%	53%					
d	Frequency of reading settlement measurement devices																
		1	4	6	0	2	12	33%	50%	0%	25%	35%					

Table C2 : Analysis of Questionnaire B by dam type

		CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
Question	Possible responses	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
		NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
	1.25	0	0	0	0	0	0%	0%	0%	0%	0%					
	1.5	0	0	0	0	0	0%	0%	0%	0%	0%					
	1.75	0	0	0	0	0	0%	0%	0%	0%	0%					
	2	0	0	0	1	1	0%	0%	0%	13%	3%					
	2.5	0	0	0	0	0	0%	0%	0%	0%	0%					
	5	1	0	0	0	1	8%	0%	0%	0%	3%					
	>5	2	0	0	1	3	17%	0%	0%	13%	9%					
	Blank	5	6	2	4	17	42%	50%	100%	50%	50%					
Action taken to control		0	0	0	0	0	0%	0%	0%	0%	0%					
50 What action was taken immediately on detection, and in your opinion how effective was it? a Lower reservoir																
	Effective	7	10	1	4	22	58%	83%	50%	50%	65%					
	Minor	0	0	0	0	0	0%	0%	0%	0%	0%					
	No Effect	1	1	0	1	3	8%	8%	0%	13%	9%					
	Not Undertaken	1	1	1	0	3	8%	8%	50%	0%	9%					
	Blank	3	0	0	3	6	25%	0%	0%	38%	18%					
b Filter downstream																
	Effective	1	0	2	0	3	8%	0%	100%	0%	9%					
	Minor	1	0	0	0	1	8%	0%	0%	0%	3%					
	No Effect	0	0	0	0	0	0%	0%	0%	0%	0%					
	Not Undertaken	6	12	0	3	21	50%	100%	0%	38%	62%					
	Blank	4	0	0	5	9	33%	0%	0%	63%	26%					
c Dump material into reservoir																
	Effective	1	0	1	0	2	8%	0%	50%	0%	6%					
	Minor	0	0	0	0	0	0%	0%	0%	0%	0%					
	No Effect	0	0	0	0	0	0%	0%	0%	0%	0%					
	Not Undertaken	6	12	1	3	22	50%	100%	50%	38%	65%					
	Blank	5	0	0	5	10	42%	0%	0%	63%	29%					
d Other																
51 What physical works were then																
	Diaphragm wall	1	4	0	0	5	8%	33%	0%	0%	15%					
	Sheetpiling	1	1	0	0	2	8%	8%	0%	0%	6%					
	Grouting	3	4	0	2	9	25%	33%	0%	25%	26%					
	Reline conduit	0	0	0	0	0	0%	0%	0%	0%	0%					
	Add filters	0	0	1	0	1	0%	0%	50%	0%	3%					
	Other	3	2	1	6	12	25%	17%	50%	75%	35%					
	Blank	4	1	0	0	5	33%	8%	0%	0%	15%					

Table C2 : Analysis of Questionnaire B by dam type

	Question	Possible responses	CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE					CATEGORY OF DAM TYPE				
			Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
			NUMBER OF EACH RESPONSE FROM EACH CATEGORY					NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CUMULATIVE				
52	Were the physical works effective?																
		Yes	6	6	2	7	21	50%	50%	100%	88%	62%					
		Partially, no further action	1	1	0	0	2	8%	8%	0%	0%	6%					
		Partially, further action required	1	1	0	1	3	8%	8%	0%	13%	9%					
		No	1	1	0	0	2	8%	8%	0%	0%	6%					
		Blank	3	3	0	0	6	25%	25%	0%	0%	18%					
53	If supplementary physical measures were taken, what were they?																
		Diaphragm wall	1	2	0	1	4	8%	17%	0%	13%	12%					
		Sheetpiling	0	0	0	0	0	0%	0%	0%	0%	0%					
		Grouting	0	1	0	1	2	0%	8%	0%	13%	6%					
		Reline pipe	0	0	0	0	0	0%	0%	0%	0%	0%					
		Add filters	0	0	0	0	0	0%	0%	0%	0%	0%					
		Other	3	2	0	1	6	25%	17%	0%	13%	18%					
		Not Applicable	1	1	2	0	4	8%	8%	100%	0%	12%					
		Blank	7	6	0	5	18	58%	50%	0%	63%	53%					
54	Was site investigation carried out to assist in understanding the cause? If so, please give the number of exploratory holes (of any type) (leave blank if no site investigation done)																
55	Please provide any further information e.g. key findings of any investigations/ reports into the cause																
		Yes	0	0	0	0	0	0%	0%	0%	0%	0%					
		No	0	0	0	0	0	0%	0%	0%	0%	0%					
	Drawdown Capacity																
56	What was the drawdown capacity prior to the incident (over the upper third of the reservoir)?																
57	Has the drawdown capacity been modified since the event (or is it planned to be)? If so, please indicate the drawdown capability after these modifications (leave blank if no change)																
	Other Comments																

Table C2 : Analysis of Questionnaire B by dam type

	Question	Possible responses	CATEGORY OF DAM TYPE NUMBER OF EACH RESPONSE FROM EACH CATEGORY					CATEGORY OF DAM TYPE NUMBER OF EACH RESPONSE AS PERCENTAGE OF TOTAL RETURNED					CATEGORY OF DAM TYPE CUMULATIVE				
			Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall	Appurtenant works	Puddle clay	Homogenous	Other	Overall
58	Please add any other comments you may have, either in the text box or as an attached Word document																

APPENDIX D : DETAILED CASE HISTORIES

The Inception report envisaged that up to six case histories would be selected from those provided by dam owners to obtain more detailed information on the incident.

In practice five dam owners provided case histories in response to the questionnaire as follows

Owner Ref	No of case histories	Dam type	Incident level	Remarks
101	2	Puddle clay Homogenous	2 2	
102	2	Puddle clay	2, 3	To be visited
104	1	Puddle clay	3	Case History C
108	1	Other	2	
112	1	Other	2	
Total	7			

In addition a major owner who did not provide any case histories was visited and provided information recorded here as Case History A and B.

The purpose of the assessment was to

a) discuss the data provided
b) examine any investigation techniques used
c) identify issues which were not necessarily covered by the questions in the questionnaire

Case History A

This is a 34m high puddle core dam, with 4m wide crest, 1V:3H upstream slope and 1V:2.7H downstream slope. The dam experienced an incident of concentrated leakage as follows

1963	Spillway overflow permanently lowered 600mm as part of upgrading works to spillway. Freeboard by 2001 was 1.6m.
1995	Trial pits and boreholes on crest, as site investigation relating to reconstruction of wave wall in same year
March 1999	Concentrated leakage noted emerging on downstream face 2.5m below dam crest, 25m to the right of the valve tower. This dried up when the level of the reservoir dropped 50mm below spillway overflow level.
Sept 1999	Site investigation carried out, comprising four trial pits in crest and a 10m long trench just upstream of the seepage (partly to confirm level of top of clay core, and quality of clay core). Findings included that the core material was poor quality, including extensive gravel and stone inclusions
1999	Leak stopped and did not recommence
March 2000	Second concentrated leakage appeared, 5m to right of tower 7m below dam crest. Maximum recorded flow 4litre/ min when reservoir level just spilling; leak dried up when reservoir 0.1m below TWL (however, no unique correlation between flow and reservoir level or rainfall)
2000- 2001	Temporary ban on reservoir level rising within 500m of overflow level, to reduce the risk of the concentrated leak deteriorating into failure of dam
July 2000	Resistivity survey when reservoir level 83mm below spillway overflow; 3 lines parallel to dam axis, 0.5m below the embankment crest and either side of the concentrated leakage. The three traverses had lengths of 120, 72 and 48m with corresponding depths of investigation 15, 9 and 6m. This identified • Four areas of lower resistance, three at locations of previous trial pits (one put down in 1995 and two in 1999 : CH 40, 65, 90) and the fourth close to spillway wall • low resistance at 3 to 8m depth in the traverse just downstream of the core, attributed to rainfall percolating through the downstream slope
May 2001	Temperature profile along downstream side of crest of dam, with reservoir temperature of 8.7^{o}C. Probes inserted to maximum 12m depth, at 10m centres. Reservoir temporarily raised to 200mm above overflow. “Frost pulse” method also used to improve detection of elevation of leakage. Identified temperature anomalies along most of length at 3 to 6m depth below dam crest
July 2001	Contract for works, main item to replace puddle clay to 3m depth as 600mm wide trench below top of dam, for 70m length from spillway on right abutment to valve tower located in centre of dam. This was successful in stopping the concentrated leakage.

Conclusion

1. The resistivity survey identified three old trial pits located in the core as having low electrical resistance and it was concluded these were likely to be the source of the leak.
2. The temperature sensing was less successful, possibly partly due to not being carried out in winter when reservoir water temperature is lowest.
3. Replacement of the upper 3m of the core has been successful in curing the leak.
4. Technical uncertainty remains in
    - whether the low resistivity of the old trial pits was due to differences, relative to the adjacent core, in backfill material, compaction, rainwater ponding in the hole or concentrated flow from the reservoir (the core at location of the previous trial pit at Ch 90 has not been replaced yet there are no signs of seepage problems at this location)
    - why both the resistivity and temperature sensing indicated anomalies at 3 to 8m depth; whether because these are wetter areas (and if so whether due to rainfall infiltration or reservoir seepage); or because of some other reason

Case History B

A service reservoir built in the 1960's had increasing leakage in the underfloor drains, together with some sand being collected. Ground penetrating radar was used to check for the existence of voids under the floor slab. The survey was carried out in a single day in 1999 using a trolley mounted 500MHz system with readings taken every 1cm. The survey found indications of possible small scale (< 0.5m) voids in two locations, together with small scale voiding directly beneath expansion joints. It is understood grouting was subsequently carried out, and had only small grout takes.

Conclusion: Ground probing radar is a non-destructive technique that may be used for checking for significant voids below floor slabs

Case History C

Case History C (104)

This is a 21m high puddle core dam, with 3.5m wide crest and 2.3H:1V downstream slope. The outlet works comprise a 3m x 1.3m masonry culvert on the upstream and downstream shoulders, but as a 305mm diameter cast iron pipe through the core itself. The geological map shows the foundation is weathered gritstones; predominantly sandstone with some shale horizons. The dam experienced an incident of concentrated leakage into the culvert as follows

1974	Freeboard raised by crest raising (including top of core), rebuilding part of wave wall, extend wave wall into abutments
1997	Concentred leakage noted into side of culvert; issuing water looked clear but that a small amount of sand was noted in a collecting bucket and on the flagstones in the culvert. Reservoir then lowered 5m over 2 months by use of siphons (the outlet failed to operate due to an upstream paddle being sucked into the pipe and blocking it – the outlet was later restored by sinking a shaft over it). The questionnaire notes that • a similar leakage had occurred 25 years before which had self healed • the maximum flow was 0.4 litre/sec
	Inflows increased such that reservoir refilled to 0.8m below TWL. Lowered to 7.5m below TWL 4 months after start of incident, by siphons and reinstatement of a bywash. During this time the rate of leakage varied with water level, but did not appear to be getting any worse
1999	Site investigation comprising nine boreholes and tail pits carried out. This showed a) downstream shoulder described as clayey sand and sandstone with occasional peat. b) Core has sandy gravel matrix c) One borehole in upstream shoulder (BH1) – more clayey
1999	Tube-a manchete grouting of core in immediate vicinity of culvert (Ch 135- 155). Grouting records – many holes with > 40gal/port;
	Significant settlements have occurred, both due to the lowering of the reservoir and subsequently; although loss of the settlement pins has meant that some settlements have had to be inferred from the level of the top of the wave wall. It is inferred that a) the central section (Ch 120-170) settled 90 to 130mm from Oct 1997 to Oct 2000 i.e. the time the reservoir was drawn down for repairs b) from December 2000 to October 2001 there was up to 7mm settlement, with slightly less over the grouted area

Debatable technical issues are

a) why the reservoir didn't fail; the rate of erosion must have been modest

b) the mechanism of internal erosion; the owner's interpretation from the boreholes and grout takes is that suffusion occurred in the core

c) the mechanisms of settlement; candidates include that the settlement is long term where valley deep (and then slopes rapidly up to relatively limited height flank embankments); or that it follows the reservoir lowering

Case History D (102b)

This is a dam retaining a non-impounding reservoir, built in 1800's and about 1km long. No details are available of its construction. It experienced an incident of concentrated leakage as follows

<2001	No documentary evidence of previous leaks. Possibly slip near overflow
1999	Top water level raised about 50mm by insertion of grille over the bellmouth spillway, due to a steel angle forming the perimeter of the grille
2/11/01	A hole about 1.2m diameter and 0.9m deep was found at 1430 hours on Friday on the downstream face, about 0.9m below top water level, when the reservoir was 50mm above top water level. Dam height at this location was 8 to 10m high, with a downstream slope of 2.5H:1V. Water could be heard trickling close to the bottom of the sinkhole.
	It was controlled by opening the 12inch bottom outlet; this caused some flooding as garages had been built over the outlet ditch. By 1100 on the Saturday the reservoir had been lowered 200mm, by which time there was no sign or sound of leakage. By 6th Dec the reservoir level had been lowered to 2.4m below TWL
To 7/12	Dynamic probes were carried out on a 1m grid over a 5m square zone; followed by a benched trial pit (maximum depth 4.4m). This revealed a) 100 to 200mm of topsoil, over 700mm of "medium to firm" clay, over a layer of "vegetable soil" up to 800mm in thickness b) a lens of red sand about 1m long at the top of the vegetable soil c) "soft clay with firm clay containing gravel" at depth It was concluded that the problem was caused by seepage (and internal erosion) along a layer of topsoil left in when the dam had been raised in the past.
12, 13 Dec	Remedial works comprised • 4m long sheetpiles just upstream of the trial pit, (extending in plan 1m either side of the trial pit; 4.8m total length); together with • a 150mm dia drain pipe wrapped in geotextile from a gravel sump at the lowest point of the pit to the downstream face. The sheet piles toe into firmer clay encountered in the base of the pit – pushed in to 1.2m from final set; driven last 0.5m
	The drain from the trial pit had the occasional drip, but no flow
	The dam has since been discontinued and demolished, for use as fill in stabilising the other two dams in the group of three non-impounding reservoirs. The embankment fill was found to be too wet in an as-dug condition for use as fill, and lime stabilisation was necessary to bring it to an acceptable state.

Technical issues relating to early detection of internal erosion

a) it appeared to be the poor quality of the historic dam raising works that caused the leakage – a singularity that would not be expected from visual observation.
b) The only evidence of internal erosion was the sinkhole –there must have been a permeable foundation (which does not filter fines) for water flows not to emerge at the surface (there is anecdotal evidence for a toe drain)
c) uncertainties remain over the lateral extent of the vegetative layer, and whether leakage (and erosion) was occurring elsewhere. This was one of the reasons the reservoir was later discontinued

Case History E

This is a 6m high dam retaining a non-impounding reservoir. It experienced a concentrated leak and erosion as follows.

History	a) The embankment in which the leakage incident occurred was originally designed to retain water from No 2 reservoir, later had a further reservoir impounded against its downstream toe (Reservoir No 3), with Reservoir No 2 then subsequently being decommissioned and breach cut in it. Consequently water is now retained in No 3 reservoir, on the opposite side to that in the originally construction. b) Trees have become established on the reservoir floor (which was brick lined, over puddle clay) c) Available information is inconclusive as to the construction of the embankment. Some evidence suggests that it has a central clay core, whilst other suggests that the clay underlying the reservoir floor continued up the upstream face as the watertight cut-off.
1994	Two concentrated leak from Reservoir No 3; reservoir lowered. One was in the bank comprising this case history; the other, worse, concentrated leak was in the opposite corner.
2002	Leak in opposite corner repaired by repuddling top 2m of core; reservoir refilled; leak in bank comprising this case history restarted
June 02	While installing a electric fence within the old No 2 reservoir, at the toe of the embankment, to keep the public out of the No 3 reservoir area the operator fell up to his armpits into a hole which appeared (RWL was then 700mm down). The reservoir was drawn down to 2m below TWL and a deep 225mm dia toe drain was installed inside the fence. However, no significant flows were observed from this toe drain, even when the reservoir was gradually refilled
2/9/03	Ground temperature profiles were measured, partly to identify the source of the concentrated leakage and also to identify if there was any deep seepage which would explain the sinkhole. The reservoir was 0.29m below TWL (freeboard 0.76m). 18 probes were installed to a depth of 10m; generally at 10m centres but with extra probes at 5m centres adjacent to the concentrated leak. Conditions were not ideal, as the reservoir water at 17^{o}C was not significantly different from that of the embankment, such that the maximum temperature difference between zones of seepage and the "unpercolated section" was only ±1^{o}C. However it was concluded that there was a) top level leakage near the historic concentred leakage b) two small anomalies at 7m depth at chainage 70 and 120m to the west of 'a'; but no major deep leak
	Remedial works are to be decided, one option is a permanent lowering (partly to obtain the required freeboard against wave action)

Technical issues relating to early detection of internal erosion

a) preference for temperature sensing to be done at the peak of winter/ summer when maximum temperature difference between the reservoir and embankment reinforced; however even with only a small temperature difference the technique seems to have identified leakage locations (although in retrospect the profiling might have been better delayed to say December when the reservoir was cooler?)

b) the cause of the "sinkhole" at the toe is thought to be due to waterlogging of natural ground below the reservoir floor (pocket within what is generally rock) after the brick/ puddle clay had been punctured by a fence post installed at some time in the past;

c) temperature sensing gave comfort that major foundation seepage was not occurring i.e. that the associated potential failure mode was not a threat

Case History F

This is a 14m high dam, built about 1800. The dam has a long established leakage history, as follows

	Dam constructed of "peaty soil with boulders"
	Long history of leakage, with 4 V notch weirs measuring flows at various locations. Leakage generally restarts when reservoir refills in winter, but often ceases after a few weeks (ascribed to the peat swelling).
1980's	Leakage inferred by Prof. Rowe as occurring in a buried glacial valley forming the foundation; advised against grouting on basis that this may cause the phreatic surface to rise into the body of the embankment.
	Various site investigations
1994	Reservoir emptied for construction of new valve tower, crest wall and spillway (latter on insitu right abutment soils)
	On refilling water seen running into the pitching just upstream of the spillway, and emerging in the downstream toe. Grouted
April 2001	Re-emergence of concentrated leak into ditch along base of right abutment (and 60mm head over V notch No 1) led to decision to carry out temperature profile along dam. There was no sign of suspended fines, and the leak dried out when the reservoir was lowered by 0.48m. However, when the reservoir started refilling V notch No 3 started flowing.
12/7/01	21 temperature soundings up to 16m depth; 0.5m from downstream edge of crest (designed to penetrate 2m below original ground level; into glacial till foundation) RWL 1.3m below crest. Soundings continued in dogleg for 20m down side of spillway, 3m from wall (6m deep, as could not get across front of spillway). The reservoir temperature was 16.8^{o}C at the surface, falling gradually to 16.5^{o}C at 5m depth, and then falling more rapidly to 13^{o}C at 7m depth (no measurements below this depth). Embankment temperature fell from 17^{o}C at crest to 9^{o}C at 4m depth and then varies between 8 and 10^{o}C to 16m depth. The profiles showed two areas of hotter ground (16-17^{o}C) indicating seepage, a) along the spillway wall b) at 13m depth along the fill/abutment interface
	Remedial works to seepage along the spillway interface comprised two lines of grouting in front of the spillway, with a clay blanket still to be added. There will be no treatment of the deep seepage path.

Technical issues relating to early detection of internal erosion

a) leakage appearing on the embankment face was identified by the temperature profile as being along the interface of the spillway and embankment; inferred as being due to spillway construction having "disturbed" the natural soils

b) identification of the deep seepage was consistent with existing interpretations of the seepage regime

Case History G (102a)

This is a 12m high embankment dam with 7.3m wide crest, and upstream and downstream slopes of 3H:1V and 2H:1V respectively. The foundation is a massive blocky sandstone. It comprises one of two embankments retaining an impounding reservoir. The embankment experienced a concentrated leakage with associated significant erosion of material from within the body of the dam in the vicinity of the drawoff culvert as follows

History	No as built drawings available. The available drawings indicate a) a straight culvert, whereas the as built is curved. It is conjectured that this may have been because during construction the culvert was relocated from the bottom of the valley onto the left abutment, because of swampy in the valley bottom, thus providing a rock foundation for the culvert and allowing the river to be diverted through the culvert whilst the soft material in the valley bottom was dug out. b) A puddle clay surround to the culvert, for 15m downstream of the vertical core, plus for 45 feet upstream of the core (although part of the upstream section is the draw off tower, itself surrounded by puddle)
9/1/01	At 1200 the Reservoir keeper noticed a stream of brown water coming from the culvert. This came from a weephole on the left hand side of the culvert, about 4m downstream of the downstream side of the vertical puddle clay core. An inspection at 1515 showed large quantities of sand and gravel in the tunnel. It was decided to plug the weephole by shoring sheets of timber in front of it; completed by 1930hrs. The scour valves were then opened and the reservoir ceased overflowing by 1000 the next morning NB a) 2 hours after first detected the leak had self healed, such that there was no brown coloration in the stream b) the stream downstream backs up into the culvert when the spillway is overflowing; which was the situation when the leak occurred)
	The reservoir was lowered by the intermittent use of the 600mm scour valves. (the reservoir had been lowered 7m by Friday 18/01) • 10/1: 1400 The temporary plug had been washed away, but the leak had reduced to a trickle • 11/1: 1000 Examined leak – when a small amount of material in the weephole was dislodged the flow became a torrent carrying sand and gravel. The contractor was asked to construct a more permanent plug with acrow props etc, in place by 1330. • Leak stopped when the reservoir had been lowered by 5.5m
	Dynamic probing – revealed a) culvert founded on shelf cut into rock forming left abutment. b) The fill above the culvert, in the upstream shoulder, included brick rubble
	Remedial works comprised a) 3 rows of TAM grouting over the culvert and adjacent core, the outer two first to tighten, then the central row b) 2 rows of grouting from within the culvert, one vertical and one inclined downstream
	The grouting revealed a) high annulus takes at the foundation interface, when grouting in the TAM pipes b) no obvious high takes around culvert c) one connection into the “leak” weephole; from a grout hole on the upstream row (5.5m depth), approx 10m to the right of the drawoff culvert (i.e. the connection path was parallel to the axis of dam, across the culvert) d) the main grout takes were in fractured rock; with smaller takes than expected in the body of the embankment
	Comments on the various “leaks” are

	i) the “dirty leak” was in the culvert wall opposite a longstanding leak, which showed only a slight increase in flow and no signs of fines ii) none of the other existing (or new) leaks showed any visible signs of fines being eroded iii) “an upwelling seepage” also occurred along the embankment toe from the culvert (this may have been long standing; only noted when vegetation cleared?) iv) there are many weeps from the wall forming an edge between the ditch along the toe of the embankment, and the downstream face of the embankment v) the rock foundation is fairly permeable; although drawings show a clay core this is only of modest depth (piezometers show a 6m head drop across the core, but only 2m head drop across the foundation, suggesting the cut-off is ineffective) vi) the leaks into the culvert and lower spillway appear to be linked to surface flows in the spillway (which is an unlined rock channel on the left abutment, above the culvert) – one leak increased in flow by 40l/min when the spillway started overflowing – there may be future separate works to try to isolate seepage into the culvert from surface flows in the spillway vii) some of the leaks respond to rainfall viii) the culvert is generally wetter now than prior to the incident

Technical issues relating to early detection of internal erosion

a) The significant sand and gravel in the eroded material suggest that shoulder/ foundation (and core?) material was being eroded, such that failure would have occurred fairly soon if the weephole had not been plugged and the reservoir lowered

b) The complex pattern of leaks (most having no signs of eroded material) and response to reservoir and rainfall is noted i.e. there is more than one mechanism causing leaks

c) Real time monitoring of leakage (and turbidity) is impractical because the culvert and dam toe are drowned out by stream flows when the spillway is spilling

d) The incident is believed to have been within the body of the embankment. This is based on the connection from the grout hole to the dirty weephole in the culvert. I.e. alternative mechanisms of erosion along the foundation interface, or along the culvert, or related to the rock step are discounted

e) There is the debatable issue of whether it would be better to block all the weepholes within the culvert, or whether this might encourage leakage (and erosion) along the outside of culvert

APPENDIX E : EXPERT ELICITATION

E.1 Introduction

Before describing the Cooke et al technique, a brief mention is made of other variations from this. Other references are

- Meyer MA, Booker JM, 1991 (Los Alamos Nat. Lab., New Mexico for US Nuclear Regulatory Commission.
- Quigley et al (2000) for aircraft industry
- O'Hagan, 1998 (UK Statistician; Nottingham, then Sheffield University; used consensus approach on Sellafield)
- Roberd

Meyer and Booker describe expert elicitation as

"Despite the diversity in the elicitation processes, there are only three basic elicitation situations and a general sequence of steps. Expert judgement can be elicited through the following:

- *Individual interviews* in which an interviewer or knowledge engineer interviews the expert in a private, usually face-to-face, environment. This situation allows an interviewer to obtain in-depth data from the expert, such as how to solve a proposed problem, without having him or her distracted or influenced by other experts.

  The individual interview is also called the *staticized* or *nominal-group* situation when the experts' estimates are mathematically combined to form one *group* answer.

- *Interactive groups* in which the experts and a session moderator meet in a face-to-face situation to give and discuss their data. The participants' interactions with one another can be structured to any degree: (1) a totally unstructured group resembles a typical meeting, while (2) a highly structured group is carefully choreographed as to when the experts present their views and when there is open discussion; such procedures help prevent some of the negative effects of interaction

- *Delphi situations* in which the experts, in isolation from one another, give their judgements to a moderator. The moderator makes the judgements anonymous, redistributes them to the experts, and allows them to revise their previous judgments. These iterations can be continued until consensus, if it is desired, is achieved. Rand Corporation developed this elicitation situation to counter some of the biasing effects of interaction, such as when a dominant expert causes the other experts to agree to a judgment that they do not hold.

The general sequence of steps in the elicitation process follows:

1. Selecting the question areas and particular questions
2. Refining the questions
3. Selecting and motivating the experts
4. Selecting the components (building blocks) of elicitation
5. Designing and tailoring the components of elicitation to fit the application
6. Practising the elicitation and training the in-house personnel
7. Eliciting and documenting expert judgments (answers and/or ancillary information)."

E.2 Expert judgment method

The methodology for expert judgment has been presented in Cooke (1991) and applied in many risk and reliability studies. See Goossens et al (1998) for a recent overview. This section briefly describes the expert judgment method, and is based largely on Frijters et al (1999), and Cooke and Goossens (2000a,b).

The goal of applying structured expert judgment is to enhance rational consensus. Rational consensus is distinguished from ‘political consensus’ in that it does not appeal to a “one-man-one-vote” method for combining the views of several experts. Instead, views are combined via weighted averaging, where the weights are based on performance measures, and satisfy a proper scoring rule constraint (Cooke 1991). This model for combining expert judgments bears the name “classical model” because of a strong analogy with classical hypothesis testing. We restrict discussion to the case where experts assess their uncertainty for quantities taking values in a continuous range. There are two measures of performance, calibration and information. These are presented briefly below, for more detail see Cooke (1991).

Calibration

The term “calibration” was introduced by psychologists (Kahneman et al 1982) to denote a correspondence between subjective probabilities and observed relative frequencies. This idea has fostered an extensive literature and can be implemented in several ways. In the version considered here, the classical model treats an expert as a classical statistical hypothesis, and measures calibration as the degree to which this hypothesis is supported by observe data, in the sense of a simple significance test.

More precisely, an expert states n fixed quantiles for his/her subjective distribution for each of several uncertain quantities taking values in a continuous range. There are n+1 ‘inter-quantile intervals’ into which the realizations (actual values) may fall. Let

$$p = (p1, \ldots pn+1)$$
(1)

denote the theoretical probability vector associated with these intervals. Thus, if the expert assesses the 5%, 25%, 50%, 75% and 95% quantiles for the uncertain quantities, then n = 5 and p = (5%, 20%, 25%, 25%, 20%, 5%). The expert believes there is a 20% probability that the realization falls between his/her 5% and 25% quantiles, etc.

In an expert judgment study, experts are asked to assess their uncertainty for variables for which the realizations are known post hoc. These variables are chosen to resemble the quantities of interest, and/or to draw on the sort of expertise which is required for the assessment of the variables of interest. They are called “calibration” or “seed” variables.

Suppose we have such quantile assessments for N seed variables. Let

$$s = (s1, \ldots sn+1)$$
(2)

denote the empirical probability vector of relative frequencies with which the realizations fall in the inter quantile intervals. Thus s2 = (#realizations strictly above the 5% quantile and less than or equal to the 25% quantile)/N, etc.

Under the hypothesis that the realizations may be regarded as independent samples from a multinomial distribution with probability vector p, the quantity[1]

$$2NI(s,p) = 2N\sum i=1..N\ siln(si/pi)$$
(3)

is asymptotically Chi-square distributed with n degrees of freedom and large values are significant. Thus, if χn is the cumulative distribution function for a Chi-square variable with n degrees of freedom, then

$$CAL = 1 - \chi n(2NI(s,p)) \qquad (4)$$

is the upper tail probability, and is asymptotically equal to the probability of seeing a disagreement no larger than I(s,p) on N realizations, under the hypothesis that the realizations are drawn independently from p.

We take CAL as a measure of the expert's calibration. Low values (near zero) correspond to poor calibration. This arises when the difference between s and p cannot plausibly be the result of mere statistical fluctuation. For example, if N = 10, and we find that 8 of the realizations fall below their respective 5% quantile or above their respective 95% quantile, then we could not plausibly believe that the probability for such events was really 5%, as the expert maintains. This would correspond to an expert giving 'overconfident' assessments. Similarly, if 8 of the 10 realizations fell below their 50% quantiles, then this would indicate a 'median bias. In both cases, the value of CAL would be low. High values of CAL indicate good calibration.

It is well to emphasize that we are not testing or rejecting hypotheses here. Rather, we are using the standard goodness-of-fit scores to measure an expert's calibration.

Information

Loosely, information measures the degree to which a distribution is concentrated. This loose notion may be operationalized in many ways. For a discussion of the pro's and con's of various measures, see Cooke (1991). We shall measure information as Shannon's relative information with respect to a user-selected background measure. The background measure will be taken as the uniform measure over a finite 'intrinsic range'. For a given uncertain quantity and a given set of expert assessments, the intrinsic range is defined as the smallest interval containing all the experts' quantiles and the realization, if available, augmented above and below by K%. The overshoot term K is chosen by default to be 10, and sensitivity to the choice of K must always be checked.

To implement this measure, we must associate a probability density with each expert's assessment for each uncertain quantity. When the experts have given their assessments in the form of quantiles, as above, we select that density which has minimal Shannon information with respect to the background measure and which complies with the expert's quantile assessments. When the uniform background measure is used, the minimum information density is constant between the assessed quantiles, and the mass between quantiles i-1 and i is just pi. If fk,j denotes the density for expert k and uncertain quantity j, then Shannon's relative information with respect to the uniform measure on the intrinsic range Ij is:

$$I(f_{k,j}, U_j) = \int_{u \in I_j} f_{k,j}(u) \ln(f_{k,j}(u))du + \ln(|I_j|) \qquad (5)$$

---

[1] I(s,p) is called the relative Shannon information of s with respect to p. For all s,p with $p_i > 0$, i = 1,…N, we have I(s,p) ≥ 0 and I(s,p) = 0 if and only if s=p (see Kullback 1959).

where |Ij| is the length of Ij. For each expert, an information score for all variables is obtained by summing the information scores for each variable. This corresponds to the information in the expert’s joint distribution relative to the product of the background measures under the assumption that the expert’s distributions are independent. Roughly speaking, with the uniform background measure, more informative distributions are gotten by choosing quantiles which are closer together whereas less informative distributions result when the quantiles are farther apart.

The calibration measure CAL is a ”fast" function. With, say, 10 realizations we may typically see differences of several orders of magnitude in a set of, say 10 experts. Information on the other hand is a “slow” function. Differences typically lie within a factor 3. In the performance based combination schemes discussed below, this feature means that calibration dominates strongly over information. Information serves to modulate between more or less equally well-calibrated experts. The use of the calibration score in forming performance-based combinations is a distinctive feature of the classical model and implements the principle of empirical control discussed above.

Combination

Experts give their uncertainty assessments on query variables in the form of, say, 5%, 25%, 50%, 75% and 95% quantiles. An important step is the combination of all experts‘ assessments into one combined uncertainty assessment on each query variable. The three combination schemes considered here are examples of "linear pooling"; that is, the combined distributions are weighted sums of the individual experts' distributions, with non-negative weights adding to one. Different combination schemes are distinguished by the method according to which the weights are assigned to densities. These schemes are designated "decision makers". Three decision makers are described briefly below.

Equal weight decision maker
The equal weight decision maker results by assigning equal weight to each density. If E experts have assessed a given set of variables, the weights for each density are 1/E; hence for variable i in this set the decision maker's density is given by:

$$f_{eddm,i} = \left(\frac{1}{E}\right)\sum_{j=1\cdots E} f_{j,i} \qquad (6)$$

where $f_{j,i}$ is the density associated with expert j's assessment for variable i.

Global weight decision maker
The global weight decision maker uses performance based weights which are defined, per expert, by the product of expert's calibration score and his(her) overall information score on seed variables, and by an optimization routine described below (see, Cooke 1991 for details). For expert j, the same weight is used for all variables assessed. Hence, for variable i the global weight decision maker's density is:

$$f_{gwdm,i} = \frac{\sum_{j=1\cdots E} w_j f_{j,i}}{\sum_{j=1\cdots E} w_j} \qquad (7)$$

These weights satisfy a "proper scoring rule" constraint. That is, under suitable assumptions, an expert achieves his (her) maximal expected weight, in the long run, by and only by stating quantiles which correspond to his(her) true beliefs (see Cooke 1991).

Item weight decision maker
As with global weights, item weights are performance based weights which satisfy a proper scoring rule constraint, and are based on calibration and informativeness, with an optimization routine described below. Whereas global weights use an overall measure of informativeness, item weights are determined per expert and per variable in a way which is sensitive to the expert's informativeness for each variable. This enables an expert to increase or decrease his(her) weight for each variable by choosing a more or less informative distribution for that variable. For the item weight decision maker, the weights depend on the expert and on the item. Hence, the item weight decision maker's density for variable i is:

$$f_{iwdm,i} = \frac{\sum_{j=1\cdots E} w_{j,i} f_{j,i}}{\sum_{j=1\cdots E} w_{j,i}} \qquad (8)$$

Optimization

The proper scoring rule (Cooke 1991) constraint entails that an expert should be unweighted if his/her calibration score falls below a certain minimum, $\alpha > 0$. The value of α is determined by optimization. That is, for each possible value of α a certain group of experts will be unweighted, namely those whose calibration score is less than α. The weights of the remaining experts will be normalized to sum to unity. For each value of α we thus define a decision maker dmα computed as a weighted linear combination of the experts whose calibration score exceeds α. dmα is scored with respect to calibration and information. The weight which this dmα would receive if he were added as a “virtual expert” is called the "virtual weight" of dmα. The value of α for which the virtual weight of dmα is greatest is chosen as the cut-off value for determining the unweighted expert.

Validation

When seed variables are available, we can use these variables to score and compare different possible combinations of the experts’ distributions, or as we shall say, different decision makers. In particular, we can measure the performance of the global and item weight decision makers with respect to calibration and information, and compare this to the equal weight decision maker, and to the experts themselves.

Implementation

The Cooke ‘Classical’ procedure for the elicitation of expert opinion, described above, was originally implemented in an MS DOS computer program EXCALIBR, developed with support from the EU. More recently, the code has been superseded by a commercial package compiled for the Windows environment.

References

Cooke, R. (1991) Experts in Uncertainty, Oxford University Press

Cooke, R.M. and Goossens, L.H.J. (2000 a) “Procedures guide for structured expert judgment in accident consequence modelling” Radiation Protection Dosimetry vol. 90 No. 3, pp 303-309.

Cooke R.M. and Goossens, L.H.J (2000 b) Procedures Guide for Structured Expert Judgment European Commission, Directorate-General for Research, EUR 18820 EN, Luxembourg.

Frijters, M., Cooke, R. Slijkhuis, K. and van Noortwijk, J. (1999) Expertmeningen Onzekerheidsanalyse, kwalitatief en kwantitatief verslag, Ministerie van Verkeer en Waterstaat, Directoraat-Generaal Rijkswaterstaat, Bouwdienst; ONIN 1-990006.

Goossens, L.H.J., Cooke, R.M. and Kraan, B.C.P. (1998) ‘Evaluation of weighting schemes for expert judgment studies’ Proceedings of the 4th International Conference on Probabilistic Safety Assessment and Management Springer, New York, 1937-1942.

Kahneman, D., Slovic, P. and Tversky, A. (eds) (1982) Judgment under Uncertainty, Cambridge University Press.

Kullback, S. (1959) Information Theory and Statistics Wiley, New York.

Meer, J.W. van der, (1997) Golfoploop en golfoverslag bij dijken (wave run up and overtopping of dikes, in Dutch) Delft, Waterloopkundig Laboratorium, H2458/H3051.

Saltelli, A., Chan, K. and Scott, E.M. (2000) Sensitivity Analysis, Wiley, Chichester.

Slijkhuis, K.A.H. (1998) ‘Beschrijvingenbundel’ (in dutch) Ministerie Verkeer en Waterstat, Directoraat-Generaal Rijkswaterstaat, Bouwdienst Rijkswaterstaat, Utrecht.

Slijkhuis, K.A.H., Frijters, M.P.C., Cooke, R.M. and Vrouwenvelder, A.C.W.M. (1998) “Probability of flooding: an uncertainty analysis”, Safety and Reliability (Lyderson, Hansen and Sandtorv - eds), 1419-1425, Balkema, Rotterdam.

E.3 Questions posed to Experts

The questions adopted for the elicitation exercise follow in the form of an Excel table, being grouped as shown in Table E.1.

Questions could be subdivided by

- Dam type (puddle clay, homogenous, rolled clay, zoned)
- Whether or not appurtenant works are present
- Type of internal erosion (suffusion, piping, concentrated leak)
- Location of internal erosion, i.e. through embankment, through foundation or embankment into foundation

We chose to concentrate on the most common form of internal erosion and most common dam type i.e. concentrated leaks through the embankment of puddle clay core and homogenous dams.

Questions that were considered but rejected include

Potential issue to be quantified through expert elicitation	**Reason for rejection**
What minimum velocity of flow in a concentrated leak is necessary to cause erosion?	Cannot easily be measured or verified. Not a useful parameter for surveillance
Effect of contributory factors (Intrinsic condition) on annual probability of failure	Less important than effect of contributory factors on rate of internal erosion
Annual probability of failure of good condition dams	Not a core subject for this research task (and insufficient space to add)
Most common/ vulnerable elevation for hydraulic fracture in body of dam	Obtain from responses to questionnaires
Later chance nodes in event tree (those dealing with migration in shoulders)	Too many options/ questions

E.4 Assessment of technical information provided by Elicitation

The analysis of the output from the elicitation are considered in relation to whether there is any corroboration from the case histories provided to the questionnaire. This comparison is generally made graphically, in the form of figures in the main body of the text (see Table 1.4 of main report)

Table E.1 Questions for elicitation

NAME: 11/11/04

The purpose of this questionnaire is to allow an assessment to be made, for the two most common types of embankment dam in Britain, of the likelihood that internal erosion is occurring, or could occur, and at what rate. The questions are all limited to dams in service (more than 5 years old). For each question, you are asked to supply your best-estimate answer and, because of the uncertainties involved, an indication of the range within which you consider that the true answer should lie. In statistical terms, each lower-bound figure might be presumed to correspond to the 5% confidence level and each upper-bound figure to the 95% confidence level. Example: if you judgement is that the true answer is most likely to be 9 bananas, and you are very confident it does not fall outside the range 5 - 25 bananas, you should enter 5, 9, 25 in the boxes.

		Quantiles for your subjective uncertainty distribution			**Units**	**Remarks (voluntary)**	
		5%	**50%**	**95%**		e.g. what assumptions you made, explanation as to how you arrived at estimate	

Calibration Questions for elicitation

Probability of failure of dams

		5%	**50%**	**95%**	**Units**		
	What was the total number of occurrences over the last ten years somewhere in the whole population of all UK embankment dams under the Reservoirs Act, as reported by dam owners in their response to the recent KBR questionnaire, of the following types of incident						
1	Level 2 Incident - Serious incident involving emergency drawdown or emergency works; where emergency is defined is defined as where the dam is likely to fail in a short period if no action were taken	☐	☐	☐	Total Number over 10 years	For period 1975-2000, based on data in BRE database	(5 x 10-4)
2	Level 3 Incident - Any of the following; a) Incident leading to unplanned site visit by Inspecting Engineer; b) Precautionary drawdown; c) Incident leading to unplanned physical works	☐	☐	☐	Total Number over 10 years	there are 2100 embankment dams	(1.2 x 10-2)
3	Level 4 Incident - Physical works arising out of periodic safety review	☐	☐	☐	Total Number over 10 years		
	ICOLD Bulletin No 109 (published 1997) publishes statistics on failures of fill dams built worldwide. For each of the following subdivisions of dams built in the industrialised countries between 1930 and 1997, what was by 1997 the total number of failures due to piping, expressed as a percentage of the total number of that type of dam built in the given period.						
4	dams between 15 and 30m high, with reservoir less than 100 Mm^3	☐	☐	☐	%		0.20%
	There are 122 moraine-core rockfill (MCR) dams in Norway built between 1965 and the mid 1970's (giving 2830 dam years of operation), seven of which have experienced a total of 23 documented 'leakage' events resulting from internal erosion in the moraine-core materials. The events occurred at a time after construction varying from one to many years. The leakage events were self-healing.					Form 1997 conf. Unfortunately paper does not give detail of time line of events other than "several hours to several days"	
5	What was the mean peak flow from these internal erosion incidents?	☐	☐	☐	litre/sec	80 l/s	80
6	What was the standard deviation on the mean peak flow?	☐	☐	☐	litre/sec		45
	Johansen, Vick and Rikartsen (1997) present the results of a risk analysis for three of these dams, considered to span the range of performance of MCR dams. The risk analyses were carried out individually for each dam, and conducted in workshop format over a four day period with a group of five to seven persons that included technical specialists and owners representatives familiar with dam operation. Please give what you think would have been the estimated range of annual probability of failure from internal erosion, expressed as the expected number of failures of dams in the whole portfolio over 1000 years.						
7	Highest annual probability of failure from internal erosion i.e. number of failures has 95% chance of being less than this	☐	☐	☐	Total Number over 1000 years		5.5 x 10-4
8	Median probability of failure from internal erosion i.e. best estimate of number of failure over 1000 years	☐	☐	☐	Total Number over 1000 years		5.0 x 10-5
9	Lowest annual probability of failure due to internal erosion (least likely to fail). I.e. the number of failures has a 5% chance of being less than this	☐	☐	☐	Total Number over 1000 years		6.0 x 10-6

Rate of progression of internal erosion

10	For the failure of the 60m high Teton dam in the USA in June 1976, what was the time between the first muddy flow being seen and the first whirlpool being seen in the reservoir? (*The dam core was built of wind deposited nonplastic to slightly plastic clayey silts, and founded on moderately to intensely jointed volcanic rocks)*	☐	☐	☐	hours	2.5 hours - Fig 21. of Report into failure of TETON	2.5 hours
11	For the failure of Warmwithins dam in Lancashire in November 1970, what was the time between the first development of progressive erosion to the onset of failure (all as inferred from the chart recorder recording reservoir level) *(The dam is a 10m high puddle clay core dam built in the 1860's, the failure occurring in November 1970 along a new 1.5m diameter tunnel lined with concrete segments installed about 1965)*	☐	☐	☐	hours	12 hours - Article by Don Wickham in dams and Reservoirs	12 hour

MAIN QUESTIONS ON WHICH EXPERT JUDGMENT IS SOUGHT

D ***There is some evidence that ongoing internal erosion is occurring at a slow steady rate at some British dams.***

For the following types of dam and location in the dam, what percentage of the total population of that type of dam have some form of ongoing, steady leakage flow

12	Puddle clay - in body of dam	☐	☐	☐	%
13	Puddle clay - along interface with appurtenant works	☐	☐	☐	%
14	Puddle clay - body of dam into foundation	☐	☐	☐	%
15	Puddle clay - leakage through foundation	☐	☐	☐	%
16	Homogenous - in body of dam	☐	☐	☐	%
17	Homogenous - along interface with appurtenant works	☐	☐	☐	%

		Quantiles for your subjective uncertainty distribution			Units	Remarks (voluntary)
		5%	50%	95%		e.g. what assumptions you made, explanation as to how you arrived at estimate
18	Homogenous -body of dam into foundation				%	
19	Homogenous - foundation				%	
	For the dams with steady leakage flow, what percentage of these dams have associated ongoing (steady) internal erosion?					
20	Puddle clay - in body of dam				%	
21	Puddle clay - along interface with appurtenant works				%	
22	Puddle clay - body of dam into foundation				%	
23	Puddle clay - foundation				%	
24	Homogenous - in body of dam				%	
25	Homogenous - along interface with appurtenant works				%	
26	Homogenous -body of dam into foundation				%	
27	Homogenous - foundation				%	
	For all locations in a particular dam type with ongoing internal erosion, what is the average erosion rate (averaged over the whole year)?					
28	Puddle clay				gram/day	
29	Homogenous				gram/day	
	For all locations in a particular dam type with ongoing internal erosion, what is the average leakage flow rate (averaged over the whole year)? (1.0 litre/ sec = 86 m^3/day)					
30	Puddle clay				m^3/day	
31	Homogenous				m^3/day	
B	***We would also like to quantify the elements of the change from ongoing to progressive internal erosion at these dams. An indicative model is shown on Figure 2.3.***					
	What is the minimum flow rate which would be detected by visual inspection, as seepage out of the downstream face or toe:					
32	when the face is grass which is cut several times a year?				litre/sec	
33	when the face is not maintained e.g. scrubby woodland (not mature woodland)?				litre/sec	
	For the population of all UK embankment dams what is the Dam Critical Flow for internal erosion i.e. the uncontrolled internal erosion flow at which control of the reservoir has been lost and failure is inevitable? Refer to Figure 2.3; this is flow when even if lowering of the reservoir could be commenced immediately, internal erosion has progressed so far that lowering the reservoir would not avert failure					
34	5% value i.e. the dam critical flow is higher in 95% of cases				m^3/s	
35	the median i.e. in 50% of cases				m^3/s	
36	95% value i.e. the dam critical flow is higher in only 5% of cases				m^3/s	
	For the population of all UK puddle clay dams, we would like to establish (if progressive internal erosion commenced at every dam) the range of time from internal erosion being detected at a level of concern sufficient to call an Inspecting Engineer, to the point when this internal erosion would reach a dam critical flow rate if there were no intervention. **What is this time, in hours for:-** *As the initial elicitation gave gaps between responses, such that responses are starting to fragment into 2 or 3 groups it would be helpful if you could include in the Remarks column some explanation of the reason for your values e.g. gut feel, based on knowledge of dam X which was considered to be slow (or typical) etc etc*					
37	the worst (quickest deterioration) 2% of incidents i.e. 98 of incident are slower than this?				hours	
38	the worst (quickest deterioration) 10% of incidents i.e. 90% of incidents are slower than this?				hours	
39	the median time i.e. 50% of incidents are slower than this				hours	
40	the least dangerous (slowest deterioration) 10% of incidents i.e. only 10% of incidents re slower than this?				hours	
41	the least dangerous (slowest deterioration) 2% of incidents i.e. only 2% of incidents are slower than this?				hours	
	For the population of all UK homogenous dams, we would like to establish (if a concentred leak developed at every dam) the range of time from internal erosion being detected at a level of concern sufficient to call an Inspecting Engineer, to the point when this internal erosion would reach a dam critical flow rate if there were no intervention. **What is this time, in hours for** *It would be helpful if in your response you could include some explanation (as the note in italics in front of question 37), PLUS some explanation as to why your answer is different from the population of puddle clay dams*					
42	the worst (quickest deterioration) 2% of incidents i.e. 98 of incident are slower than this?				hours	
43	the worst (quickest deterioration) 10% of incidents i.e. 90% of incidents are slower than this?				hours	
44	the median time i.e. 50% of incidents are slower than this				hours	
45	the least dangerous (slowest deterioration) 10% of incidents i.e. only 10% of incidents re slower than this?				hours	
46	the least dangerous (slowest deterioration) 2% of incidents i.e. only 2% of incidents are slower than this?				hours	

		Quantiles for your subjective uncertainty distribution 5%	 50%	 95%	Units	Remarks (voluntary) e.g. what assumptions you made, explanation as to how you arrived at estimate

A We also wish to quantify the importance of the various contributory factors that may control the rate of progressive (accelerating) internal erosion (Figures 2.1, 2.3).

We set out below the base values of particular characteristics of a puddle clay core dam, and ask for your estimate of how much quicker internal erosion would progress to failure for the specified changes in values of these characteristics, assuming that the fines could wash out through the downstream fill and no intervention. *(The response should be the ratio of the duration of accelerating erosion (Figure 2.3) for the base characteristic to the duration for the changed parameter. Thus if the dam with the changed characteristic would fail quicker, as the duration will be shorter the ratio will be greater than unity)*

		5%	50%	95%	Units	Remarks (voluntary)
	Base value of hydraulic gradient (head/ hydraulic gradient) along a concentrated leak is 1.0. How would the duration to failure change if the hydraulic gradient were					
47	2.5				ratio	
48	5.0				ratio	
	Base value of plasticity of the puddle clay is CH (Clay of high plasticity). How would the duration to failure change if the puddle clay were					
49	CL - Clay of low plasticity				ratio	
50	ML - Silt of low plasticity				ratio	
51	CV - Clay of very high plasticity e.g. London Clay				ratio	
52	SC - clayey sand (fines, i.e. passing 0.0425mm CH)				ratio	
53	GW - well graded clayey gravel (fines, i.e. passing 0.0425mm CH)				ratio	
	Base degree of compaction of the puddle is 98% of maximum dry density (Standard proctor i.e. 2.5kg hammer) (MDD). How would the duration to failure change if compaction were					
54	90% of MDD				ratio	
55	80% of MDD.				ratio	
	Base soil for upstream shoulder is CL (Clay of low plasticity). How would the duration to failure change if the shoulder were					
56	SC - clayey sand (fines, i.e. passing 0.0425mm CH)				ratio	
57	rockfill				ratio	
	Downstream shoulder is CL How would it change if					
72	SC				ratio	
73	Glacail till				ratio	
74	Coarse gravel (London emabenkments)				ratio	

C We would also like to quantify some of the steps in the event tree we have postulated for internal erosion (Figure 2.2)

For the whole population of UK dams, if internal erosion were to occur, what is your assessment of the % split at each of the following chance nodes (the total at the 50% node should equal 100%)

		5%	50%	95%	Units	Remarks (voluntary)
	For puddle clay core dams what % would be due to					
58	concentrated leaks through the body of the dam?				%	
59	concentrated leaks along the interface with an appurtenant works?				%	
60	Suffusion in body of dam				%	
61	Piping in body of dam				%	
62	Foundation				%	
63	Embankment into Foundation				%	
	Similarly for homogenous dams what % would be due to					
64	concentrated leaks through the body of the dam?				%	
65	concentrated leaks along the interface with an appurtenant works?				%	
66	Suffusion in body of dam				%	
67	Piping in body of dam				%	
68	Foundation				%	
69	Embankment into Foundation				%	
	For incidents relating to concentrated leaks at puddle clay core dams; for what % of dams:-					
70	would the fill downstream of the puddle clay act as a filter?				%	
71	would any hole in the puddle core caused by internal erosion along a concentred leak remain open; rather than migrating vertically upwards				%	

E.5 Report on Elicitation by Elicitator

Aspinall & Associates

Elicitation of Experts in support of DEFRA reservoir safety study: second round results

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10th December 2003

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Contents

SECOND ROUND RESULTS FROM ELICITATION OF EXPERTS

Report prepared for Kellogg Brown & Root
by Aspinall & Associates

1 DOCUMENT STATUS

This document provides a preliminary report on the outcome of a second round elicitation of expert opinion in support of a reservoir safety study for DEFRA, that was conducted at the offices of Kellogg Brown & Root (KBR) on 21st July 2003. It supersedes a preliminary version, submitted on 9th October 2003, and closes out a draft version submitted on 24th October 2003.

2 RECORD OF SECOND ELICITATION OF EXPERTS

A second Elicitation of Experts (EoE) was conducted at KBR's offices on 21st July 2003 in connection with a DEFRA sponsored study on the safety of dams in Britain. On this occasion, where previously there had been nine experts, eleven people were involved in the exercise, with Dr W.P. Aspinall again acting as facilitator. The two additional experts, who were not present for the previous exercise on 24th April, were furnished with the same set of seed questions for calibration that had been used for the remainder of the group in the first elicitation, and, upon completion, the group's individual weightings were then updated to produce revised rankings for the whole team. In this report, the identities of individual experts are not revealed - where necessary, each is simply denoted by a unique number, or not identified at all.

The group was assembled to act as an expert panel on issues concerned with the integrity of old embankment dams, and with the problem of devising a model for internal erosion in particular. The two 'new' experts were introduced to the concepts and principles of structured elicitation of opinions, and the whole group was then given a refresher on the procedure used to provide a weighted linear pooling of their views. Emphasis was again placed on getting the experts to express their true scientific and engineering judgements on the uncertainties in the parameters of interest.

The study leader, Mr Alan Brown (KBR), then reviewed the results obtained in the first round elicitation. He highlighted specific questions arising from that EoE which had shown particular noteworthy or undesirable features, such as excessive spread of uncertainty, bimodality or inconsistency with other parameters. This involved showing several of the results graphically and, for these items (and the original nine participants), the second elicitation thus represented an opportunity for the experts to update their opinions in the light of those previous outcomes.

From the results of the first EoE, it had become clear from inspection that for a number of the questions (i.e. Q47 – 57 incl.), which involved responses in the form of a ratio, there had been potential for misinterpreting which way up the quotient should be expressed. Following that experience, the group were reminded of this possible ambiguity and were invited to read again carefully the re-worded questions.

After various other technical matters relating to the internal erosion model problem had been aired and discussed, the group was requested to provide their individual responses to the same sixty technical questions that had been addressed in April, together with a further three questions, posed at the workshop itself. The electronic and paper questionnaire forms for all these questions (a blank form was used for the new questions) had been prepared in advance by KBR, in collaboration with the facilitator. The original question set had benefited from the comments of two independent external specialists (Dr. B.O. Skipp and Mr. D.J. Mallard). On this occasion, the sequence of subsets of questions was changed, however, in order to: a) make sure the most critical or ambiguous issues were dealt with first, and b) to attempt to 'reset' the experts' thinking patterns.

During the working session, while participants were completing their questionnaires, the facilitator noted that some of the group had equipped themselves with their previous response forms. These experts were likely to 'anchor' their opinions to those prior values; others may have perhaps used their memory in the same way, but the two additional experts were clearly coming fresh to the questions.

The facilitator undertook the processing the questionnaire responses, using the EXCALIBR program (Cooke, 1991: *Experts in Uncertainty*), and the results are presented here, for review by KBR.

As usual, a small number of minor inconsistencies or typographical errors were detected in the completed forms, and these were remedied either by consulting the expert concerned, or by direct intervention by the facilitator. For one of the 'new' experts, there were a number of missing entries, some ambiguous answers and some extreme values. This particular expert was given the opportunity to review all his responses, subsequent to the workshop.

In order to keep track of any impact this might have on the outcomes of the elicitation, and for completeness generally, all the sets of results are recorded in an appendix to this report.

3 PERFORMANCE OF THE EXPERTS

As noted above, eleven dam experts took part in the second workshop, comprising two owners' representatives (who are both Supervising Engineers), two academics, and seven consultants' staff (six Panel AR and one Supervising Engineer). The independent facilitator is not an engineer, but has familiarity with safety-critical risk assessment in engineering applications.

Some comments on the performance of the selected experts in the elicitation are in order: for instance, is the 'best' expert the one that the group itself expected? At the first workshop, a simple exercise of mutual self-weighting was undertaken by the nine dam engineers (at that stage, the two academics had not been empanelled), in which every expert 'scored' each of his colleagues on a scale of 1 to 9 for 'expertise', also giving an indication of how familiar he was with the work of that person on a scale of 1 to 3. All the responses were then combined by simple summing and averaging individual ‘expertise’ scores, weighted by the familiarity index, to generate a ranking order. The range of scores attributed in this way was quite narrow, with the top score being only 1.5*x* greater than the lowest, indicating the group perceived itself as quite homogeneous as regards ‘expertise’.

Fig. 1 shows a chart of how the individual experts were ranked, first by the self-weighting scheme, and then by the scores calculated by EXCALIBUR on the basis of performance with the set of known seed questions (the latter with the academics included). There are some significant differences in ranking between the two: most notably, Experts A and C scored less well on the performance-based measure than their colleagues might have anticipated, while Experts H and I did much better.

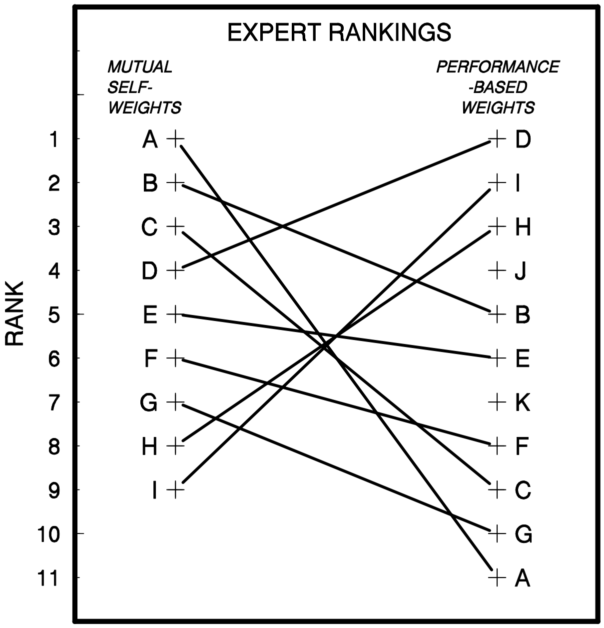


Fig. 1 Ranking of experts by mutual self-weighting (LH column), and on performance, using EXCALIBUR method (RH column)

This is not an uncommon finding when ranking individuals in groups of specialists of any discipline: some experts are well-regarded by their peers but tend to be strongly opinionated when it comes to expressing quantitative judgments, while others, who may be considered indecisive or diffident are, in fact, better estimators of uncertainty. These contrasting traits are manifest in many of the range graphs recorded in Appendix 2, for instance, showing typical diversity of strengths of opinion within such a group. In the present case, where the quantification of model parameter uncertainties is one of the main objectives, it is appropriate that the latter experts gain credit for their ability to judge these things well.

Although the selection of experts came from a range of working backgrounds, no particular pattern of ranking emerges with respect to that factor. This, perhaps, may also serve as a general indication that the experts were being scored by EXCALIBUR on their attributes in relation to judgment of uncertainties in quantification, rather than on any specialism bias.

Further details concerning the relative scoring by individual experts are presented in Fig. 2. For the seed items, which have known values, the relationship between each expert's entropy score (informativeness) and their corresponding calibration score is depicted in Fig. 2a; in general, as with all expert groups, different balances are struck in attempting to achieve 'good' informativeness and 'good' calibration, and not all are successful. For example, Expert K is the most informative of the group, but also one of the least well-calibrated, whereas Expert J scores well on calibration, but mainly as a consequence of his wide confidence limits. With the synthetic decision-maker not optimized (and statistical test power restricted), the pooled combination of the group results in a well-calibrated but very uninformative DM (see Fig. 2a).

Experts D and I have good calibration scores and better-than-average informativeness, and this is manifest in Fig. 2b, where the individual's normalized performance weight (the product of calibration score and entropy score, normalized for the whole group, including the DM) are shown in relation to his or her calibration score. This plot indicates that, despite low informativeness, the DM has an effective performance weight that is better than all, except Experts D and I. Expert J is fourth in ranking, even though the third expert, H, is significantly less well-calibrated.

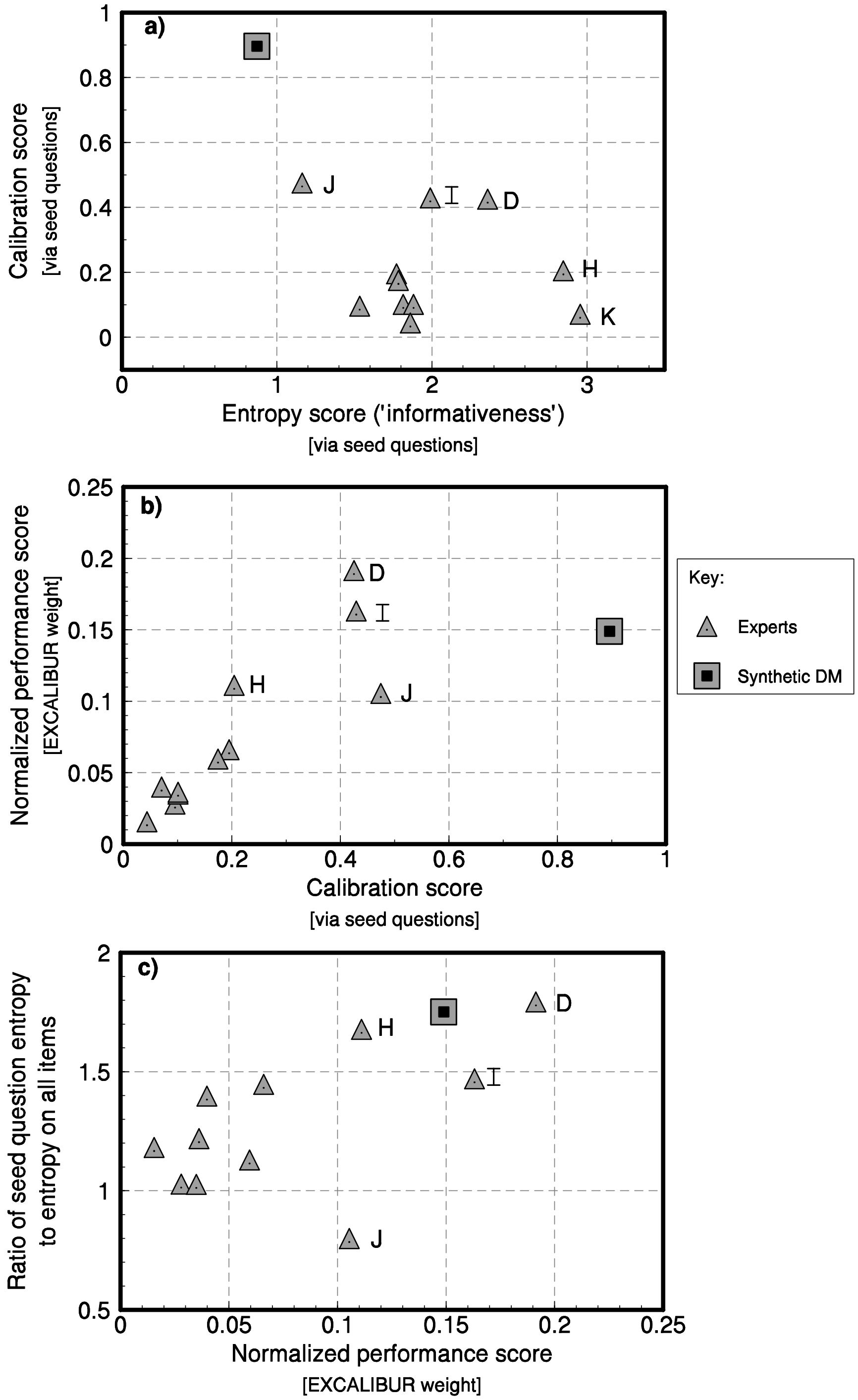


Fig. 2 Charts showing: a) Experts' calibration scores as a function of their information entropy scores; b) Experts' normalised performance scores, in relation to calibration score; and c) the ratio of an Expert's entropy score for seed items relative to his entropy for all questions in the elicitation. See text for a discussion of these charts.

The third panel on this plot, Fig. 2c, indicates the ratios of the experts' information entropy scores for responses to the seed items relative to their responses for all questions in the elicitation, as a function of calibration score. A ratio greater than unity indicates that the expert was more 'certain' about his answers to the seed items than he was about the values to give to the questions of interest for the internal erosion model. Only one person, Expert J, seemed generally more 'confident' about answering the modeling questions than the seed items, although it has to be noted his responses on the former included several examples with significant uncertainty - on average, his tendency was to provide tighter confidence limits on his values for the model, but not invariably so. The others in the group, with ratios close to unity, show no propensity to change their confidence limits from seed items to model questions.

Here again, there is no obvious evidence for the experts' performances in the elicitation exercise to be related to the working background of the individual expert. Using a proprietary data mining package, a further inspection of the complete set of elicitation responses, both seed items and elicitation questions, also failed to evince any sign of systematic patterns of response amongst the assembled specialists. This additional analysis reinforces the conclusion that the group was well harmonized, and satisfactorily uniform as a sample of dam engineering expertise.

With the EXCALIBUR scoring scheme, an individual's performance-based weight is determined by the product of his entropy score (informativeness) with his calibration score, on the seed items only. Informativeness measures in respect of the other questions being elicited, as represented on Fig. 2c, are provided by the program in order to allow further analysis of responses, item-by-item, if required, but are not used in calculating the individual's weight for pooling purposes.

In the present exercise, the power of the statistical test for the 'calibration' performance, which, with each individual's 'informativeness' score, determines his overall weighting, had been lowered in order to reduce the apparent 'granularity' of the scoring results (i.e., deliberately smoothing out, between experts, small scoring differences of doubtful meaningfulness). This decision was made by the facilitator firstly because the set of seed questions devised for the calibration were probably not fully diagnostic for the problem at hand (compared with more focused questions that are possible, say, for weather forecasting) and, second, to ensure a result that represented the desired rational consensus of the whole group. With Cooke's method, it is possible to search for an optimized value of the DM's weight, but this can result in some real experts in the group receiving zero weights; thus, whilst applying this adjustment to the statistical power setting moderates the DM maximization, the overall outcome is one that still remains objective, and based on a fair, coherent, and auditable, treatment of all the experts and their opinions.

Further details of this 'tuning' of the analysis are provided in the next section.

4 OUTCOME OF THE SECOND ELICITATION

The first elicitation questionnaire contained the calibration and informativeness ‘seed’ questions used for scoring each expert in the EoE. With the two additional experts also completing that part of the procedure, new individual scoring weights were computed with EXCALIBR for all members of the extended group in the second elicitation. These new weights were then used for each question in that elicitation, by which means pooled combinations of the individual judgements were formed.

The weighted pooling of the individual experts’ opinions creates, in effect, a synthetic decision-maker (labelled ‘DM’ in the results and graphs that follow). This synthetic decision-maker can be included in the analysis as another, virtual expert, and accorded a calibration weight, as with the others. The total of all experts’ calibration weights were then normalized to unity, producing relative weights for each.

In the calibration part of the elicitation procedure, the statistical power of the Chi-squared test was held at the same level as before (i.e. CP = 0.25); the purpose of selecting this factor is to modulate of the relative ratio of the calibration scores of the highest weighted expert to the lowest (when there are several experts being assessed with multiple seed items, individual calibrations tend to be low, and scores may coincide due to discretization in the internal Chi square table). In other words, the degree to which such scores are resolved and distinguished between and across experts is a modeling constraint, usually decided by the analyst, and for applications where reasonable and apparent equity of treatment of experts may be an important consideration, some adjustment of the power of the hypothesis test may be justified.

With this constraint, the highest normalized weight attributed to an individual in the second EoE was 0.19 (previously 0.22), and the lowest, 0.02 (unchanged). Thus the corresponding ratio of highest–to-lowest is equivalent to a factor of just under 10*x***.**

On this occasion, the synthetic DM is ascribed a relative weight of 0.15 (last time 0.19), the reduction indicating that the addition of the two further experts had had the effect of reducing the coherency of the group as a whole. That said, while the DM is now marginally less well weighted relative to the two highest scoring individuals, the virtual expert is still better than all the rest. This outcome, and the highest/lowest scoring ratio, are not atypical when the statistical power of the calibration test is curtailed to reflect the way available seed questions are limited in terms of their capability to verify the expert judgement method in a quantitative, predictive sense.

The results of this elicitation, item by item, are presented graphically at the end of the report, together with the results obtained from the first EoE and those from a constrained optimization analysis of the group’s responses (next section).

5 CONSTRAINED DECISION-MAKER OPTIMISATION

As noted above, the main results from the elicitation were derived by fixing, pragmatically, the calibration power and significance level parameters, so as to ensure that all experts get a positive, non-zero weight, and that the ratio between the highest and lowest weights are not too extreme. This approach, in which the weights of individuals are factored before pooling the whole group, quite strongly moderates the optimization of the synthetic decision-maker, and hence curtails the weight given to that entity as a virtual expert. One of the strengths of the EXCALIBR method, however, is that it allows a wide variety of pooling and scoring schemes to be explored quantitatively for any individual elicitation exercise.

In the present instance, additional analysis has been conducted for the purpose of optimizing (but not maximizing), in some realistic sense, the synthetic decision-maker's performance so that the harshness of rejection of low-weighted real experts is limited. This is achieved by adjusting the power of the chi-square test and the related significance level setting, which determines the calibration threshold value. There is a wide range of possible combinations of these tests and, in the present case, it was decided that, whatever changes were made, a majority of the group (*i.e.* for no less than six of the experts) must retain non-zero weights.

Supplementary analysis runs were undertaken, therefore, to examine how the elicitation results might change if this stance is adopted. The calibration power and significance level were each increased incrementally to allow the analysis to give more weight to the synthetic expert, until the minimum size of majority, mentioned above, is reached. This point was reached for a calibration power of 0.5, and a chi-squared significance level of 1%. The net effect of this is to raise the normalized relative weight of the synthetic decision-maker to 0.44, from 0.15, with the six surviving real experts having weights ranging from 0.19 down to 0.02 (equivalent to a ratio of 9*x*, as before). The synthetic DM would now have more than twice the weight of the best individual expert, and 22*x* the weight of the lowest, non-zero weighted expert.

The results produced by this alternative pooling configuration are presented on the following graphical plots of the item solutions, and are repeated in the appendix where they can be compared directly with the other results. The effects in going from the updated second elicitation results to the constrained optimized results are not dramatic, although there are notable changes for a few items, and hints of systematic shifts in central value outcomes in several others. Where appropriate, these shifts are commented on individually, in the commentary (Section 6).

The fact that the differences are generally modest is not surprising, however, if it is remembered that the five discounted experts have quite low individual normalized scores, and were not exerting much influence on the joint pooling, anyway. What is significant, however, is the much greater authority that is now given to the synthetic decision-maker: this increased weighting represents a shift towards a more homogeneous collective combination of the views of the six most influential experts, and the synthetic decision-maker now significantly out-performs the best individual expert. On this basis, it could be argued that these results represent a better and more rational consensus, and should be preferred over those from the whole group as a consequence.

Further analysis of the experts' contributions to the synthetic DM is possible by activating EXCALIBR's 'expert robustness' option. This is a facility for re-running the analysis iteratively, dropping one expert at a time, to show what impact his omission has on the DM's calibration score and informativeness. In the present case, a breakdown of the six weighted experts indicates that three of them have detectable influences: two influence (in a positive sense) the DM's calibration score, and another exerts pressure on the DM's informativeness. The other three experts also contribute to characterizing the DM, but to an extent that is less marked and very similar, one to another.

The expert who influences the DM’s informativeness presents an interesting example of expert judgement: his calibration score was fairly good (but not the best), and for ALL items in the questionnaire his informativeness measure is also quite good, but not exceptional. However, he had a particularly effective informativeness score for the seed questions, and this significantly enhances his weight and ranking overall. So, in the robustness trial, dropping this one expert appears to improve the DM's calibration score more than by dropping any of the other experts (including the lowest weighted!), but in the process the DM's informativeness falls significantly, too.

Importantly, what this robustness analysis shows is that the virtual DM is not dominated by any single real expert (as has been found occasionally in other applications).

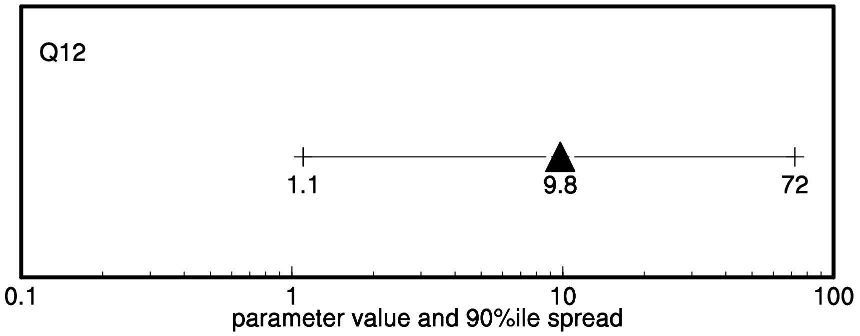
A record of the results of the constrained optimization analysis is provided in the form of simple item-by-item ‘range graph’ plots, included in an appendix to the present report. Those graphs summarise the individual inputs to each item, expert by expert (i.e. each person’s 5%ile, 50%ile and 95%ile values), together with the corresponding results obtained for the synthetic decision-maker (‘DM’). The plots are drawn with the opinions of the five zero-weighted experts segregated from those who actually contribute to the outcomes, to allow inspection for any systematic effects that might have arisen from applying the optimizing selection restrictions.

It is recommended that the synthetic decision-makers outputs, obtained with this constrained optimization, are used for informing the parameterization of the proposed internal erosion model. These values and distributions are presented graphically and numerically in the next section.

6 ELICITATION RESULTS

With the normalised weights of individual experts determined by the calibration seed question responses, and the DM optimized in the manner just described, evaluations were obtained from the second elicitation exercise for the sixty-three technical questions relating to the dam internal erosion model.

The central value and 90% confidence band for the DM’s result on each question are shown graphically in the following charts, with the items identified only by the question number code. The precisions of the values have been rounded to appropriate degrees.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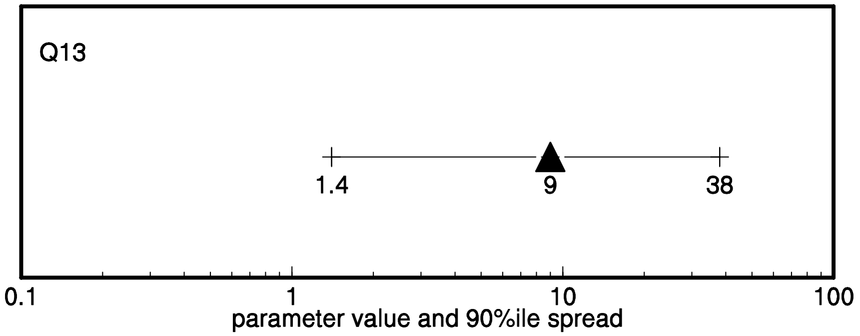
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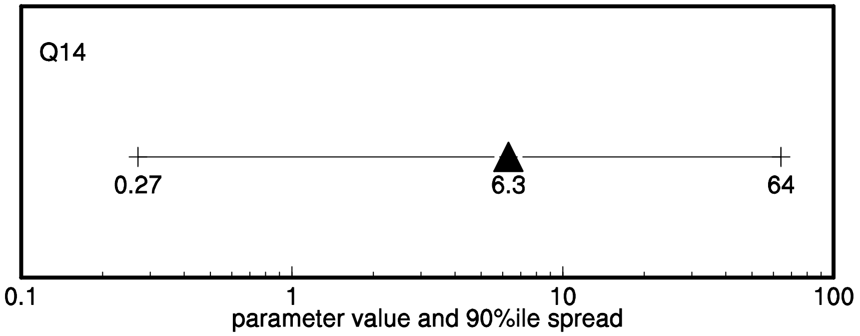
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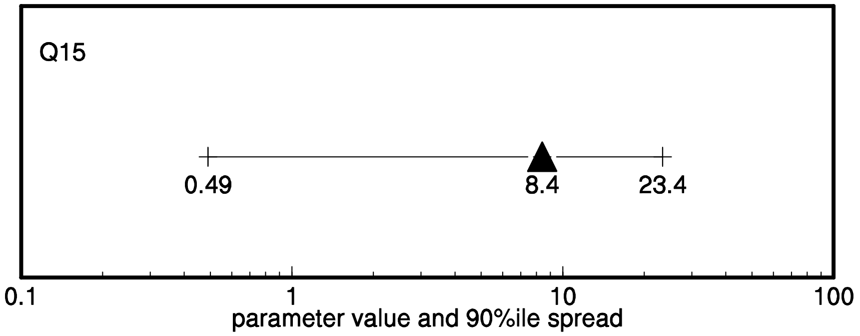
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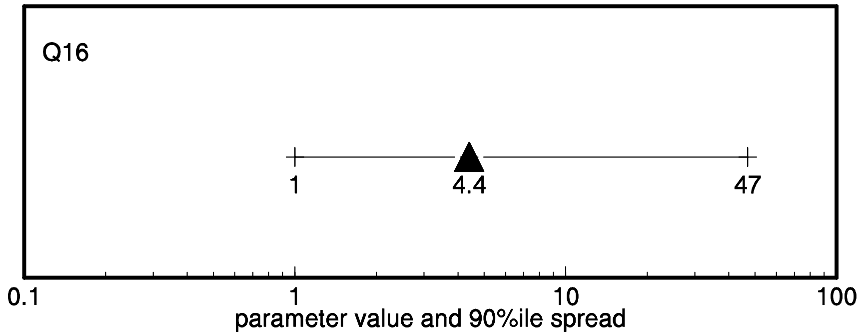
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1
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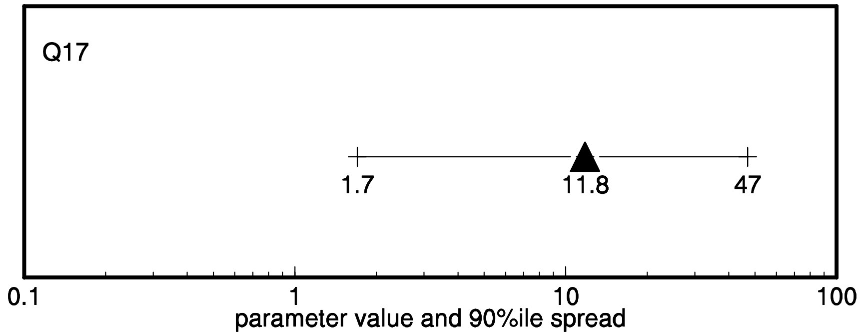
parameter value and 90%ile spread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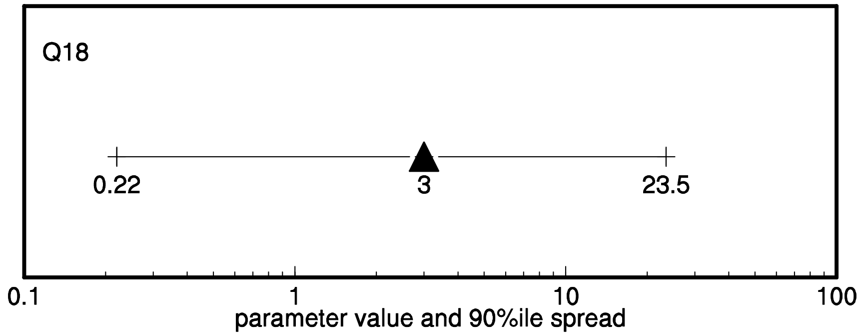
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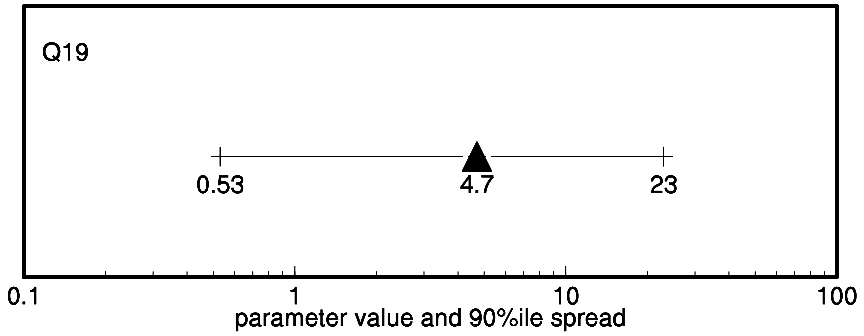
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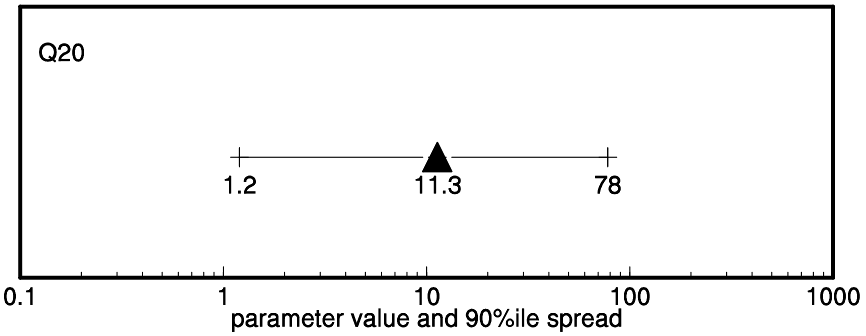
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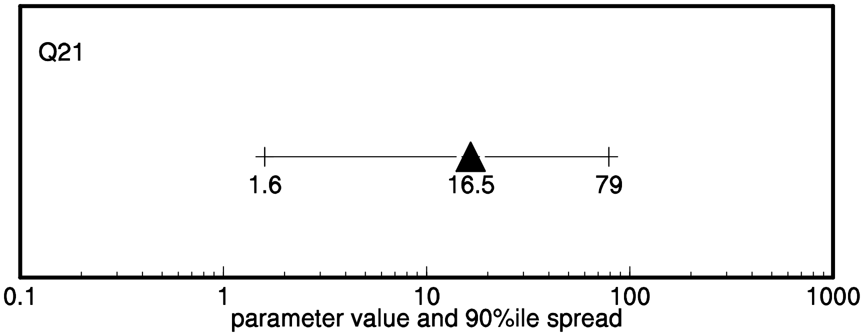
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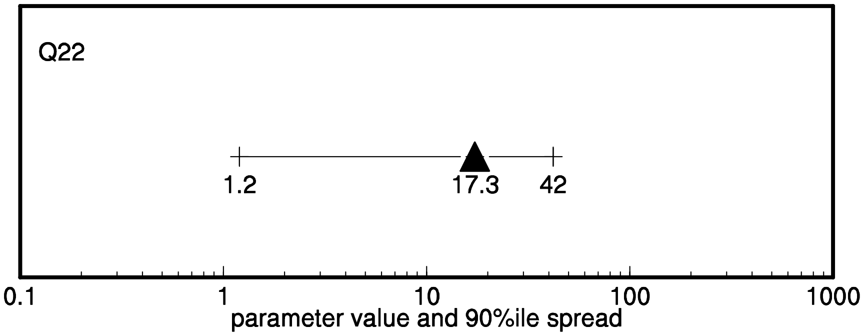
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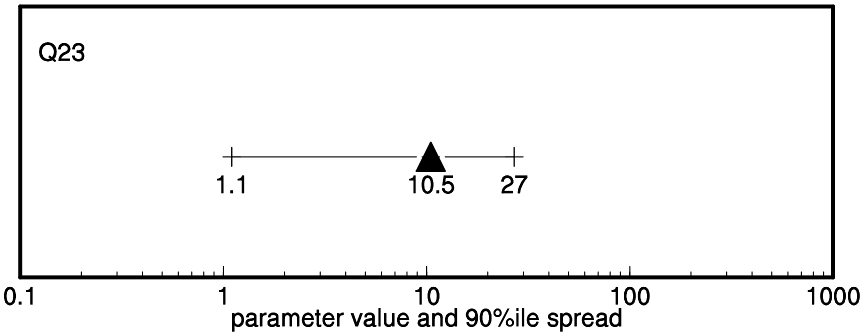
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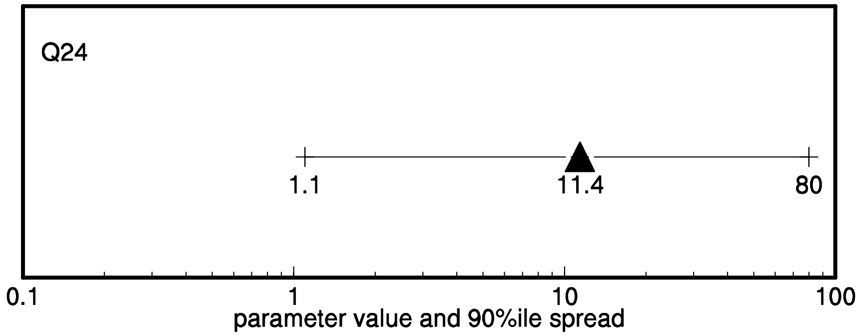
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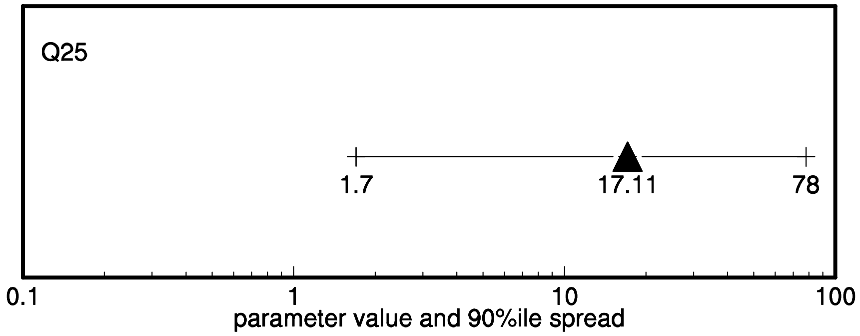
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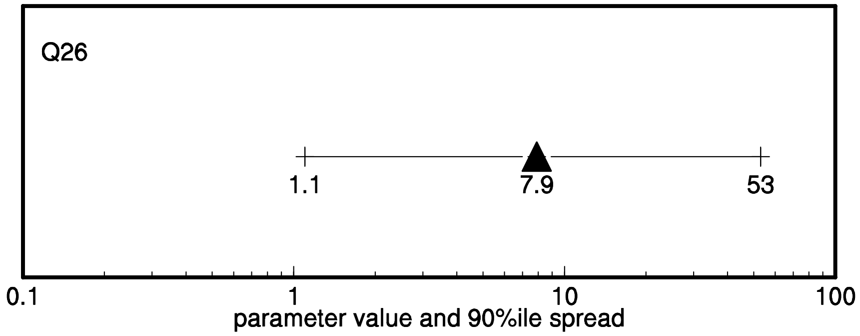
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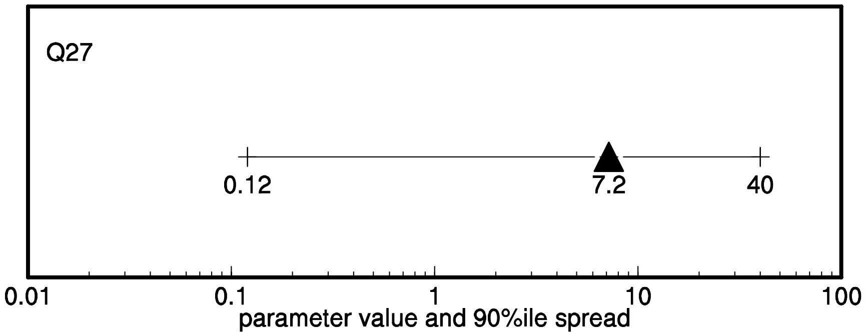
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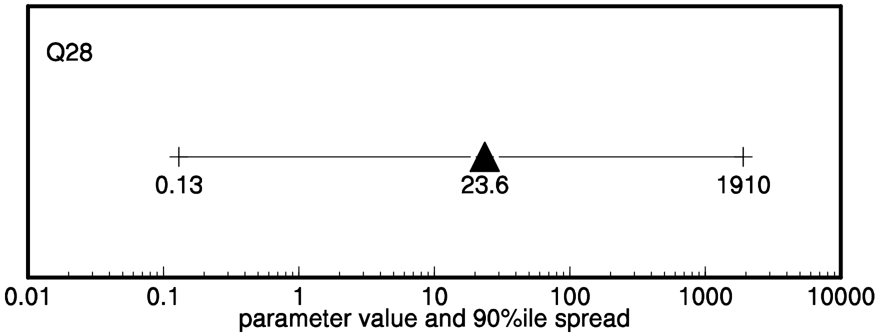
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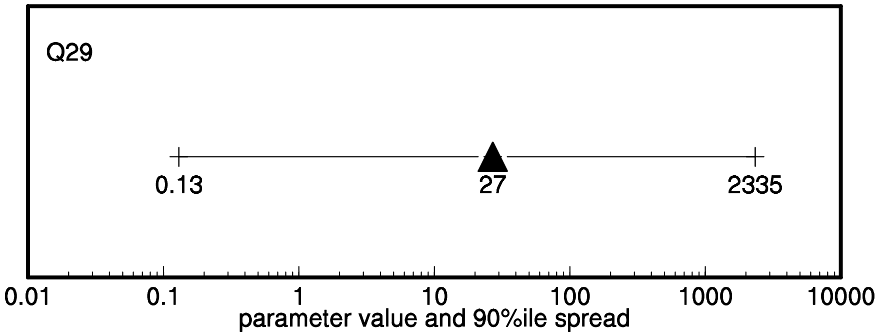
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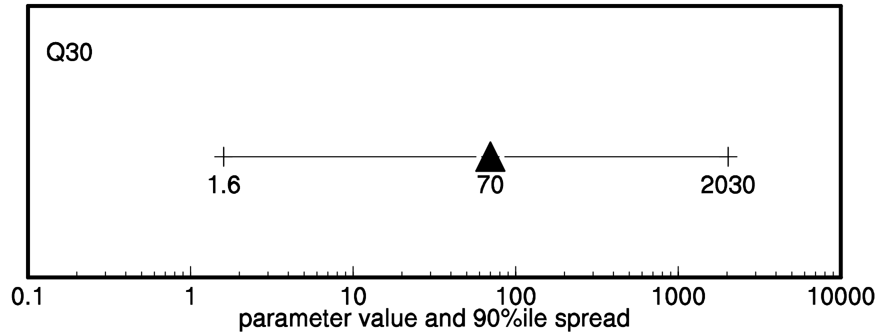
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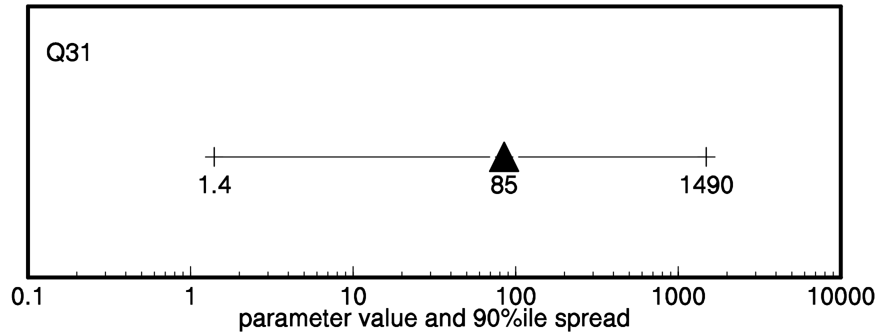
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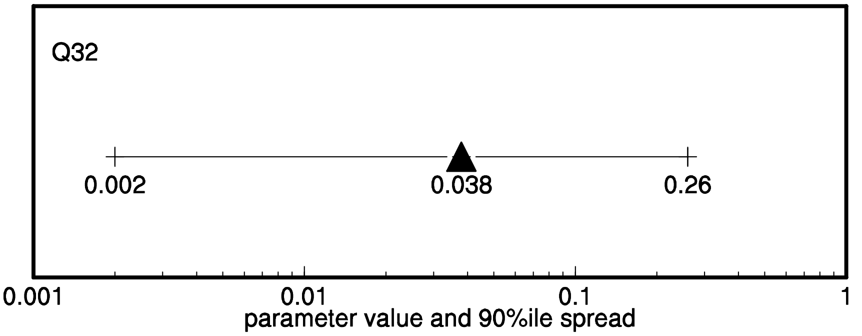
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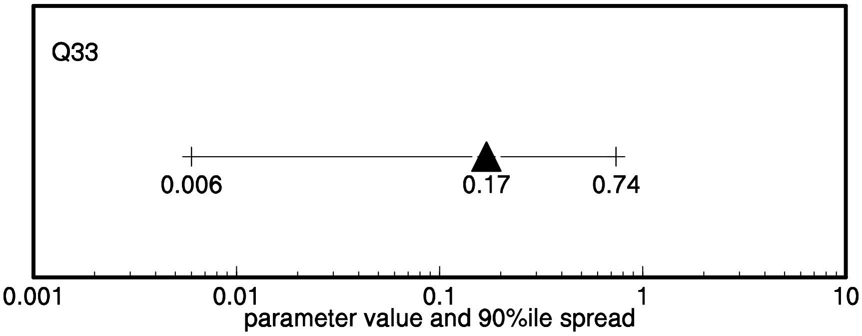
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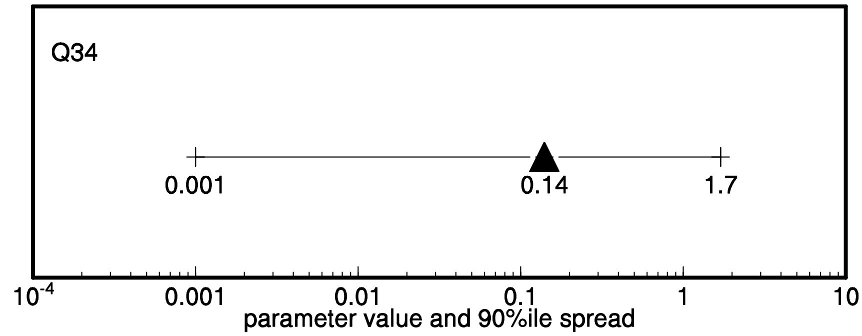
parameter value and 90%ile spread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0.1
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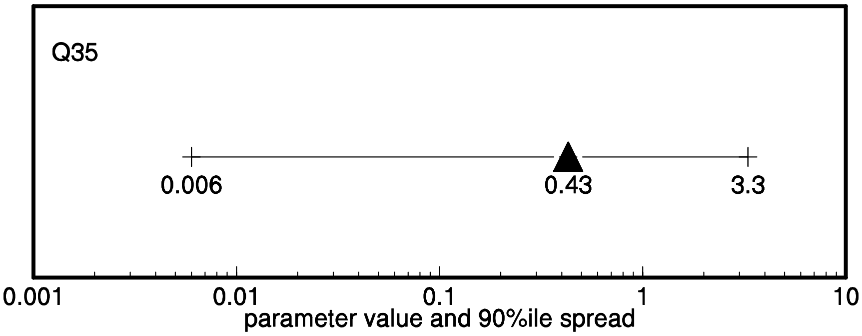
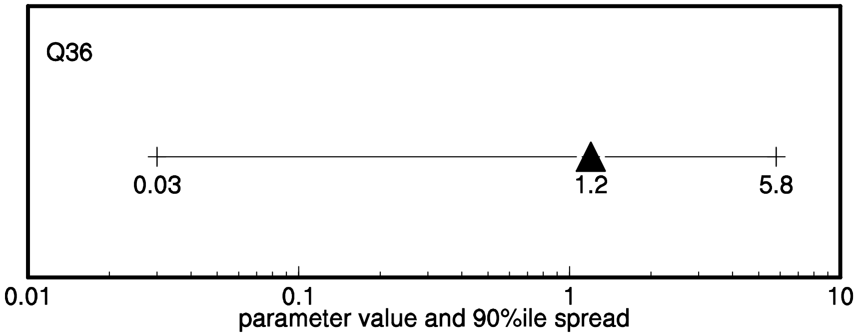
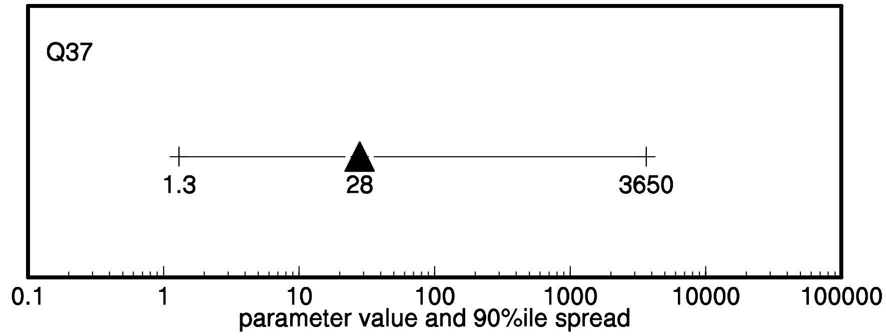
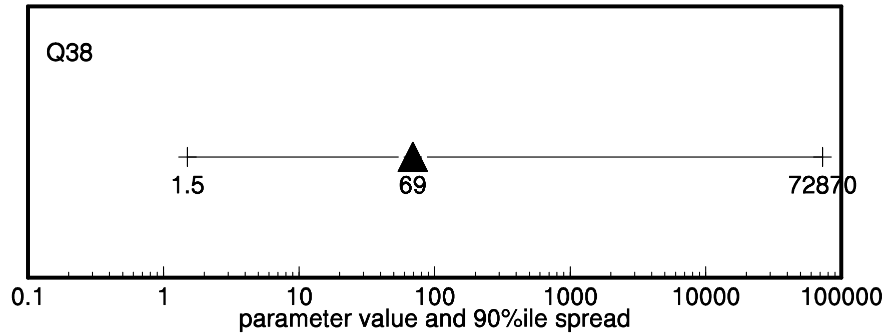
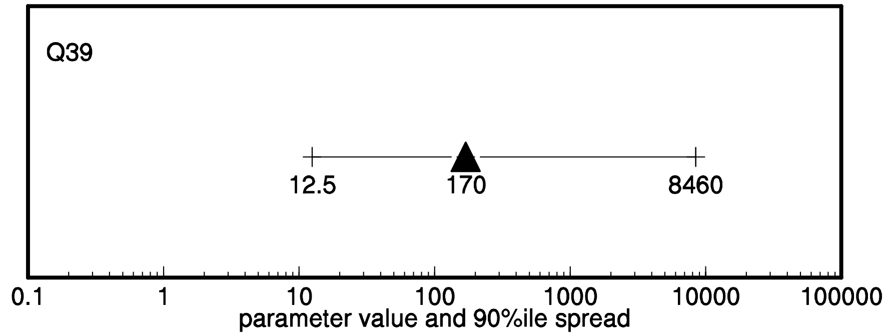
10
parameter value and 90%ile spread

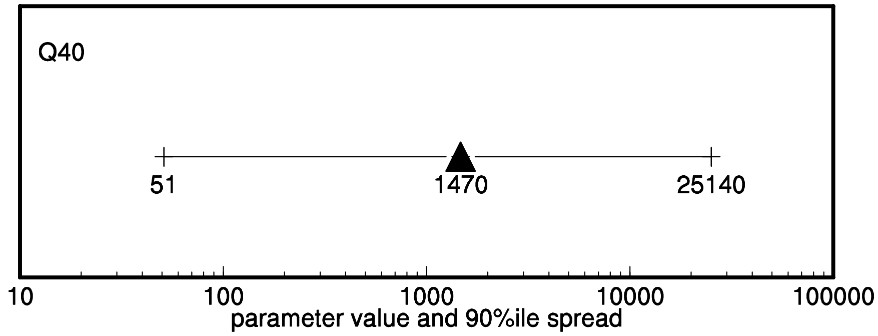

Q35
0.006
0.43
3.3
0.001
0.01
0.1
1
10
parameter value and 90%ile spread

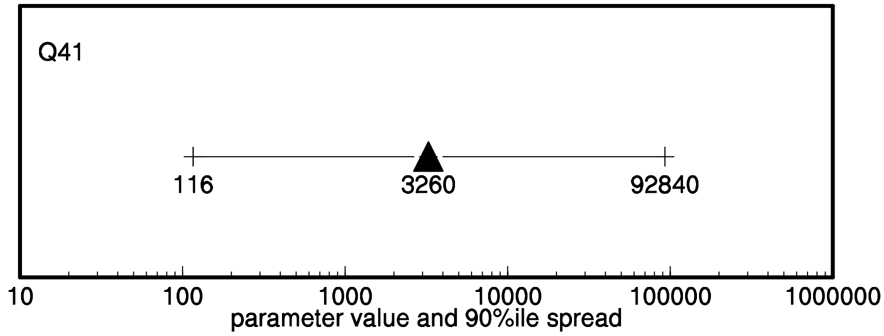

Q36
0.03
1.2
5.8
0.01
0.1
1
10
parameter value and 90%ile spread

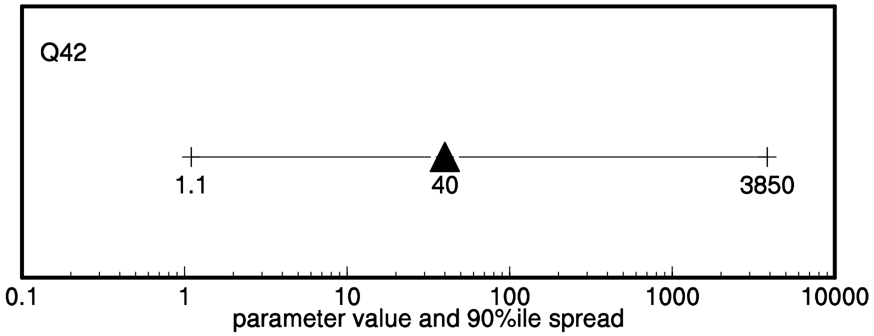

Q37
1.3
28
3650
0.1
1
10
100
1000
10000
100000
parameter value and 90%ile spread

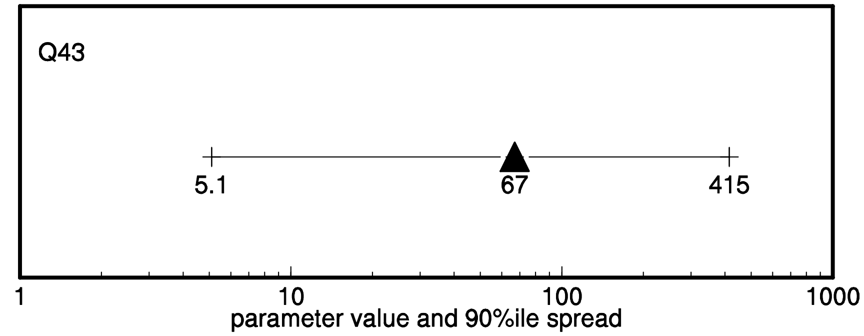

Q38
1.5
69
72870
0.1
1
10
100
1000
10000
100000
parameter value and 90%ile spread

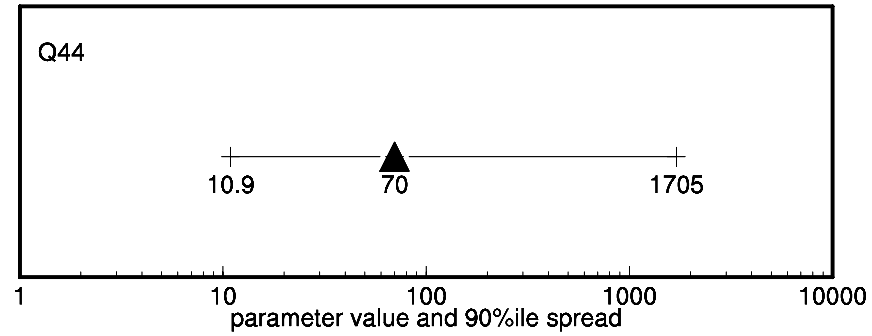

Q39
12.5
170
8460
0.1
1
10
100
1000
10000
100000
parameter value and 90%ile spread

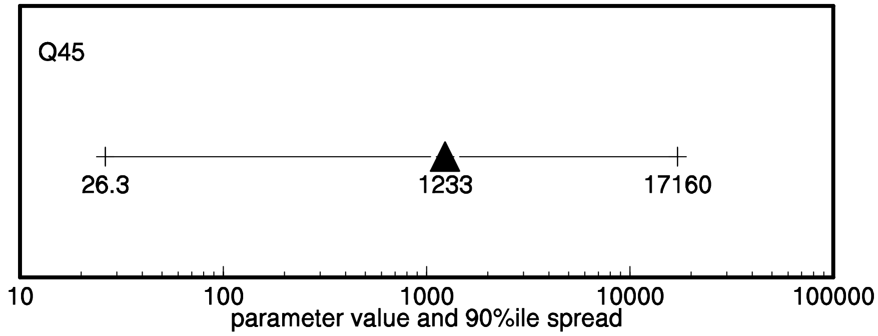

Q40
51
1470
25140
10
100
1000
10000
100000
parameter value and 90%ile spread

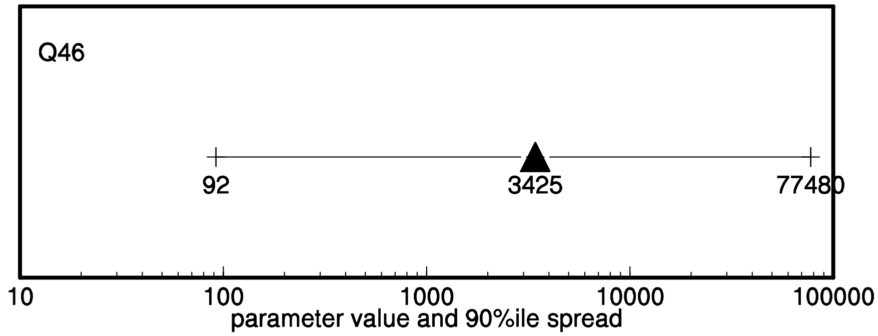

Q41
116
3260
92840
10
100
1000
10000
100000
1000000
parameter value and 90%ile spread

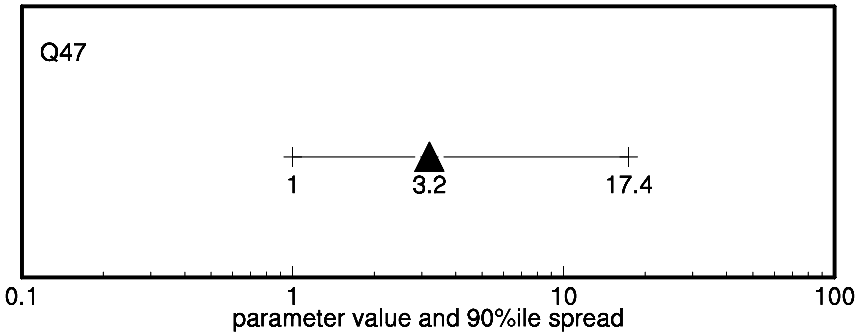

Q42
1.1
40
3850
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

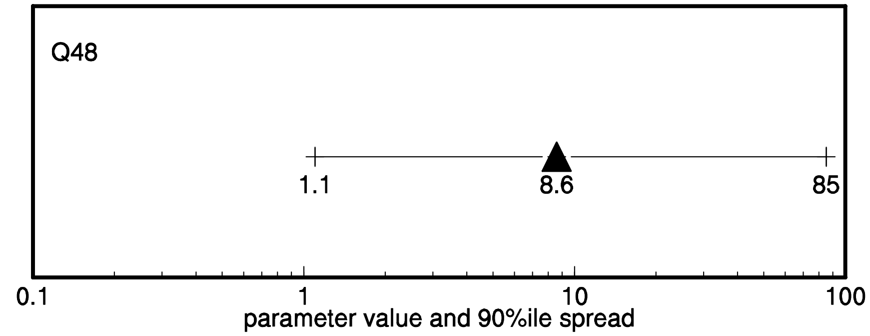

Q43
5.1
67
415
1
10
100
1000
parameter value and 90%ile spread

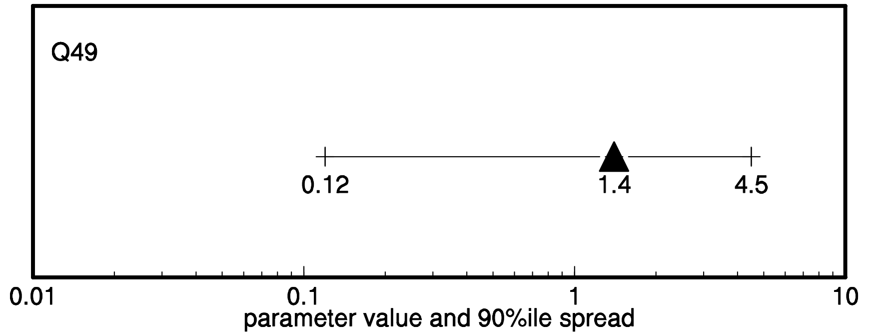

Q44
10.9
70
1705
1
10
100
1000
10000
parameter value and 90%ile spread

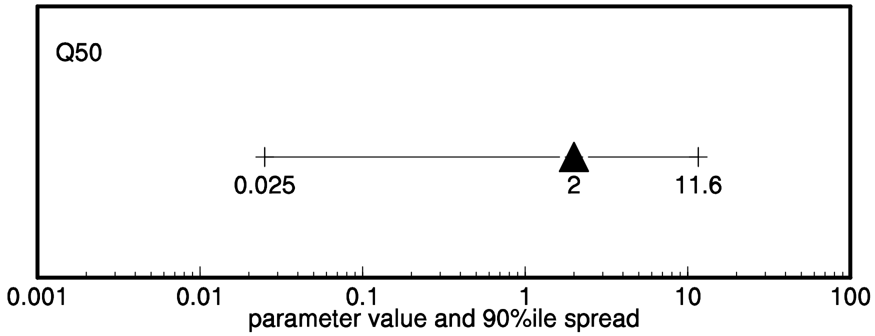

Q45
26.3
1233
17160
10
100
1000
10000
100000
parameter value and 90%ile spread

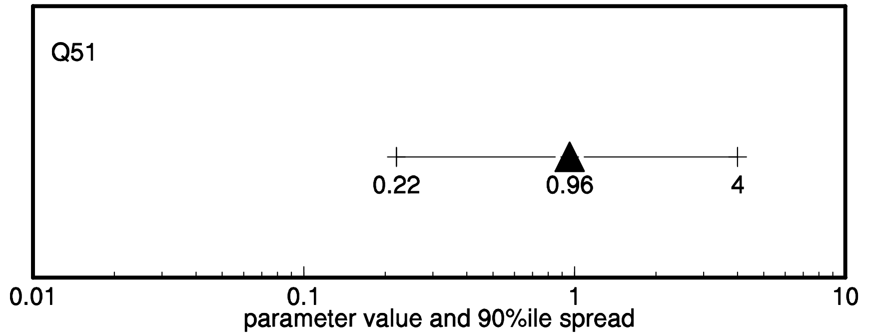

Q46
92
3425
77480
10
100
1000
10000
100000
parameter value and 90%ile spread

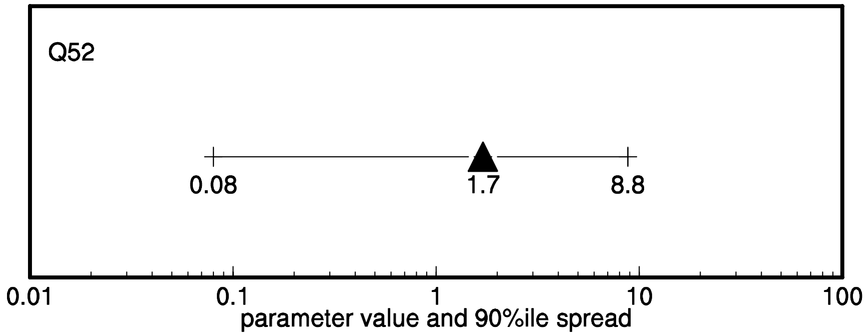

Q47
1
3.2
17.4
0.1
1
10
100
parameter value and 90%ile spread

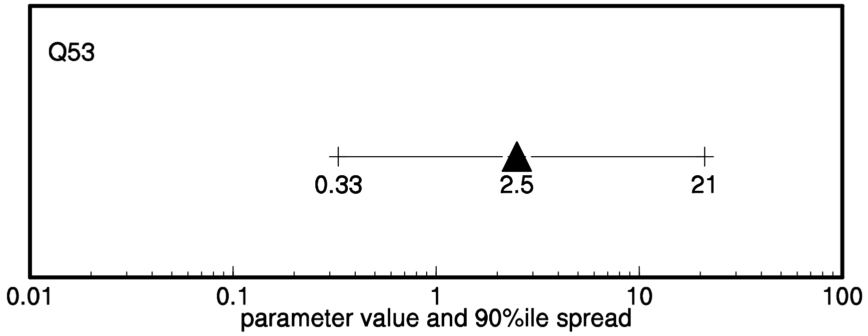

Q48
1.1
8.6
85
0.1
1
10
100
parameter value and 90%ile spread

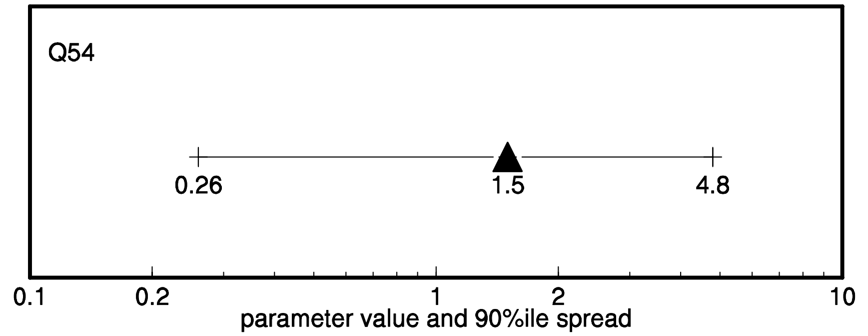

Q49
0.12
1.4
4.5
0.01
0.1
1
10
parameter value and 90%ile spread

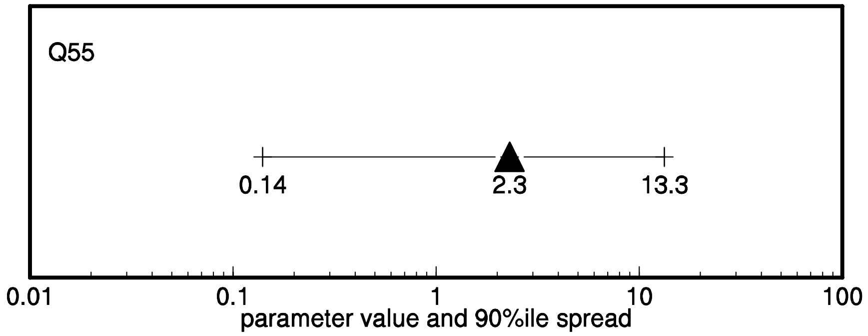

Q50
0.025
2
11.6
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread

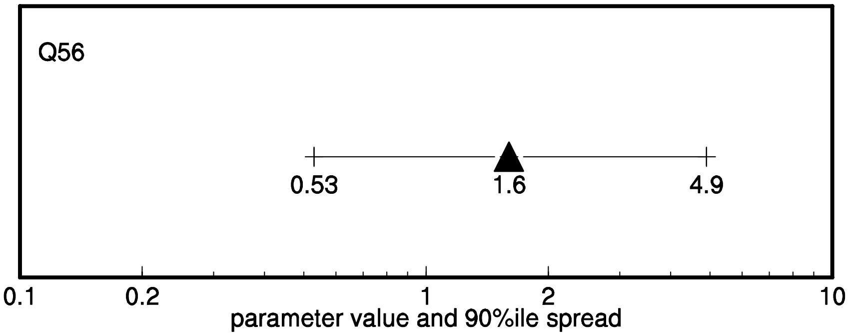

Q51
0.22
0.96
4
0.01
0.1
1
10
parameter value and 90%ile spread

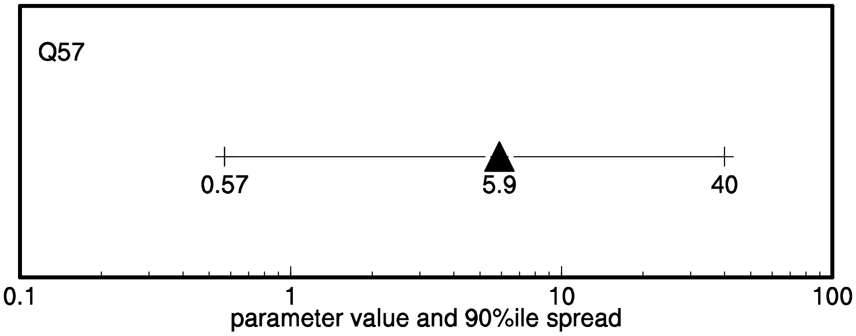

Q52
0.08
1.7
8.8
0.01
0.1
1
10
100
parameter value and 90%ile spread

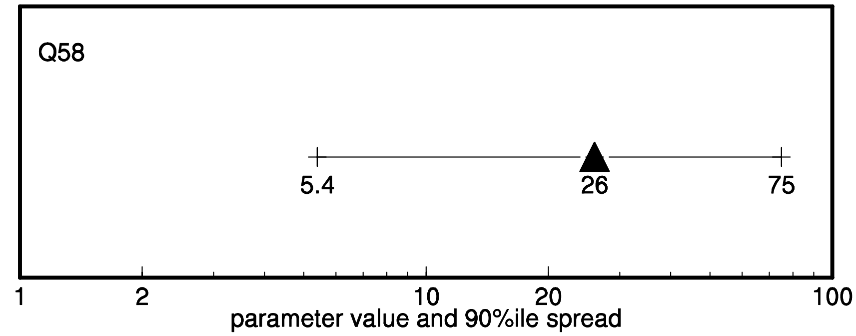

Q53
0.33
2.5
21
0.01
0.1
1
10
100
parameter value and 90%ile spread

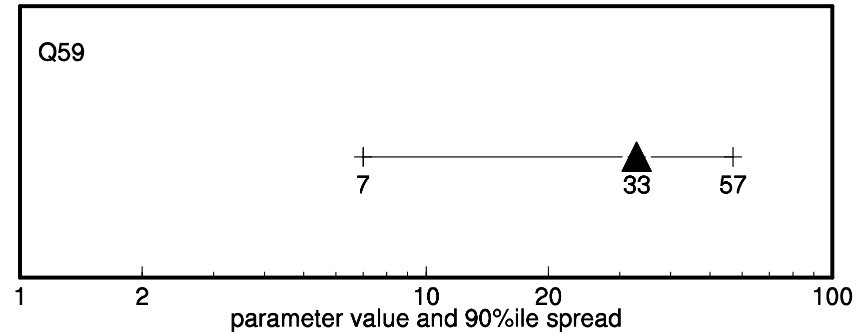

Q54
0.26
1.5
4.8
0.1
0.2
1
2
10
parameter value and 90%ile spread

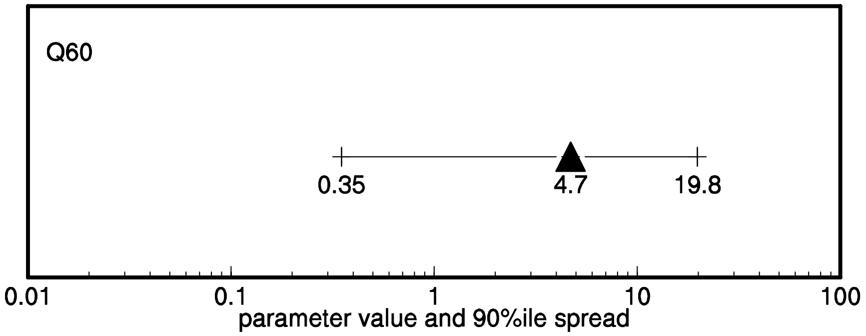

Q55
0.14
2.3
13.3
0.01
0.1
1
10
100
parameter value and 90%ile spread

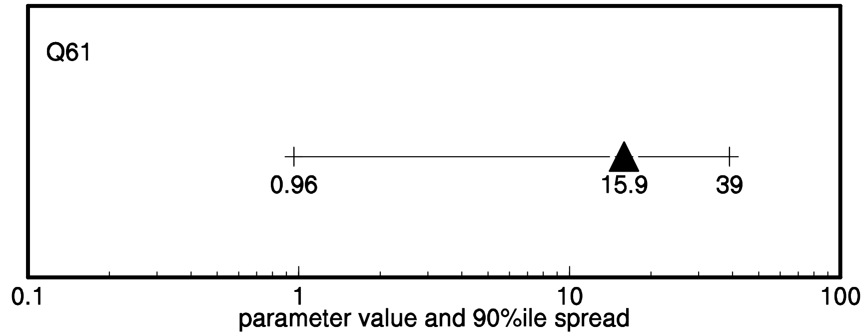

Q56
0.53
1.6
4.9
0.1
0.2
1
2
10
parameter value and 90%ile spread

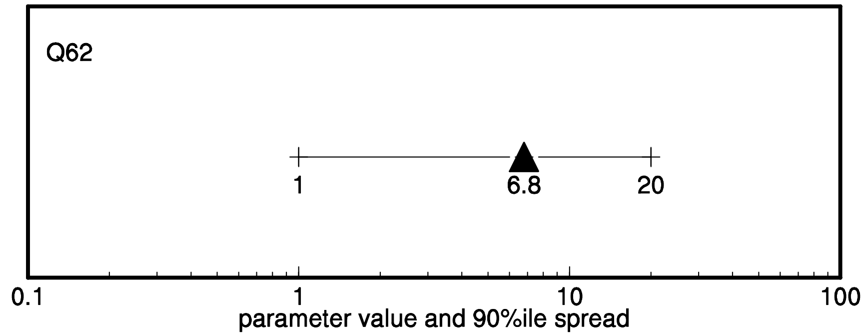

Q57
0.57
5.9
40
0.1
1
10
100
parameter value and 90%ile spread

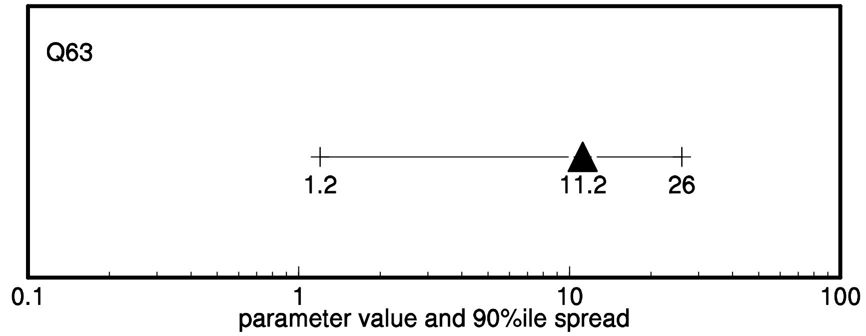

Q58
5.4
26
75
1
2
10
20
100
parameter value and 90%ile spread

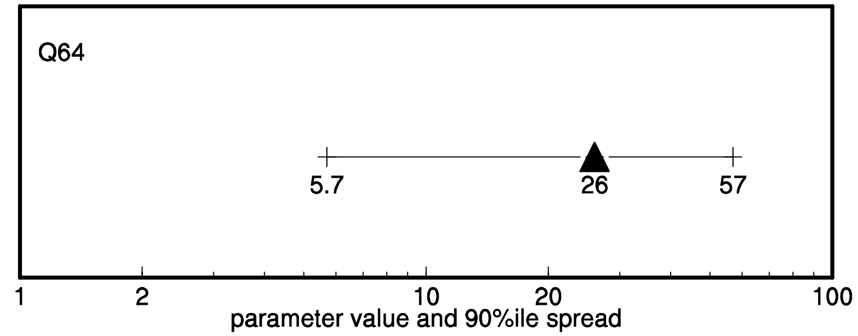

Q59
7
33
57
1
2
10
20
100
parameter value and 90%ile spread

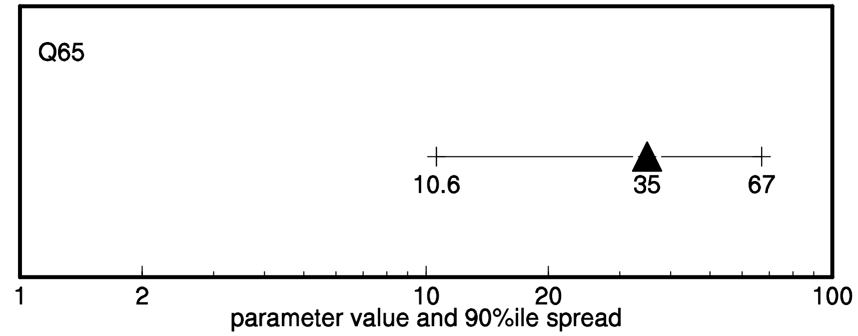

Q60
0.35
4.7
19.8
0.01
0.1
1
10
100
parameter value and 90%ile spread

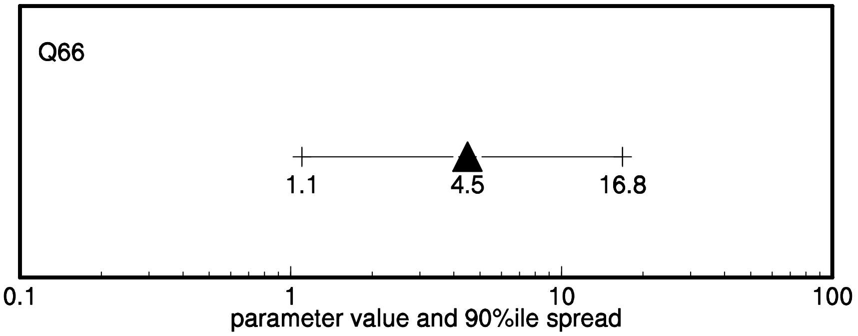

Q61
0.96
15.9
39
0.1
1
10
100
parameter value and 90%ile spread

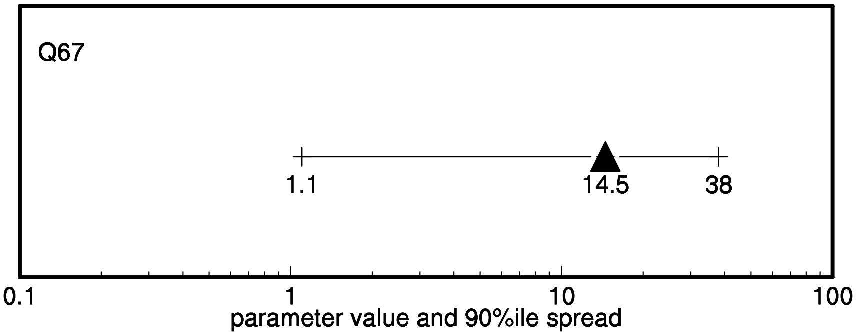

Q62
1
6.8
20
0.1
1
10
100
parameter value and 90%ile spread

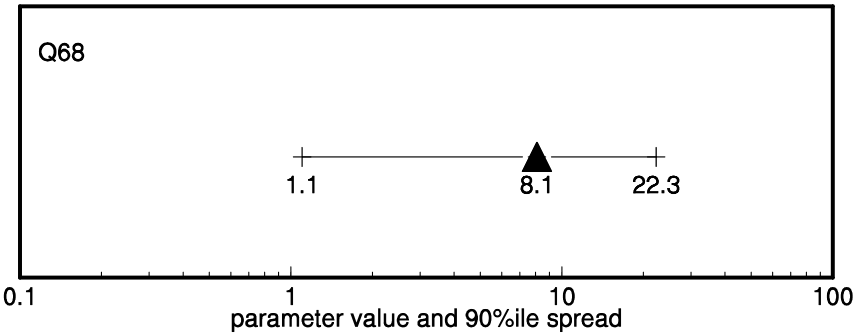

Q63
1.2
11.2
26
0.1
1
10
100
parameter value and 90%ile spread

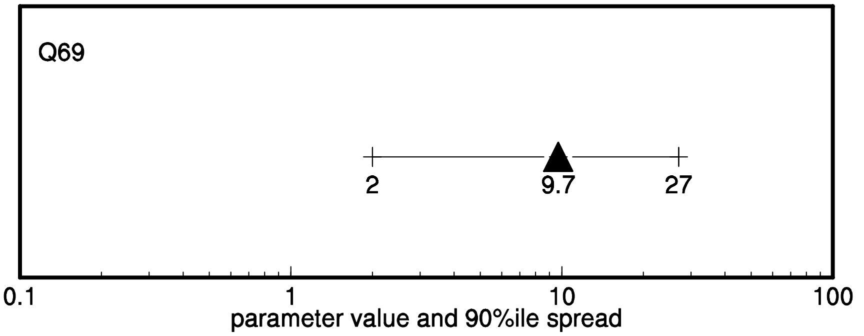

Q64
5.7
26
57
1
2
10
20
100
parameter value and 90%ile spread

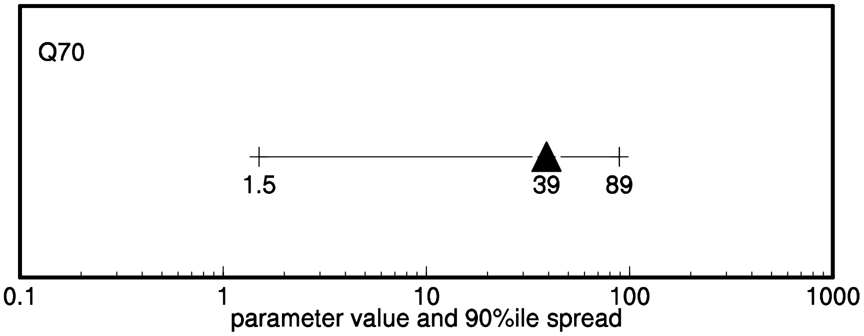

Q65
10.6
35
67
1
2
10
20
100
parameter value and 90%ile spread

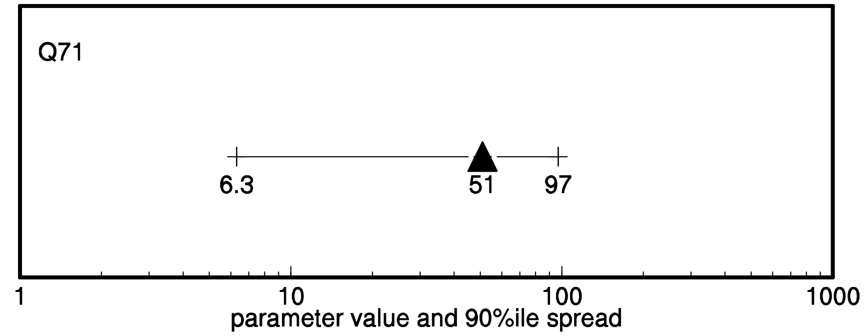

Q66
1.1
4.5
16.8
0.1
1
10
100
parameter value and 90%ile spread

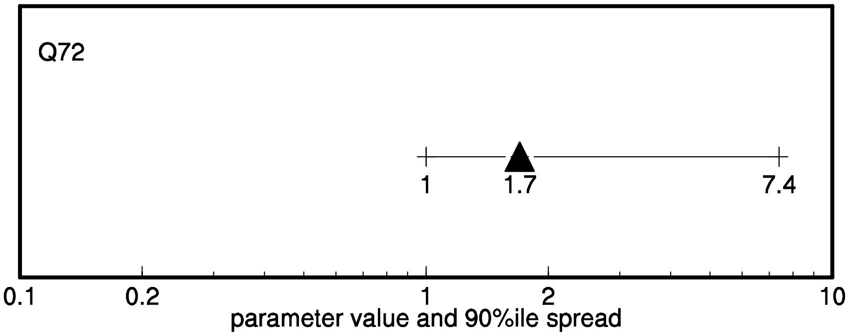

Q67
1.1
14.5
38
0.1
1
10
100
parameter value and 90%ile spread

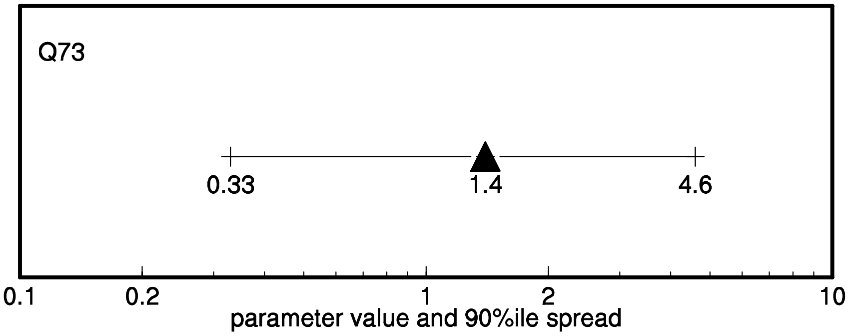

Q68
1.1
8.1
22.3
0.1
1
10
100
parameter value and 90%ile spread

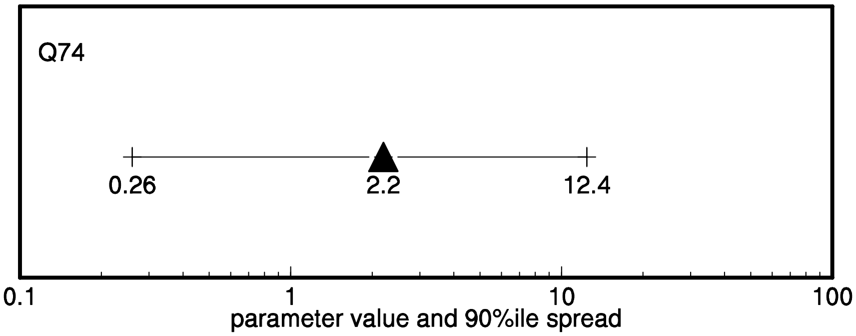

Q69
2
9.7
27
0.1
1
10
100
parameter value and 90%ile spread


Q70
1.5
39
89
0.1
1
10
100
1000
parameter value and 90%ile spread


Q71
6.3
51
97
1
10
100
1000
parameter value and 90%ile spread


Q72
1
1.7
7.4
0.1
0.2
1
2
10
parameter value and 90%ile spread


Q73
0.33
1.4
4.6
0.1
0.2
1
2
10
parameter value and 90%ile spread


Q74
0.26
2.2
12.4
0.1
1
10
100
parameter value and 90%ile spread

7 COMMENTS ON RESULTS

While these charts provide in bare summary form the preferred results from the present elicitation exercise, some comment on all the corresponding results that were generated throughout the series of elicitations can help set them in a wider context. There follows a list of comments on specific aspects of the individual items which, on simple inspection by the facilitator, seem noteworthy: the technical implications in terms of reservoir safety implications must be left for others to consider.

Certain general comments can be made first, however. The “high/low schools of thought” (where two or more experts provide uncertainty ranges that do not overlap with the remainder of the group), which were apparent in the first elicitation exercise are not considered to be an issue here. That said, some items have attracted markedly increased spreads in confidence limits, and many of these are asymmetric - where this occurs, the observation is noted below, and may call for further consideration of the issues involved.

The first set of comments, which are of a comparative nature, are made on changes that emerged in the second (whole-group) elicitation results, relative to the first elicitation results.

Q12 – 17: central values changed noticeably (increased); conf. bands more narrow.

Q18 – 19: conf. bands more narrow.

Q20 – 28: central value and conf. bands essentially unchanged.

Q29 – 31: central values changed noticeably (increased); some widening of conf. bands.

Q32: central values changed slightly (decreased).

Q33 – 36: central value and conf. bands essentially unchanged.

Q37 – 39: big shift in upper conf. limit (due to 1 expert), but central value remains within 90%ile spread of first elicitation.

Q40 – 41: large increase in central value and extension of conf. bands (due mainly to 1 expert); central values just within 90%ile spread of first elicitation.

Q42 – 43: some uplift of central values; conf. bands essentially unchanged.

Q44 – 46: central values increased significantly; conf. bands also increased.

Q47 – 48: central value and conf. bands essentially unchanged.

Q49 – 53: while central values essentially unchanged, conf. bands are narrower.

Q54 - 55: central value and conf. bands essentially unchanged.

Q56: central value unchanged, but big increase in upper conf. limit.

Q57: some increase in central value.

Q58 – 59: central value and conf. bands essentially unchanged.

Q60: decrease in central value, and extension downwards of lower conf. limit.

Q61 – 62: central value and conf. bands essentially unchanged.

Q63: increase in central value; conf. band unchanged.

Q64 – 65: central value and conf. bands essentially unchanged.

Q66: decrease in central value, wider conf. band.

Q67 – 71: central value and conf. bands essentially unchanged.

Q72 – 75: no comments (not done in first elicitation)

In summary, while many items have elicited outcomes very similar to those obtained in the first elicitation, there are several that have produced considerable shifts in the results. At first analysis, it appears many of the latter changes may be due to the opinions (and weight) of one of the added experts and, in particular, his views on the uncertainty that should attach to some of the parameters being characterised.

The next comments draw attention, selectively, to shifts and differences in results when the whole group results are updated and when the synthetic decision-maker (DM) is 'optimised', relative to the (second) whole-group elicitation results:

Q16: the central value is reduced noticeably, although the conf. bands remain unchanged

Q27: lower conf. limit extended relative to whole group

Q28 – 29: steady upward shift of central values and conf. limits through the sequence of elicitations

Q30 – 31: second elicitation updating results in lowered upper conf. limits

Q32 – 33: lower conf. limits extended, but central values stable

Q37 – 41: changes in central values and conf. limit spreads are marked when compared with the FIRST elicitation results

Q42 – 55: central values and conf. limit spreads are mostly stable, although some systematic shifts (up or down) evinced as elicitations progress

Q56: notable reduction in upper conf. limit from second update on, although central value is stable

Q57: lower conf. limits raised from second update on, modest increase in central values

Q58 - 59: notable stability in results

Q60 - 61: slight changes in central values, and conf. limit spreads

Q62 - 63: stability in results

Q64: central value has risen steadily throughout

Q65: stable results

Q66: central value has declined steadily across the elicitations, and conf. limits have narrowed

Q67 – 68: stability in results

Q69: central value has crept upwards steadily

Q70: stable results

Q71: stable central value; extension of lower conf. limits

Q72 -763: reduction in conf. limit spreads, esp. at lower ends

Q74: stable results

The implications of these observations should, ideally, receive further, careful consideration before the elicitation results are used to quantify inputs to a model of progressive internal erosion in dams; that said, however, the results from the constrained DM optimization approach have strong appeal, *prima facie*, as the most appropriate for the present purpose.

8 FINAL REMARKS

The elicitation process itself was new to all those who took part, and the key aspect that could be improved in future exercises of this kind is to increase ownership of the questions and issues by those taking part. This could be achieved by a longer workshop where the experts themselves assisted in setting the questions to be evaluated. Additionally. discussion could be stimulated by appointing protagonists to argue the case for extremes of possible responses (in some cases, it has been found particularly effective to ask people holding opposing views to play ‘devil’s advocate’, to argue the case for a particular position they themselves don’t adhere to - this often reduces strongly-held dichotomies of opinion!).

While the elicitation exercise has proved of value in making explicit the wide spread of uncertainty in relation to the internal erosion problem, and in capturing knowledge on that score, the process adopted for this research contract did not fully explore the reasons for discrepancies in opinions or results, but this could be pursued in future exercises.

Issues that could be further investigated include:

a) The observation that most of the dam experts appear to give uncertainty bounds which are narrower than the true uncertainty, particularly where the uncertainty covers orders of magnitude (but this trait has been found to be true of technical experts of all kinds);

b) the validity of questions which ask for the spread of a variable over the whole population of a particular dam type - it could be argued that for some of the dams the question is irrelevant, or inappropriate; however, in order to advance knowledge of internal erosion processes, progress is needed at both a detailed level on specific dams and in understanding of the behaviour of larger groups;

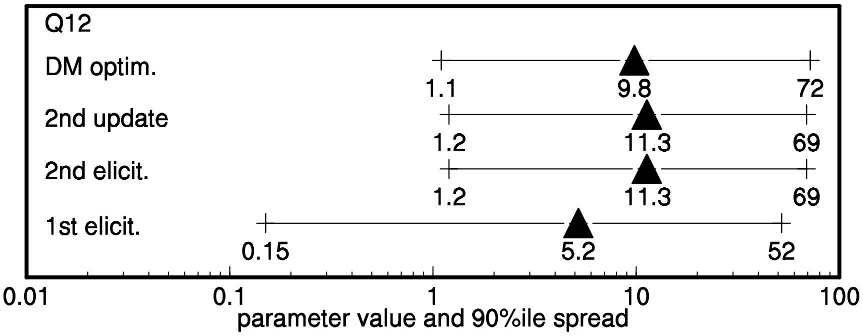
c) the validity of questions which simplify a complex problem to focus on only one aspect of the problem, assuming “all other things being equal” – for issues governed by two (or more) important interdependent variables this may be an over-simplification.

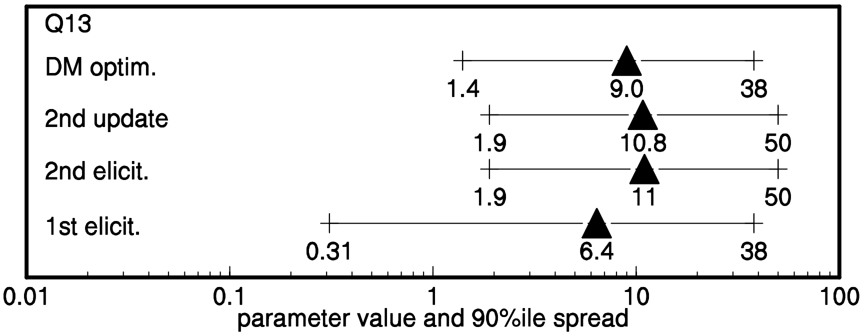
Appendix 1: The elicitations: full results in chart form

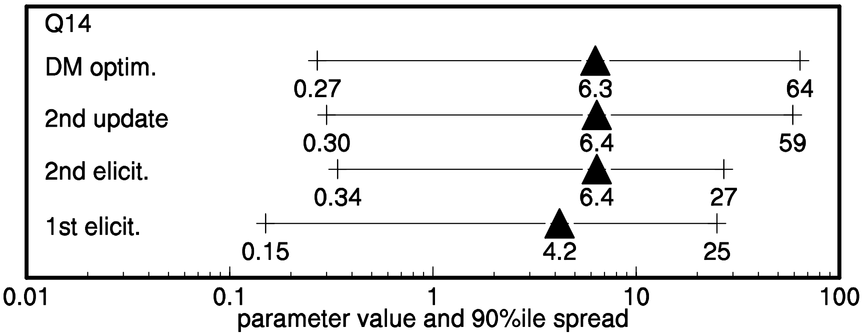
On the plots that follow, the results of the two main elicitations (24th April and 21st July 2003) are labeled '1st elicit.' and '2nd elicit.', respectively. The results obtained after revisions to the latter, when certain responses had been re-considered or amended, are denoted by the label: '2nd update'. The preferred, constrained decision-maker optimized results are labeled 'Opt. DM'.

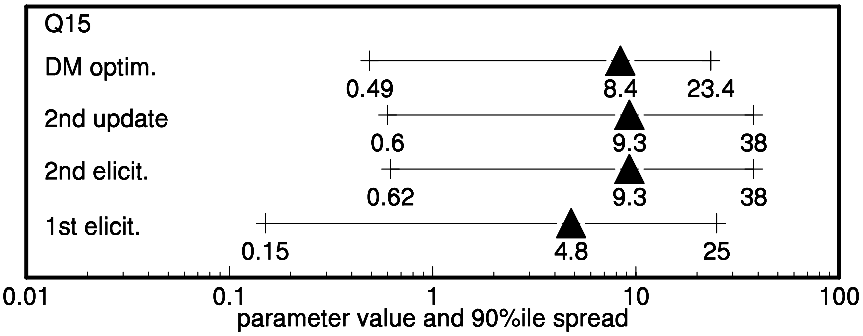
Each chart is labeled with the number used in the questionnaire to denote the different items (e.g. Q11), although the wording and details of the questions themselves are not repeated here. In each case, the charts show the 50%ile value (triangle marker) and the 90%ile spread about this value. It should be noted, however, that the scaling of the X-axis varies from item to item, for clarity, and that a logarithmic scale is used, for the same reason.

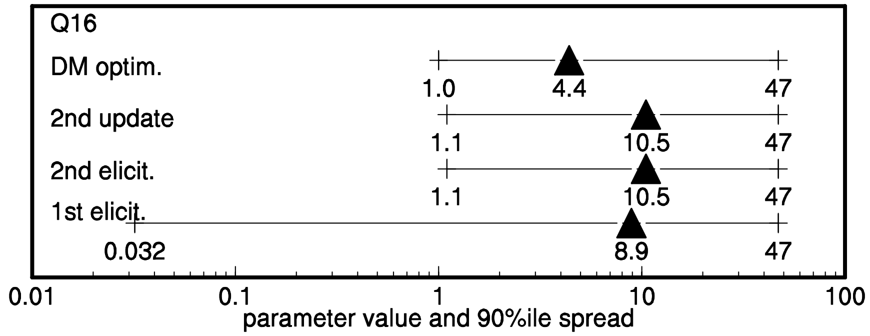
The graphical results also include plots of the weighted combination estimates for the eleven calibration seed questions (labeled 'Seed 1, …11'), together with the realization (actual) values for these items. A few brief comments on these particular charts are in order here. The addition of the two extra experts to the panel appears to have had the impact of moving most of the seed question outcomes closer to the known realization values - only in three cases (Seeds 7, 9 and 10) are the 50%ile values further away from the actual answers than they were in the first elicitation. Thus, a slight improvement in 'performance' of the group as a whole may be construed by the additional expertise. In all cases, the true realization falls within the span of the group 90%ile spread. That said, it has to be remarked from a facilitator's perspective that, overall, the closeness of match of the pooled opinions to the realizations is not as good as is normally achieved in quantitative technical areas, but in this case the scatter may reflect the sparseness of hard data and the multifactorial complexity of the problem. Evidence for this inference may be provided by the fact that 'good' performance was achieved on one particular seed question (Seed 11), which was taken from a very well-known and extensively reported British dam incident.

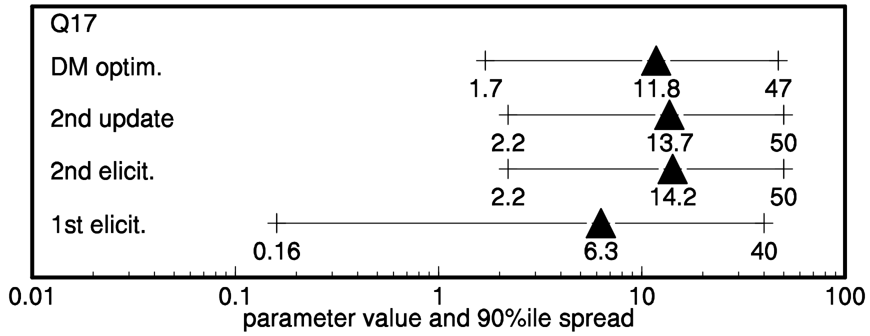

Q12
DM optim.
1.1
9.8
72
2nd update
1.2
11.3
69
2nd elicit.
1.2
11.3
69
1st elicit.
0.15
5.2
52
0.01
0.1
1
10
100
parameter value and 90%ile spread

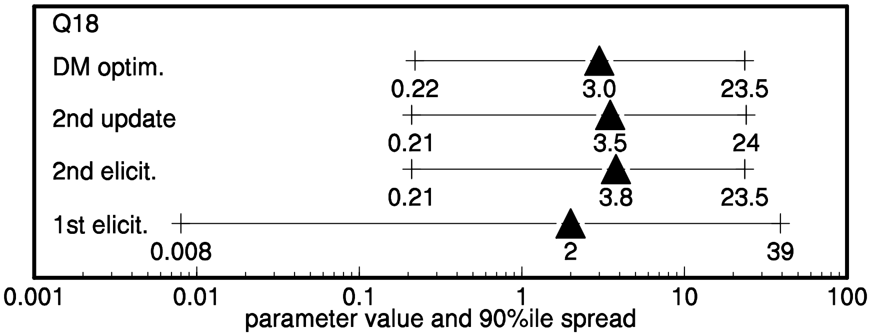

Q13
DM optim.
1.4
9.0
38
2nd update
1.9
10.8
50
2nd elicit.
1.9
11
50
1st elicit.
0.31
6.4
38
0.01
0.1
1
10
100
parameter value and 90%ile spread

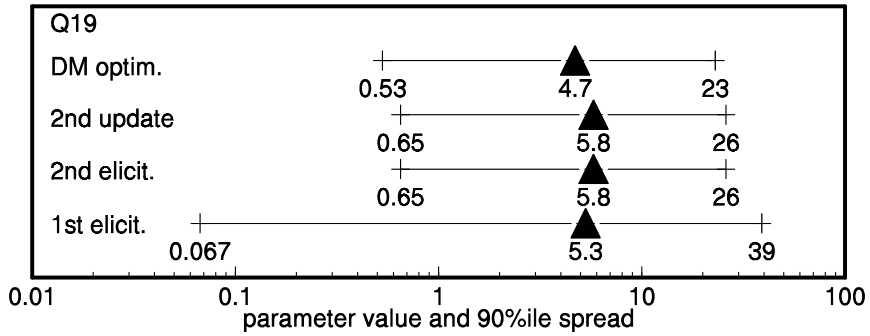

Q14
DM optim.
0.27
6.3
64
2nd update
0.30
6.4
59
2nd elicit.
0.34
6.4
27
1st elicit.
0.15
4.2
25
0.01
0.1
1
10
100
parameter value and 90%ile spread

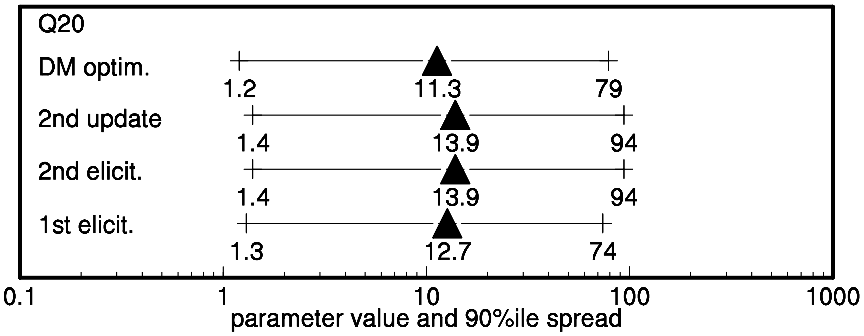

Q15
DM optim.
0.49
8.4
23.4
2nd update
0.6
9.3
38
2nd elicit.
0.62
9.3
38
1st elicit.
0.15
4.8
25
0.01
0.1
1
10
100
parameter value and 90%ile spread

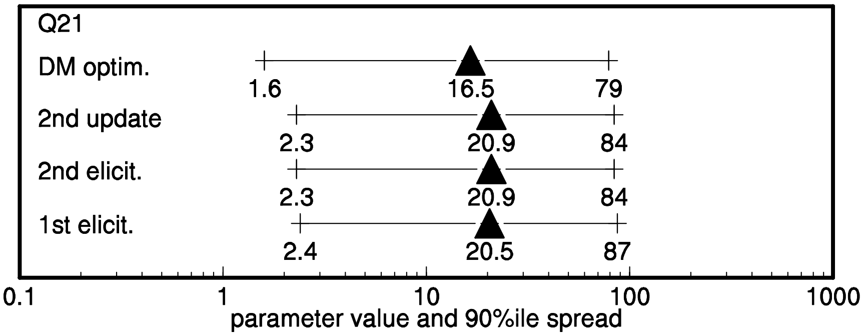

Q16
DM optim.
1.0
4.4
47
2nd update
1.1
10.5
47
2nd elicit.
1.1
10.5
47
1st elicit.
0.032
8.9
47
0.01
0.1
1
10
100
parameter value and 90%ile spread

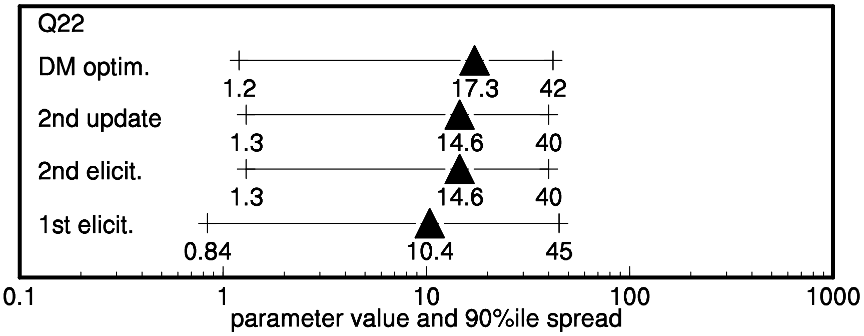

Q17
DM optim.
1.7
11.8
47
2nd update
2.2
13.7
50
2nd elicit.
2.2
14.2
50
1st elicit.
0.16
6.3
40
0.01
0.1
1
10
100
parameter value and 90%ile spread

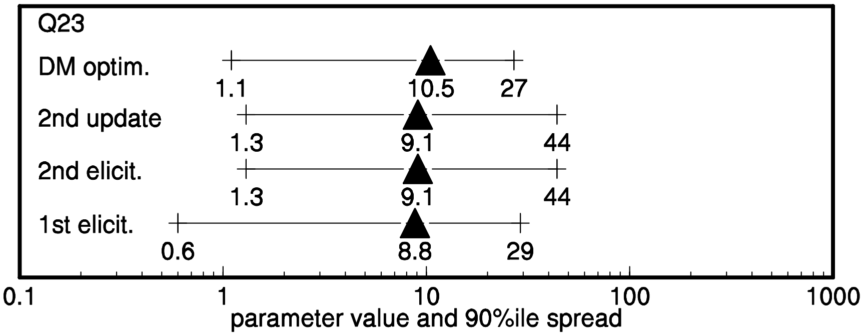

Q18
DM optim.
0.22
3.0
23.5
2nd update
0.21
3.5
24
2nd elicit.
0.21
3.8
23.5
1st elicit.
0.008
2
39
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread

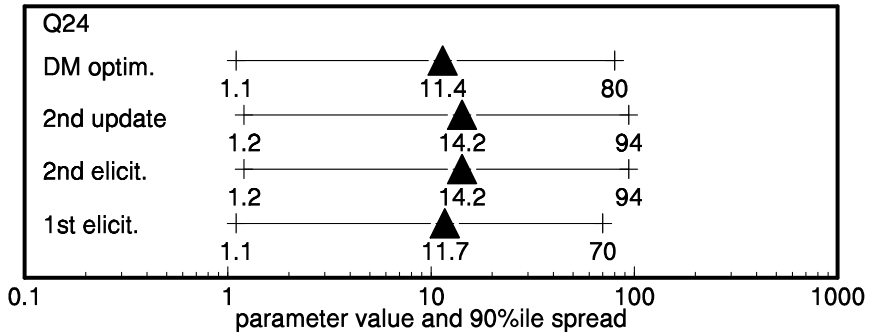

Q19
DM optim.
0.53
4.7
23
2nd update
0.65
5.8
26
2nd elicit.
0.65
5.8
26
1st elicit.
0.067
5.3
39
0.01
0.1
1
10
100
parameter value and 90%ile spread

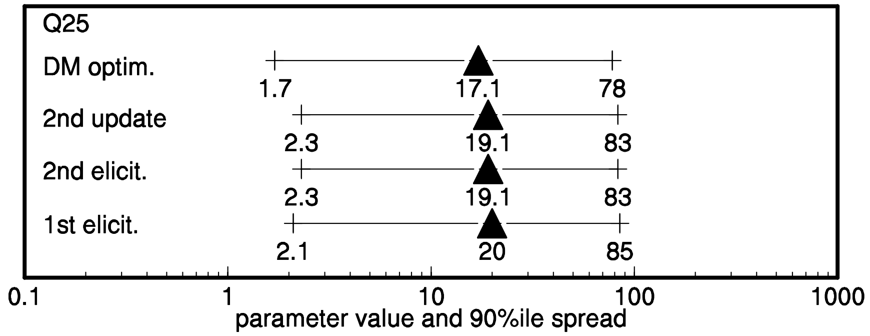

Q20
DM optim.
1.2
11.3
79
2nd update
1.4
13.9
94
2nd elicit.
1.4
13.9
94
1st elicit.
1.3
12.7
74
0.1
1
10
100
1000
parameter value and 90%ile spread

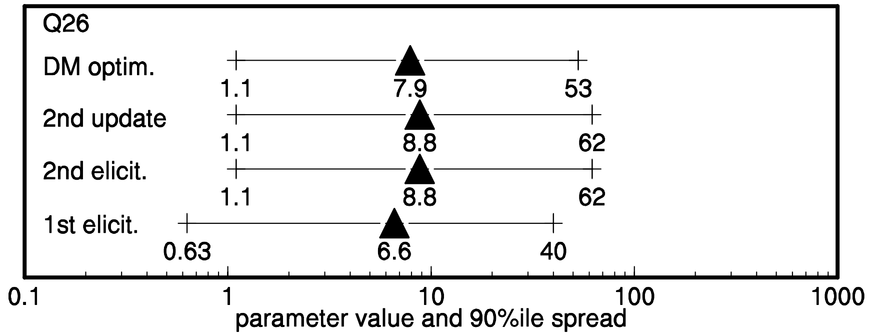

Q21
DM optim.
1.6
16.5
79
2nd update
2.3
20.9
84
2nd elicit.
2.3
20.9
84
1st elicit.
2.4
20.5
87
0.1
1
10
100
1000
parameter value and 90%ile spread

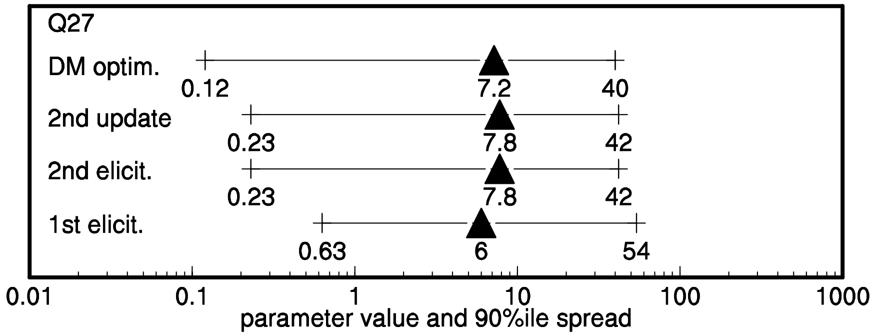

Q22
DM optim.
1.2
17.3
42
2nd update
1.3
14.6
40
2nd elicit.
1.3
14.6
40
1st elicit.
0.84
10.4
45
0.1
1
10
100
1000
parameter value and 90%ile spread

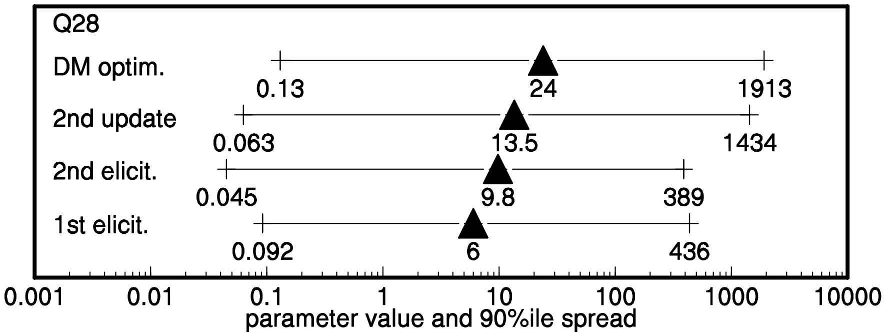

Q23
DM optim.
1.1
10.5
27
2nd update
1.3
9.1
44
2nd elicit.
1.3
9.1
44
1st elicit.
0.6
8.8
29
0.1
1
10
100
1000
parameter value and 90%ile spread

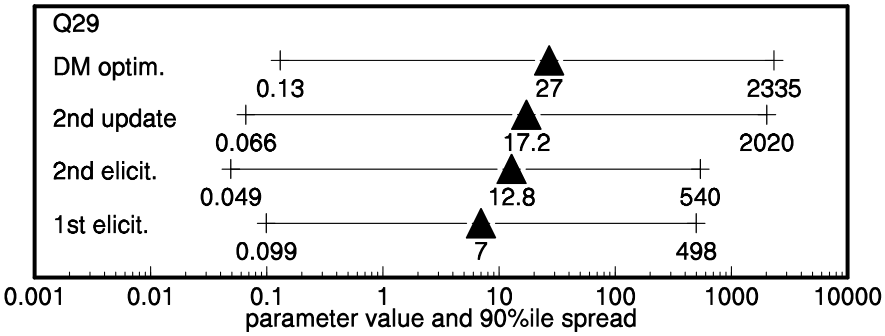

Q24
DM optim.
1.1
11.4
80
2nd update
1.2
14.2
94
2nd elicit.
1.2
14.2
94
1st elicit.
1.1
11.7
70
0.1
1
10
100
1000
parameter value and 90%ile spread

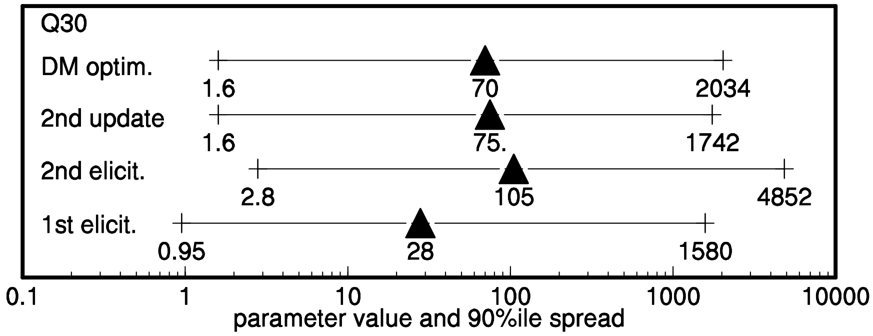

Q25
DM optim.
1.7
17.1
78
2nd update
2.3
19.1
83
2nd elicit.
2.3
19.1
83
1st elicit.
2.1
20
85
0.1
1
10
100
1000
parameter value and 90%ile spread

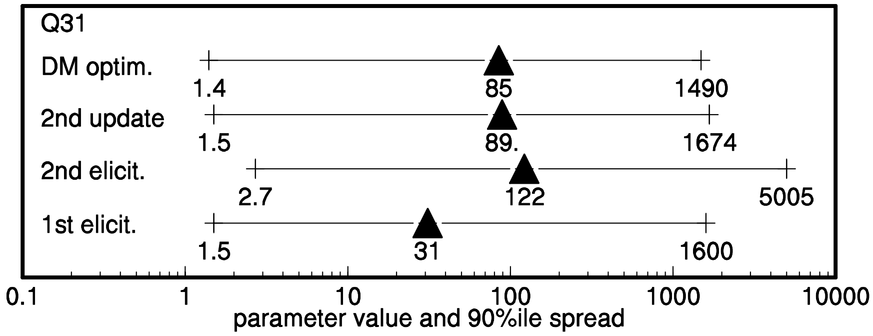

Q26
DM optim.
1.1
7.9
53
2nd update
1.1
8.8
62
2nd elicit.
1.1
8.8
62
1st elicit.
0.63
6.6
40
0.1
1
10
100
1000
parameter value and 90%ile spread

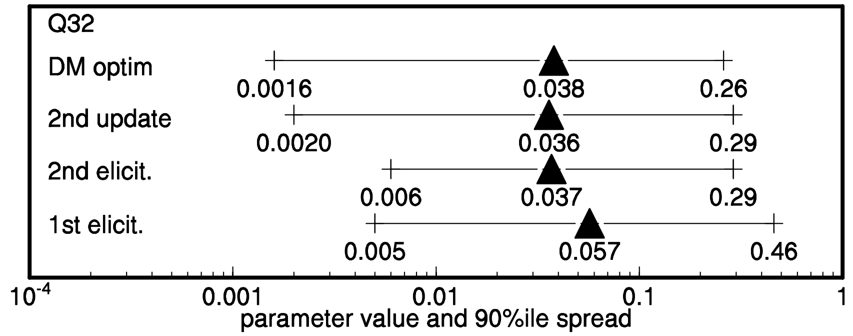

Q27
DM optim.
0.12
7.2
40
2nd update
0.23
7.8
42
2nd elicit.
0.23
7.8
42
1st elicit.
0.63
6
54
0.01
0.1
1
10
100
1000
parameter value and 90%ile spread

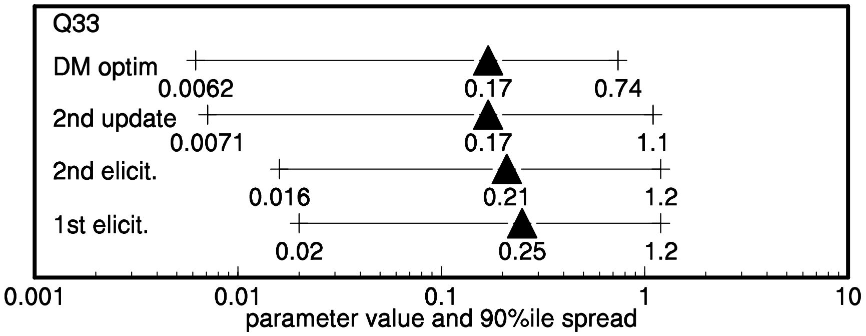

Q28
DM optim.
0.13
24
1913
2nd update
0.063
13.5
1434
2nd elicit.
0.045
9.8
389
1st elicit.
0.092
6
436
0.001
0.01
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

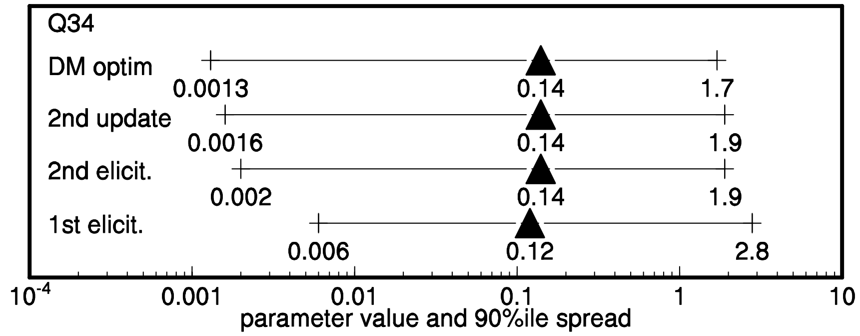

Q29
DM optim.
0.13
27
2335
2nd update
0.066
17.2
2020
2nd elicit.
0.049
12.8
540
1st elicit.
0.099
7
498
0.001
0.01
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

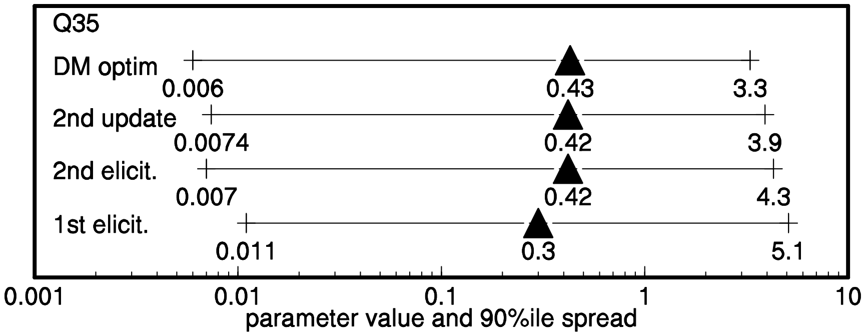

Q30
DM optim.
1.6
70
2034
2nd update
1.6
75.
1742
2nd elicit.
2.8
105
4852
1st elicit.
0.95
28
1580
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

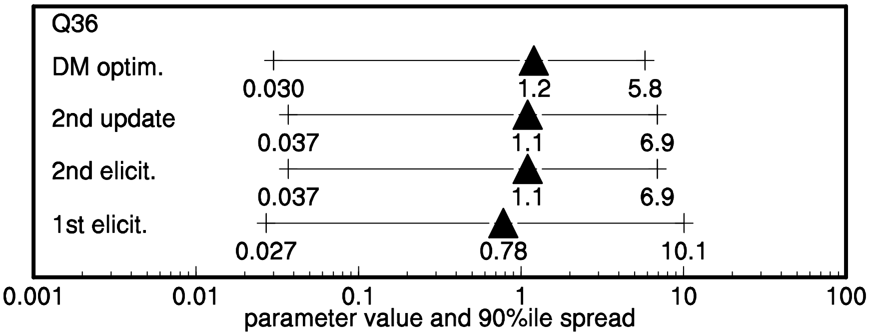

Q31
DM optim.
1.4
85
1490
2nd update
1.5
89.
1674
2nd elicit.
2.7
122
5005
1st elicit.
1.5
31
1600
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

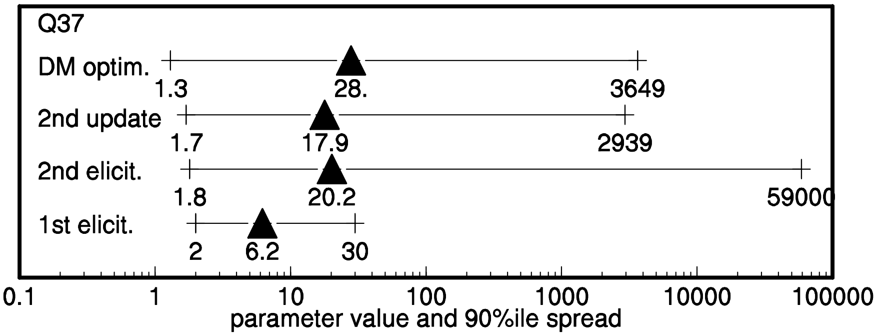

Q32
DM optim
0.0016
0.038
0.26
2nd update
0.0020
0.036
0.29
2nd elicit.
0.006
0.037
0.29
1st elicit.
0.005
0.057
0.46
10^-4
0.001
0.01
0.1
1
parameter value and 90%ile spread

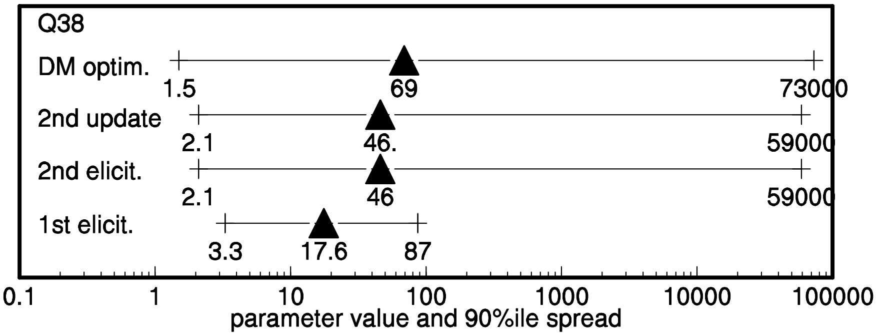

Q33
DM optim
0.0062
0.17
0.74
2nd update
0.0071
0.17
1.1
2nd elicit.
0.016
0.21
1.2
1st elicit.
0.02
0.25
1.2
0.001
0.01
0.1
1
10
parameter value and 90%ile spread

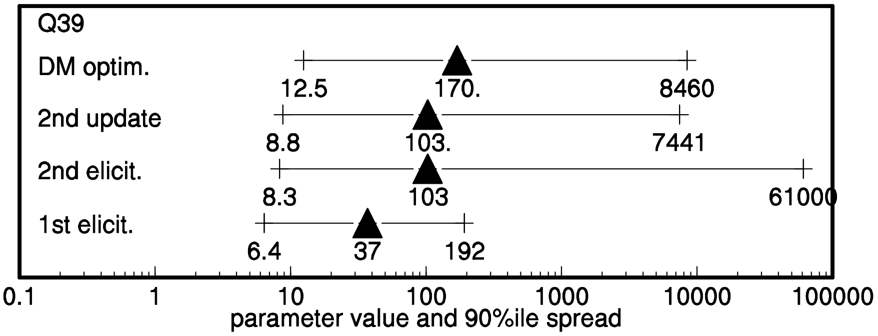

Q34
DM optim
0.0013
0.14
1.7
2nd update
0.0016
0.14
1.9
2nd elicit.
0.002
0.14
1.9
1st elicit.
0.006
0.12
2.8
10^-4
0.001
0.01
0.1
1
10
parameter value and 90%ile spread

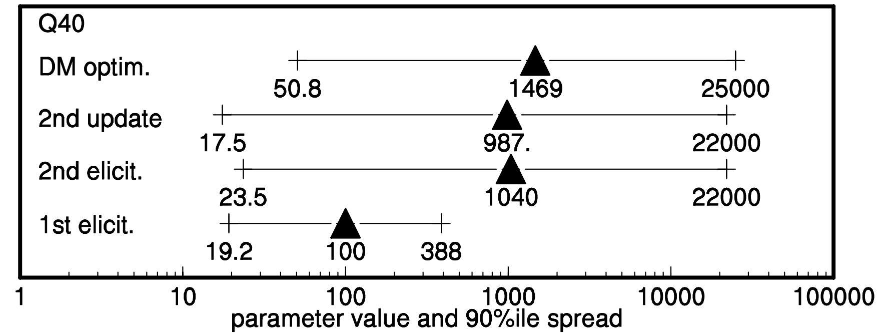

Q35
DM optim
0.006
0.43
3.3
2nd update
0.0074
0.42
3.9
2nd elicit.
0.007
0.42
4.3
1st elicit.
0.011
0.3
5.1
0.001
0.01
0.1
1
10
parameter value and 90%ile spread

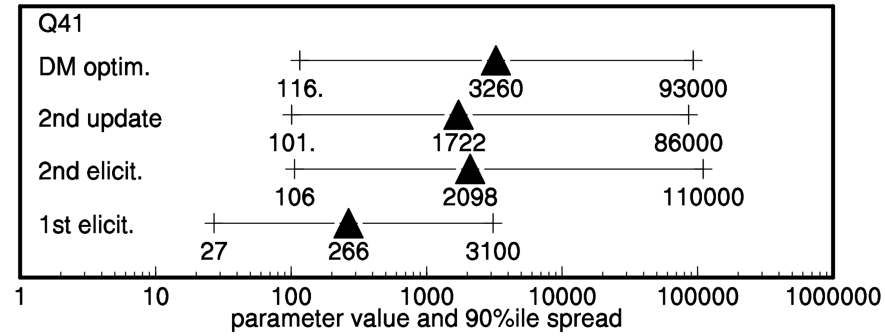

Q36
DM optim.
0.030
1.2
5.8
2nd update
0.037
1.1
6.9
2nd elicit.
0.037
1.1
6.9
1st elicit.
0.027
0.78
10.1
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread

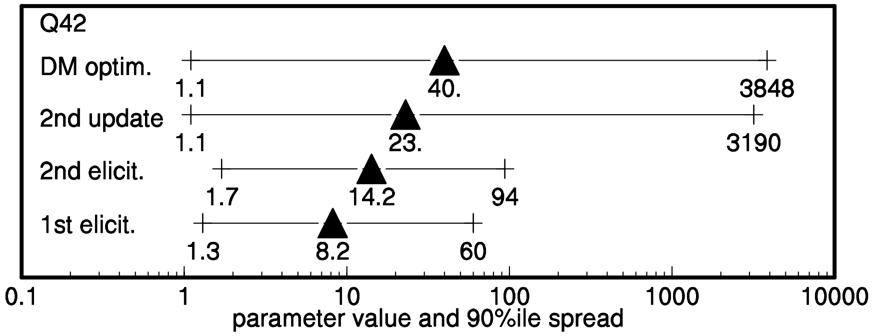

Q37
DM optim.
1.3
28.
3649
2nd update
1.7
17.9
2939
2nd elicit.
1.8
20.2
59000
1st elicit.
2
6.2
30
0.1
1
10
100
1000
10000
100000
parameter value and 90%ile spread

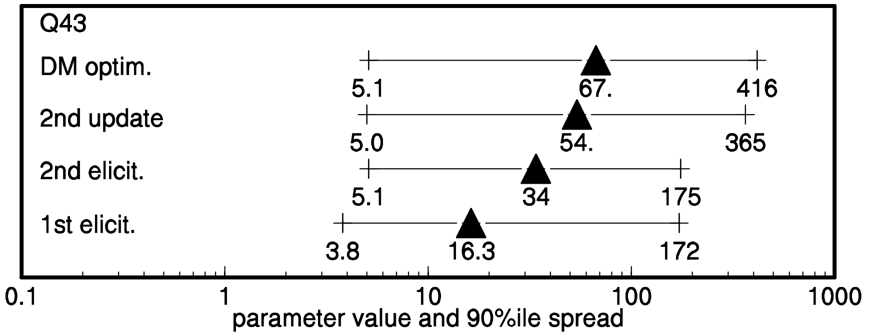

Q38
DM optim.
1.5
69
73000
2nd update
2.1
46.
59000
2nd elicit.
2.1
46
59000
1st elicit.
3.3
17.6
87
0.1
1
10
100
1000
10000
100000
parameter value and 90%ile spread

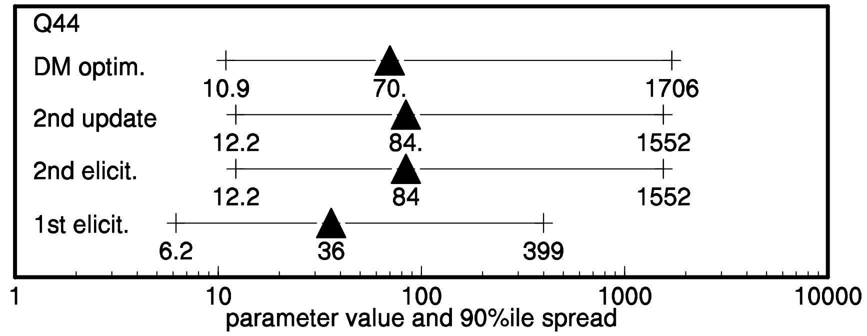

Q39
DM optim.
12.5
170.
8460
2nd update
8.8
103.
7441
2nd elicit.
8.3
103
61000
1st elicit.
6.4
37
192
0.1
1
10
100
1000
10000
100000
parameter value and 90%ile spread

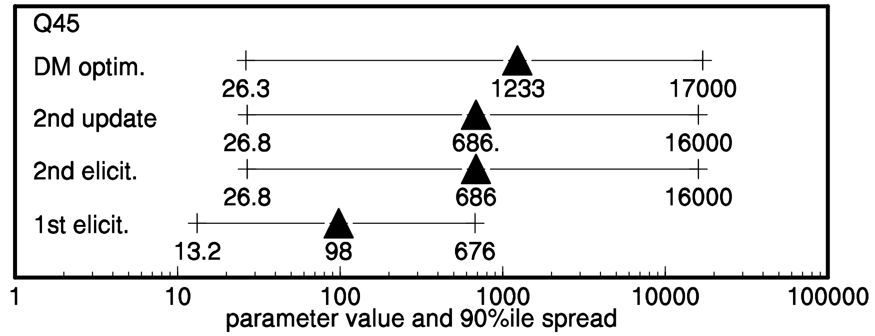

Q40
DM optim.
50.8
1469
25000
2nd update
17.5
987.
22000
2nd elicit.
23.5
1040
22000
1st elicit.
19.2
100
388
1
10
100
1000
10000
100000
parameter value and 90%ile spread

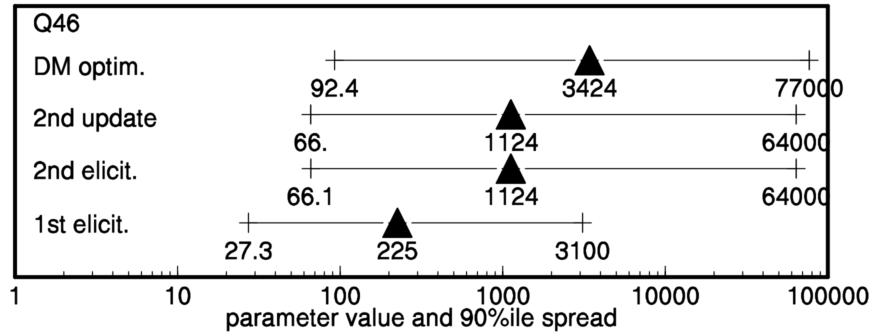

Q41
DM optim.
116.
3260
93000
2nd update
101.
1722
86000
2nd elicit.
106
2098
110000
1st elicit.
27
266
3100
1
10
100
1000
10000
100000
1000000
parameter value and 90%ile spread

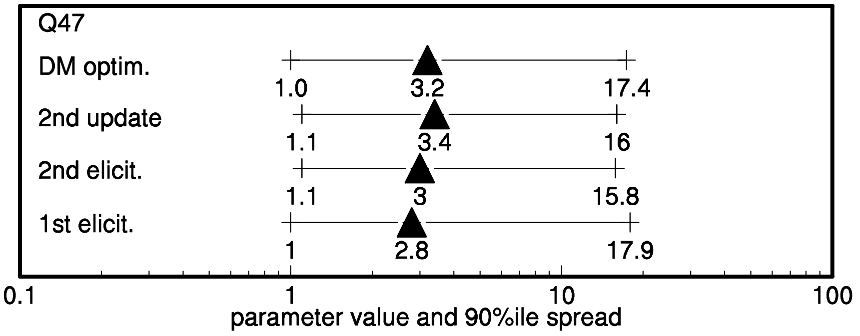

Q42
DM optim.
1.1
40.
3848
2nd update
1.1
23.
3190
2nd elicit.
1.7
14.2
94
1st elicit.
1.3
8.2
60
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

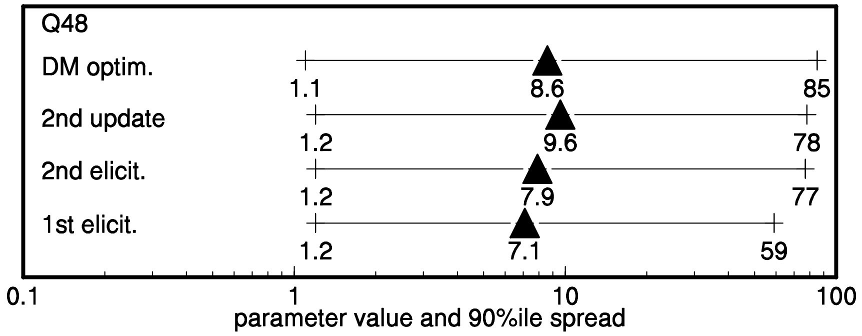

Q43
DM optim.
5.1
67.
416
2nd update
5.0
54.
365
2nd elicit.
5.1
34
175
1st elicit.
3.8
16.3
172
0.1
1
10
100
1000
parameter value and 90%ile spread

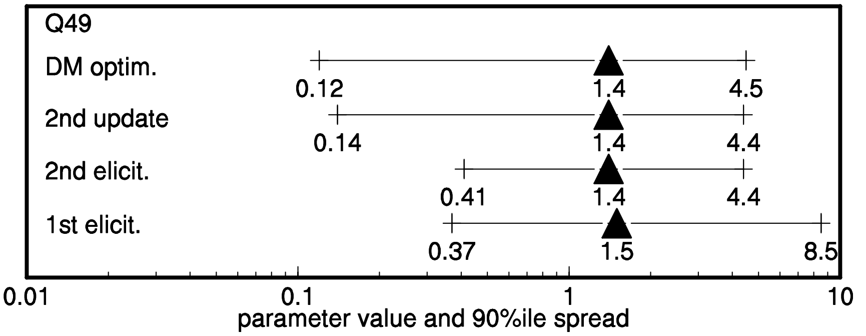

Q44
DM optim.
10.9
70.
1706
2nd update
12.2
84.
1552
2nd elicit.
12.2
84
1552
1st elicit.
6.2
36
399
1
10
100
1000
10000
parameter value and 90%ile spread

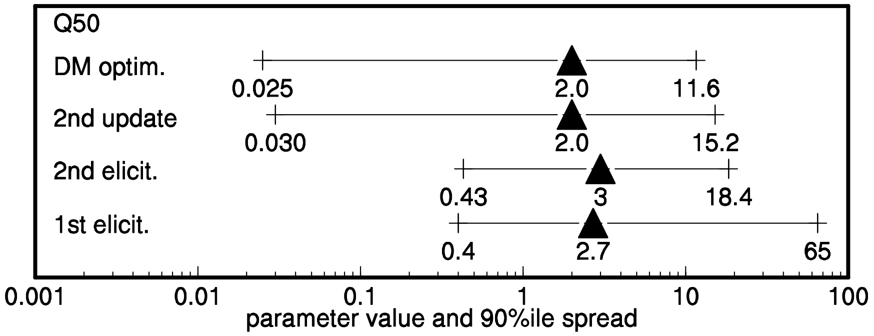

Q45
DM optim.
26.3
1233
17000
2nd update
26.8
686.
16000
2nd elicit.
26.8
686
16000
1st elicit.
13.2
98
676
1
10
100
1000
10000
100000
parameter value and 90%ile spread

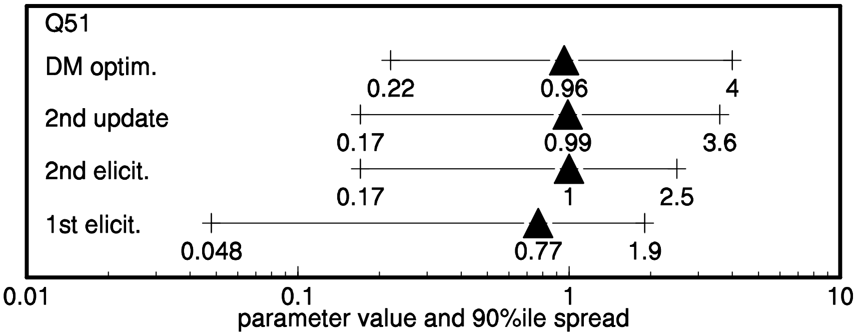

Q46
DM optim.
92.4
3424
77000
2nd update
66.
1124
6400
2nd elicit.
66.1
1124
6400
1st elicit.
27.3
225
3100
1
10
100
1000
10000
100000
parameter value and 90%ile spread

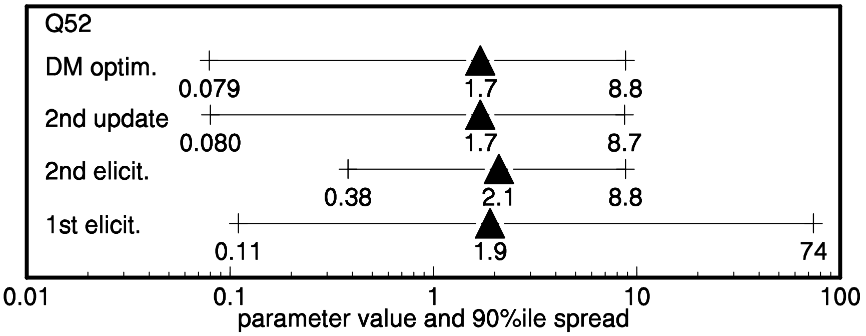

Q47
DM optim.
1.0
3.2
17.4
2nd update
1.1
3.4
16
2nd elicit.
1.1
3
15.8
1st elicit.
1
2.8
17.9
0.1
1
10
100
parameter value and 90%ile spread

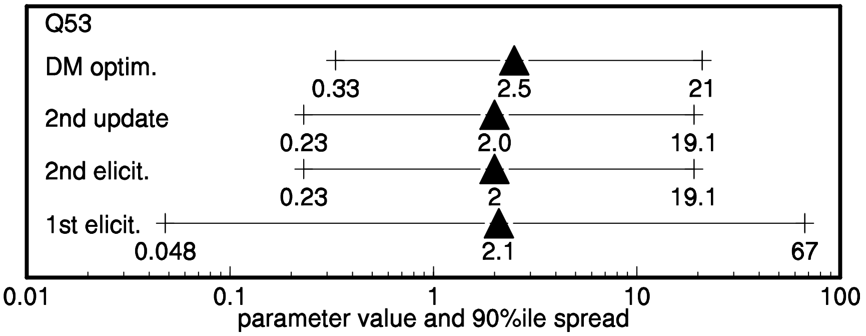

Q48
DM optim.
1.1
8.6
85
2nd update
1.2
9.6
78
2nd elicit.
1.2
7.9
77
1st elicit.
1.2
7.1
59
0.1
1
10
100
parameter value and 90%ile spread

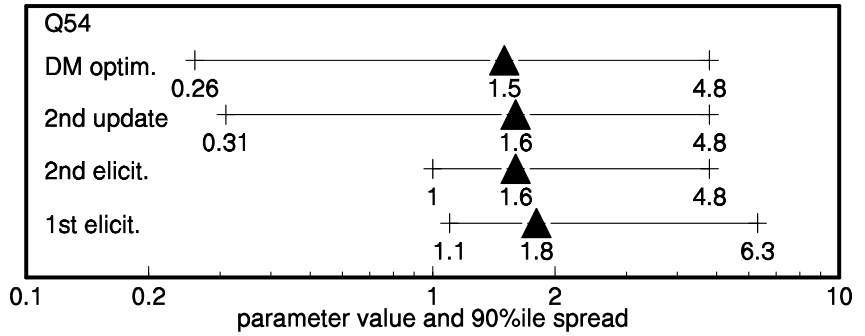

Q49
DM optim.
0.12
1.4
4.5
2nd update
0.14
1.4
4.4
2nd elicit.
0.41
1.4
4.4
1st elicit.
0.37
1.5
8.5
0.01
0.1
1
10
parameter value and 90%ile spread

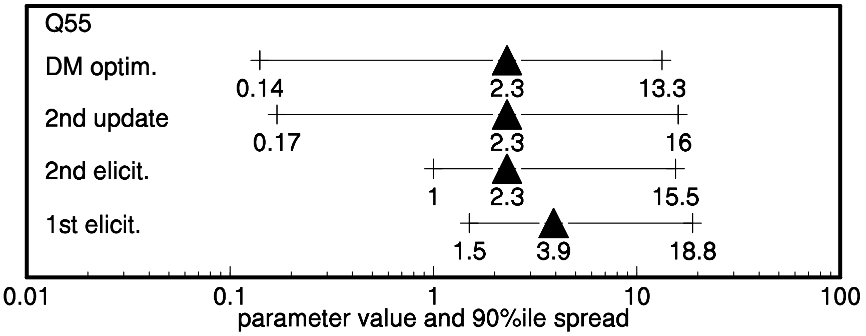

Q50
DM optim.
0.025
2.0
11.6
2nd update
0.030
2.0
15.2
2nd elicit.
0.43
3
18.4
1st elicit.
0.4
2.7
65
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread

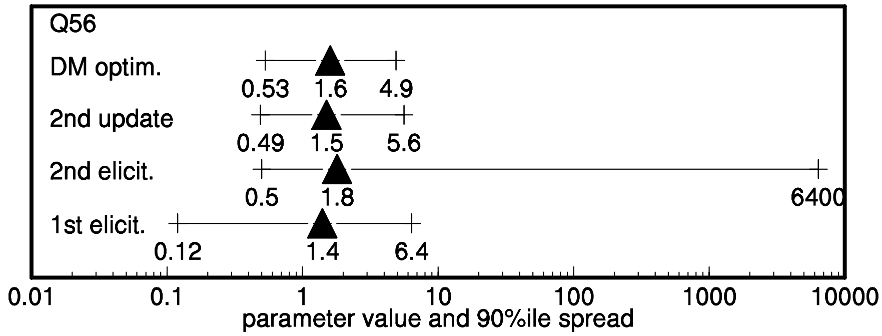

Q51
DM optim.
0.22
0.96
4
2nd update
0.17
0.99
3.6
2nd elicit.
0.17
1
2.5
1st elicit.
0.048
0.77
1.9
0.01
0.1
1
10
parameter value and 90%ile spread

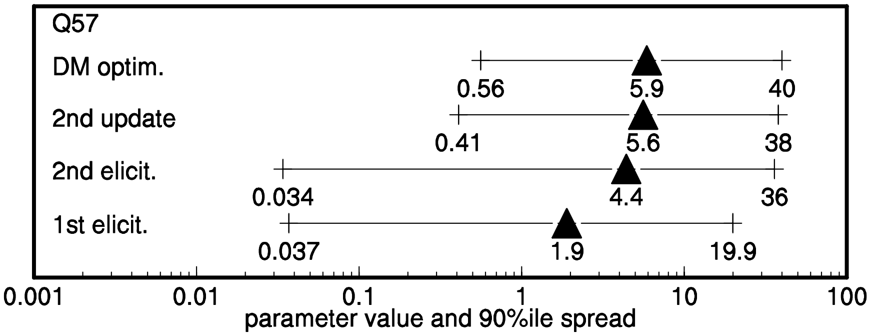

Q52
DM optim.
0.079
1.7
8.8
2nd update
0.080
1.7
8.7
2nd elicit.
0.38
2.1
8.8
1st elicit.
0.11
1.9
74
0.01
0.1
1
10
100
parameter value and 90%ile spread

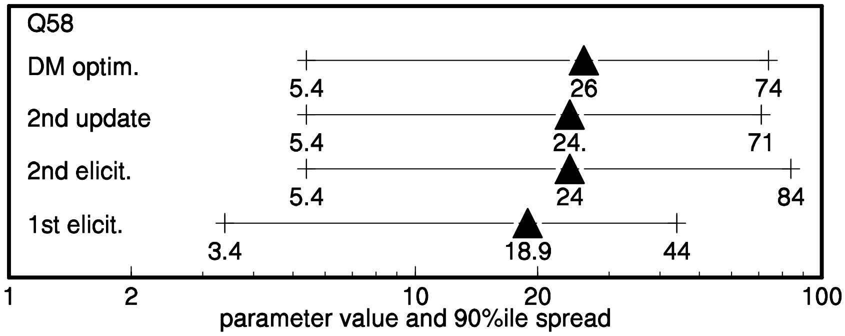

Q53
DM optim.
0.33
2.5
21
2nd update
0.23
2.0
19.1
2nd elicit.
0.23
2
19.1
1st elicit.
0.048
2.1
67
0.01
0.1
1
10
100
parameter value and 90%ile spread

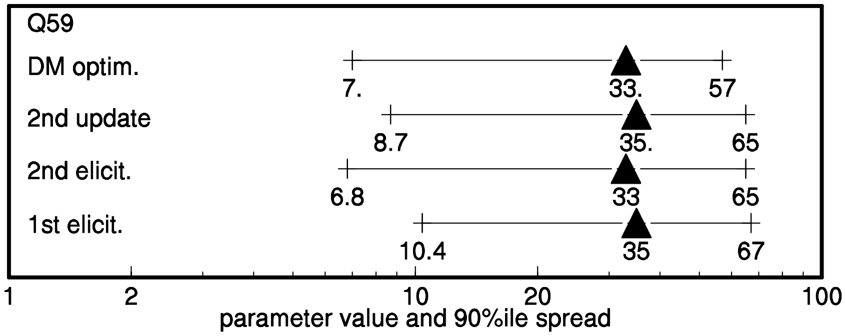

Q54
DM optim.
0.26
1.5
4.8
2nd update
0.31
1.6
4.8
2nd elicit.
1
1.6
4.8
1st elicit.
1.1
1.8
6.3
0.1
0.2
1
2
10
parameter value and 90%ile spread

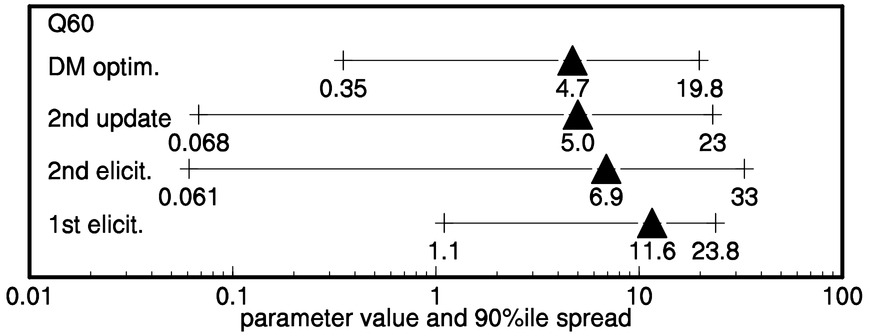

Q55
DM optim.
0.14
2.3
13.3
2nd update
0.17
2.3
16
2nd elicit.
1
2.3
15.5
1st elicit.
1.5
3.9
18.8
0.01
0.1
1
10
100
parameter value and 90%ile spread

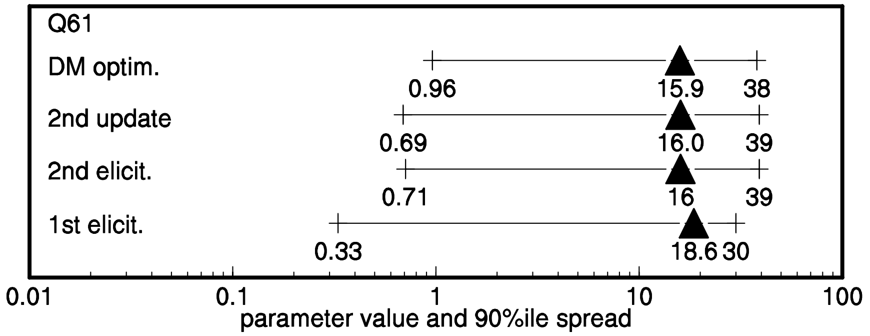

Q56
DM optim.
0.53
1.6
4.9
2nd update
0.49
1.5
5.6
2nd elicit.
0.5
1.8
6400
1st elicit.
0.12
1.4
6.4
0.01
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

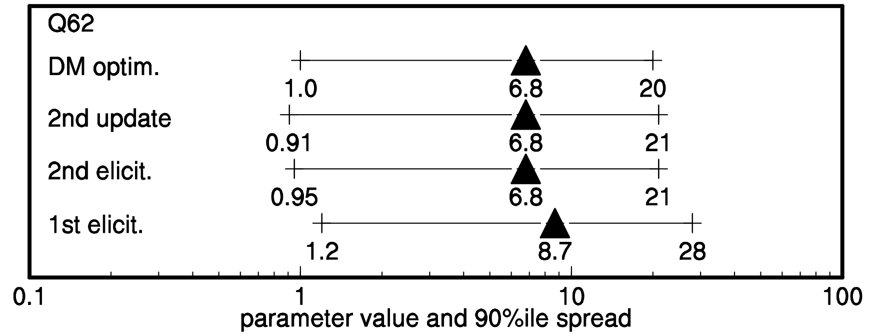

Q57
DM optim.
0.56
5.9
40
2nd update
0.41
5.6
38
2nd elicit.
0.034
4.4
36
1st elicit.
0.037
1.9
19.9
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread

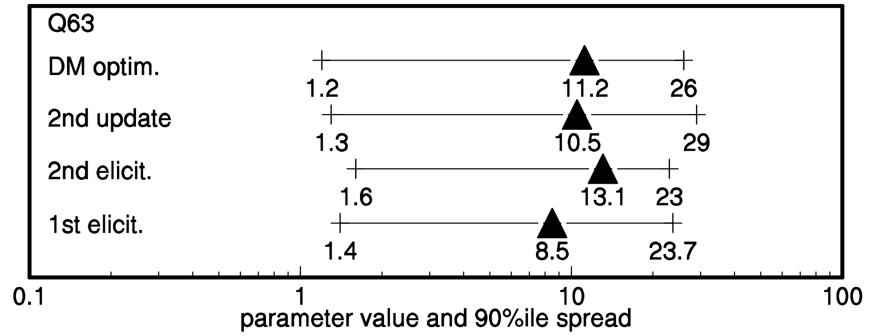

Q58
DM optim.
5.4
26
74
2nd update
5.4
24.
71
2nd elicit.
5.4
24
84
1st elicit.
3.4
18.9
44
1
2
10
20
100
parameter value and 90%ile spread

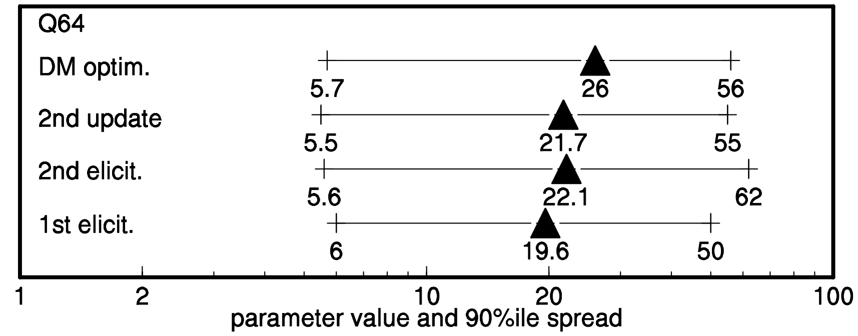

Q59
DM optim.
7.
33.
57
2nd update
8.7
35.
65
2nd elicit.
6.8
33
65
1st elicit.
10.4
35
67
1
2
10
20
100
parameter value and 90%ile spread

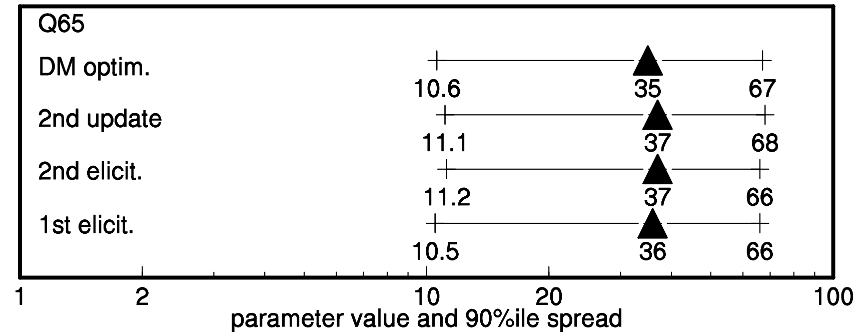

Q60
DM optim.
0.35
4.7
19.8
2nd update
0.068
5.0
23
2nd elicit.
0.061
6.9
33
1st elicit.
1.1
11.6
23.8
0.01
0.1
1
10
100
parameter value and 90%ile spread

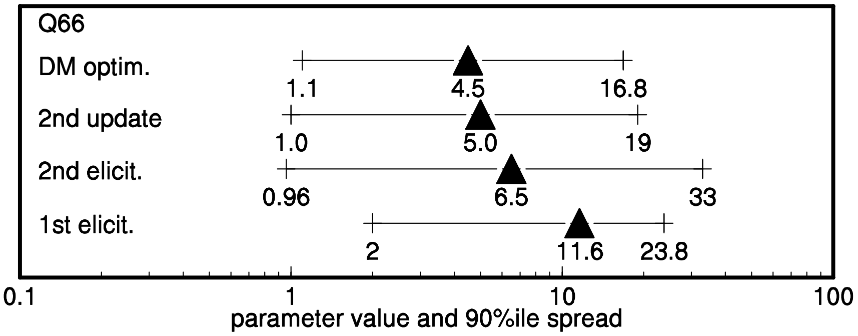

Q61
DM optim.
0.96
15.9
38
2nd update
0.69
16.0
39
2nd elicit.
0.71
16
39
1st elicit.
0.33
18.6
30
0.01
0.1
1
10
100
parameter value and 90%ile spread

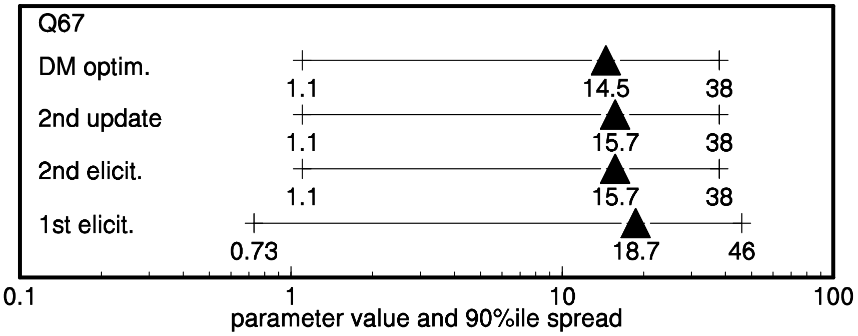

Q62
DM optim.
1.0
6.8
20
2nd update
0.91
6.8
21
2nd elicit.
0.95
6.8
21
1st elicit.
1.2
8.7
28
0.1
1
10
100
parameter value and 90%ile spread

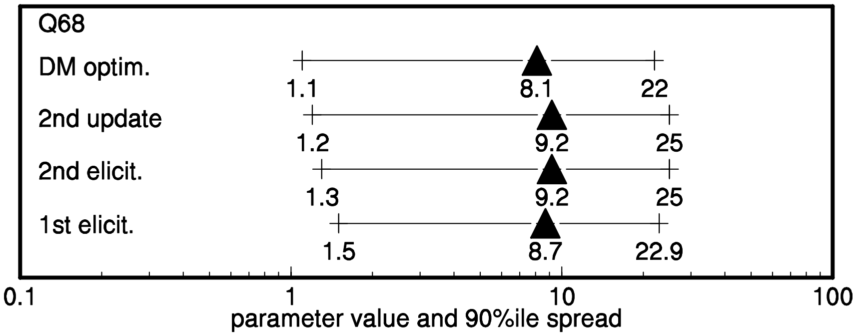

Q63
DM optim.
1.2
11.2
26
2nd update
1.3
10.5
29
2nd elicit.
1.6
13.1
23
1st elicit.
1.4
8.5
23.7
0.1
1
10
100
parameter value and 90%ile spread

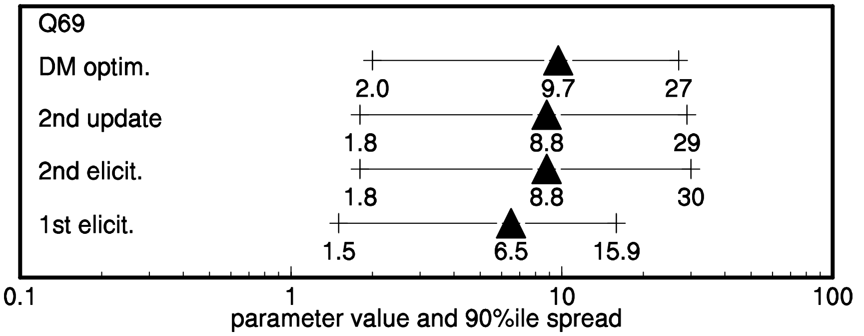

Q64
DM optim.
5.7
26
56
2nd update
5.5
21.7
55
2nd elicit.
5.6
22.1
62
1st elicit.
6
19.6
50
1
2
10
20
100
parameter value and 90%ile spread

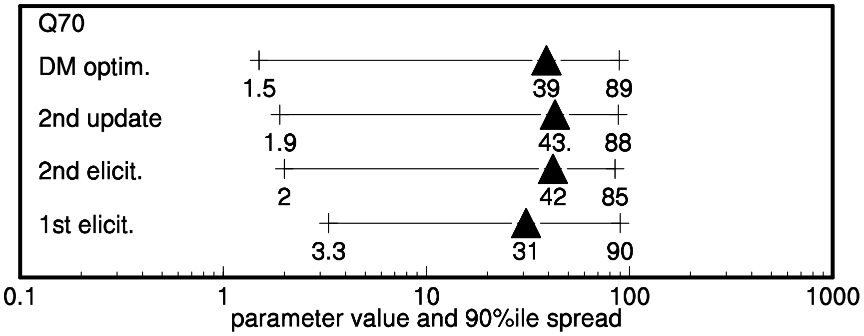

Q65
DM optim.
10.6
35
67
2nd update
11.1
37
68
2nd elicit.
11.2
37
66
1st elicit.
10.5
36
66
1
2
10
20
100
parameter value and 90%ile spread

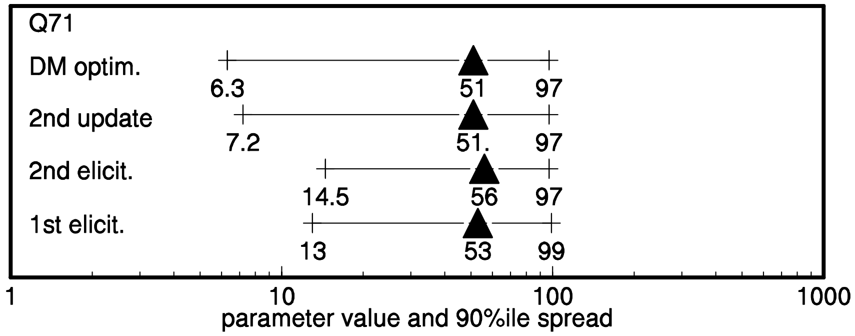

Q66
DM optim.
1.1
4.5
16.8
2nd update
1.0
5.0
19
2nd elicit.
0.96
6.5
33
1st elicit.
2
11.6
23.8
0.1
1
10
100
parameter value and 90%ile spread

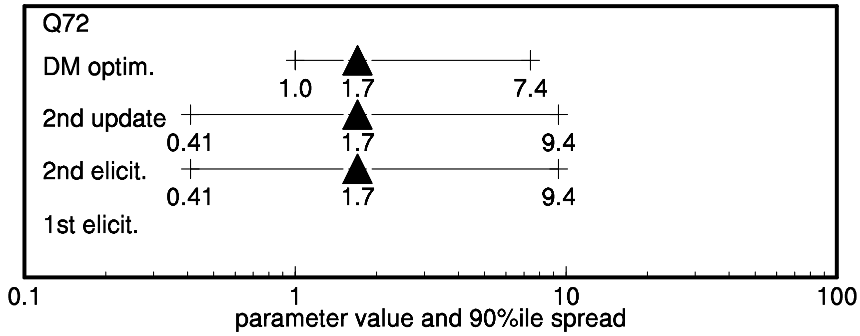

Q67
DM optim.
1.1
14.5
38
2nd update
1.1
15.7
38
2nd elicit.
1.1
15.7
38
1st elicit.
0.73
18.7
46
0.1
1
10
100
parameter value and 90%ile spread

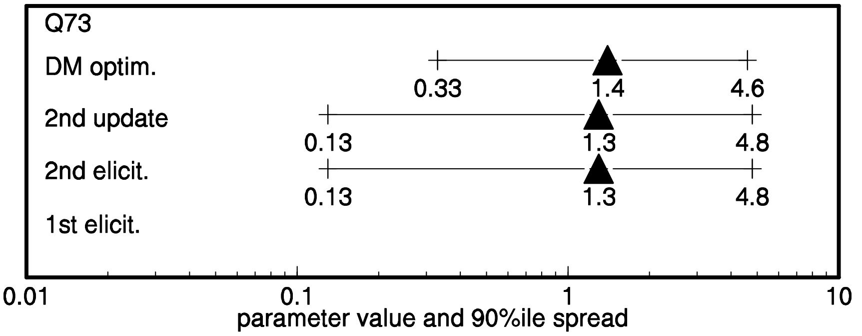

Q68
DM optim.
1.1
8.1
22
2nd update
1.2
9.2
25
2nd elicit.
1.3
9.2
25
1st elicit.
1.5
8.7
22.9
0.1
1
10
100
parameter value and 90%ile spread

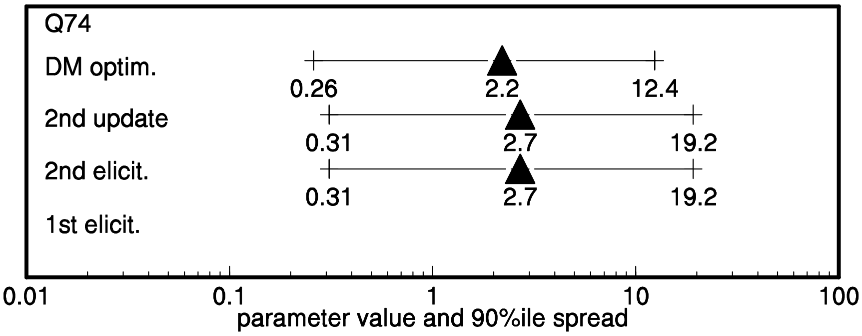

Q69
DM optim.
2.0
9.7
27
2nd update
1.8
8.8
29
2nd elicit.
1.8
8.8
30
1st elicit.
1.5
6.5
15.9
0.1
1
10
100
parameter value and 90%ile spread

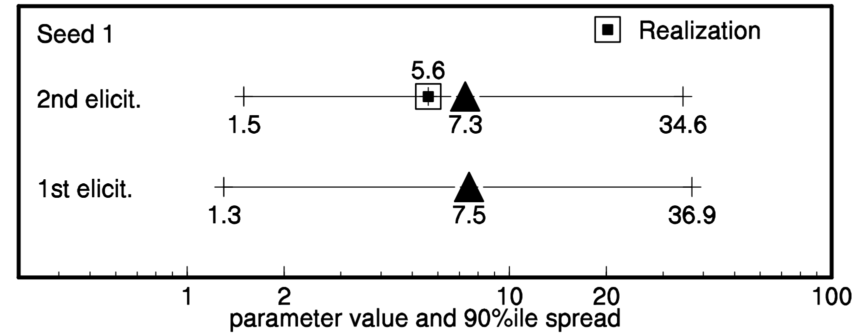

Q70
DM optim.
1.5
39
89
2nd update
1.9
43.
88
2nd elicit.
2
42
85
1st elicit.
3.3
31
90
0.1
1
10
100
1000
parameter value and 90%ile spread

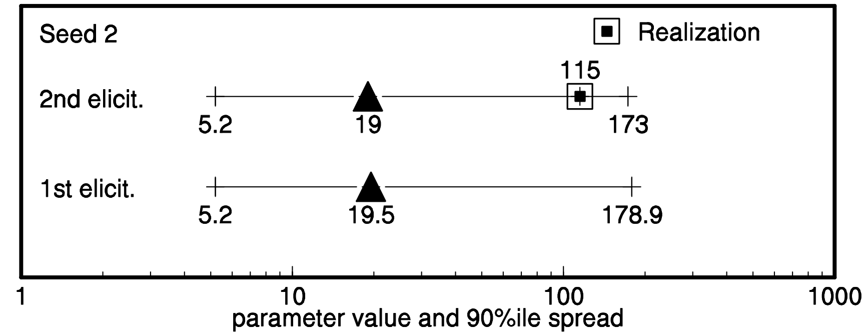

Q71
DM optim.
6.3
51
97
2nd update
7.2
51.
97
2nd elicit.
14.5
56
97
1st elicit.
13
53
99
1
10
100
1000
parameter value and 90%ile spread

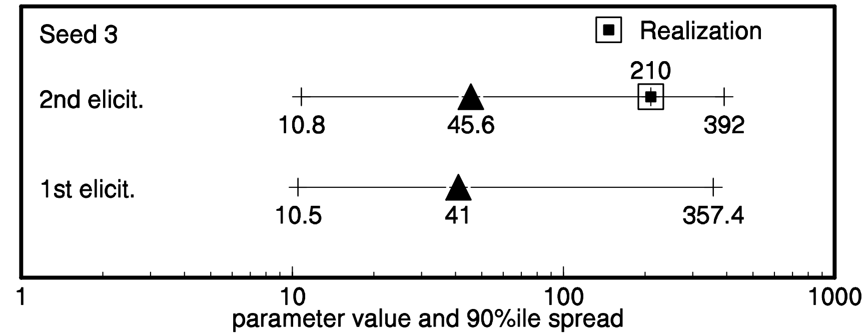

Q72
DM optim.
1.0
1.7
7.4
2nd update
0.41
1.7
9.4
2nd elicit.
0.41
1.7
9.4
1st elicit.
0.1
1
10
100
parameter value and 90%ile spread

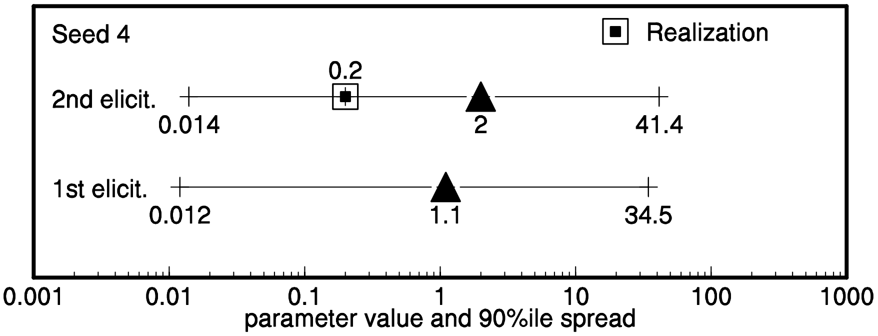

Q73
DM optim.
0.33
1.4
4.6
2nd update
0.13
1.3
4.8
2nd elicit.
0.13
1.3
4.8
1st elicit.
0.01
0.1
1
10
parameter value and 90%ile spread

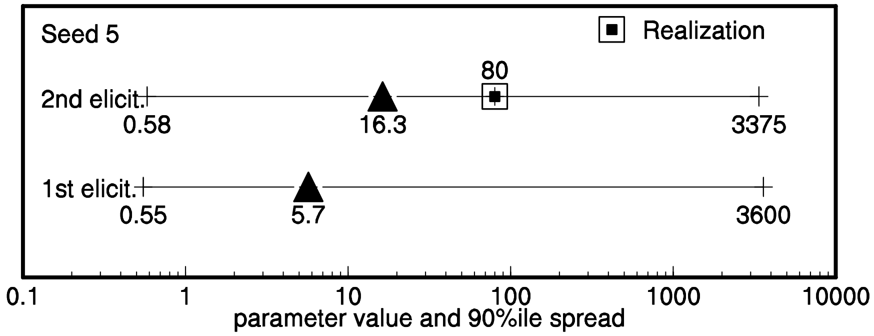

Q74
DM optim.
0.26
2.2
12.4
2nd update
0.31
2.7
19.2
2nd elicit.
0.31
2.7
19.2
1st elicit.
0.01
0.1
1
10
100
parameter value and 90%ile spread

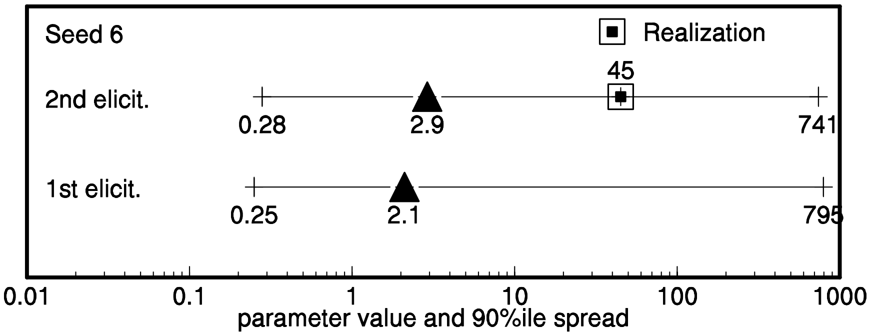

Seed 1
Realization
2nd elicit.
5.6
1.5
7.3
34.6
1st elicit.
1.3
7.5
36.9
1
2
10
20
100
parameter value and 90%ile spread

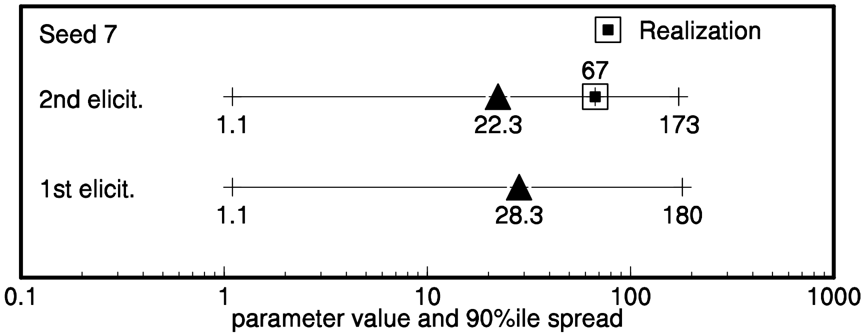

Seed 2
Realization
2nd elicit.
115
5.2
19
173
1st elicit.
5.2
19.5
178.9
1
10
100
1000
parameter value and 90%ile spread

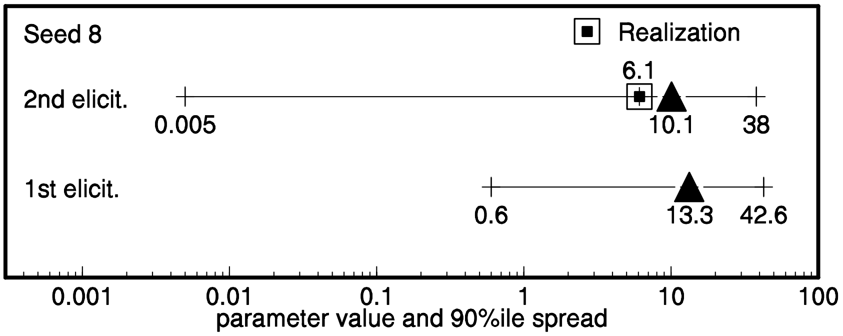

Seed 3
Realization
2nd elicit.
210
10.8
45.6
392
1st elicit.
10.5
41
357.4
1
10
100
1000
parameter value and 90%ile spread

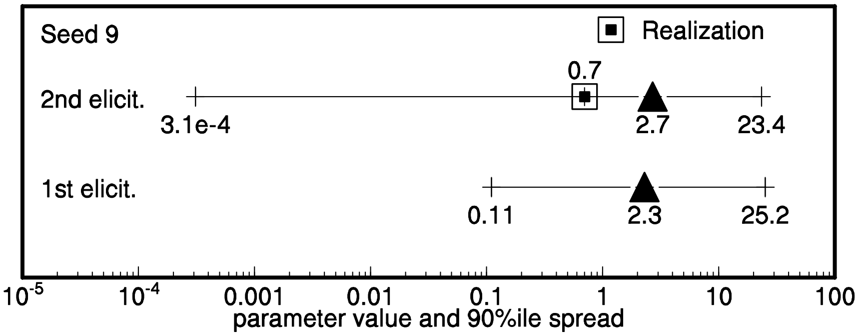

Seed 4
Realization
2nd elicit.
0.2
0.014
2
41.4
1st elicit.
0.012
1.1
34.5
0.001
0.01
0.1
1
10
100
1000
parameter value and 90%ile spread

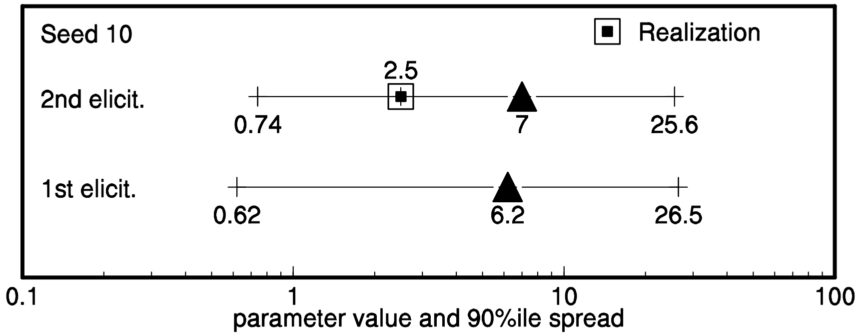

Seed 5
■ Realization
80
2nd elicit.
0.58
16.3
3375
1st elicit.
0.55
5.7
3600
0.1
1
10
100
1000
10000
parameter value and 90%ile spread

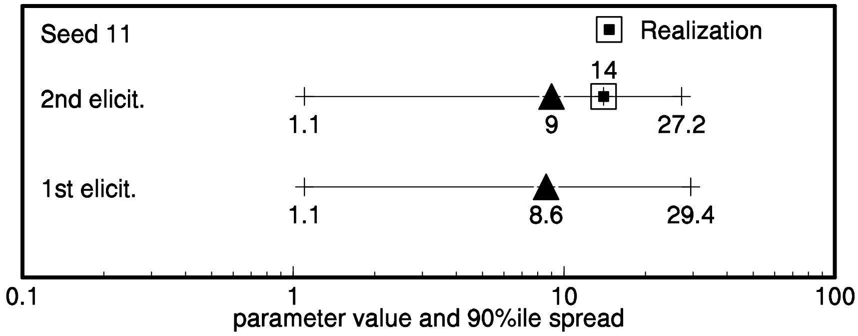

Seed 6
■ Realization
45
2nd elicit.
0.28
2.9
741
1st elicit.
0.25
2.1
795
0.01
0.1
1
10
100
1000
parameter value and 90%ile spread


Seed 7
■ Realization
67
2nd elicit.
1.1
22.3
173
1st elicit.
1.1
28.3
180
0.1
1
10
100
1000
parameter value and 90%ile spread


Seed 8
■ Realization
6.1
2nd elicit.
0.005
10.1
38
1st elicit.
0.6
13.3
42.6
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread


Seed 9
Realization
2nd elicit.
0.7
3.1e-4
2.7
23.4
1st elicit.
0.11
2.3
25.2
10^{-5}
10^{-4}
0.001
0.01
0.1
1
10
100
parameter value and 90%ile spread


Seed 10
Realization
2nd elicit.
2.5
0.74
7
25.6
1st elicit.
0.62
6.2
26.5
0.1
1
10
100
parameter value and 90%ile spread


Seed 11
Realization
2nd elicit.
14
1.1
9
27.2
1st elicit.
1.1
8.6
29.4
0.1
1
10
100
parameter value and 90%ile spread

Appendix 2: Experts' range graphs for the constrained DM optimization case

This appendix contains charts that show, in summary form for each item elicited, the central estimate and 90% confidence range provided by each expert in the group. These plots are taken directly from the program output, produced in line printer format, which are intended for simple visual display and checking purposes. In some cases, however (viz. Q37 – 40, and Q42 – 45), the range graphs have been duplicated and re-plotted to make more apparent the information contained in those particular responses. It should be noted that these plots use a logarithmic horizontal axis, for clarity, whereas the line printer plots are linear in form.

It should be further noted that while the latter carry a header item called 'Scale', which indicates either UNI or LOG as its setting, this refers not to the plotting format but to the way in which variables are assumed to be distributed between quantiles. For UNI, these are uniformly distributed and relative information (entropy) is measured with respect to the uniform distribution (suitably truncated); for LOG, the variables are assumed to be loguniformly distributed between quantiles, and in this case relative information is therefore measured with respect to the log uniform distribution.

In each item range-graph below, the experts have been segregated into those who are de-weighted under the constrained DM optimization criteria (*i.e.* the five experts above the dividing line), and those who are positively weighted (*i.e.* the six below the dotted line). The order of experts in each subgroup can change from plot to plot, so the identities may therefore differ from one to the next.

~~~~
                          Range graph of input data

Item no.:  12 Item name: 12 Scale: uni
Expert
xxx     [----*---------]
xxx          [---------*---------]
xxx          [--------------*---------]
xxx          [--------------*--------------]
xxx          [-------------------*-------------------]
```````````````````````````````````````````````````````````````````````````````````

xxx [*--]
xxx [---*--------------]
xxx        [-*-]
xxx     [----*----]
xxx          [---------*---------]
xxx               [--------------------------------------------*--------------]
DMa [=======*==============================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                      75

Item no.:  13 Item name: 13 Scale: uni
Expert
xxx     [-----*---------]
xxx          [----------*----------]
xxx     [---------------*---------------------]
xxx     [---------------------*---------------]
xxx                                                [-----*--------------------]
```````````````````````````````````````````````````````````````````````````````````

xxx   [-*-]
xxx     *------]
xxx    [---*--------------------------]
xxx [--------*----------]
xxx  [-------------*--------------------------]
xxx                     [----------*----------]
DMa [=======*===============================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                      70

Item no.:  14 Item name: 14 Scale: uni
Expert
xxx [*---]
xxx      [----*----]
xxx      [----*----------]
xxx      [----*---------------------]
xxx  [-------------*---------------------]
```````````````````````````````````````````````````````````````````````````````````

xxx *---]
xxx [--*------]
xxx    [-*-]
xxx    [------*---------------]
xxx          [----*-----]
xxx          [------------------------------------------*--------------------]
DMa [=====*=============================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.2                                                                     70
~~~~

~~~~
Item no.:  15 Item name: 15 Scale: uni
Expert
xxx   [-*-----]
xxx     [----------------*--------------------]
xxx           [----------*----------]
xxx                  [---*--------------------]
xxx           [---------------------*--------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [-*---]
xxx [---*------------]
xxx     [----------------*----------------------------------------------------]
xxx      [--------------*-------------------------------]
xxx                  [---*---]
xxx                      [----------*---------]
DMak [===============*================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     0                                                                      35
~~~~

~~~~
Item no.:  16 Item name: 16 Scale: uni
Expert
xxx            [------*-----------]
xxx            [------------*------------]
xxx                   [-----*-----]
xxx            [------------------*------------------]
xxx                   [------------------------------*------------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [*---]
xxx [--*-]
xxx [--*--------------]
xxx          [-*--]
xxx            [------------------*------------------]
xxx            [-------------------------------*------------------]
DMa [===*=====================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.5                                                                     60
~~~~

~~~~
Item no.:  17 Item name: 17 Scale: uni
Expert
xxx            [---*--------------]
xxx            [------------*-----------]
xxx            [------------*------------------------]
xxx            [------------------------*-------------------------]
xxx                                    [-------------------------*-----------]
```````````````````````````````````````````````````````````````````````````````````
xxx   [--*-]
xxx     [*------------------]
xxx    [----*-------------------------------]
xxx [----------*------------]
xxx      [------------------------------*-------------------------]
xxx                        [-----------*------------]
DMa [============*============================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                      60
~~~~

~~~
Item no.:  18 Item name: 18 Scale: uni
Expert
xxx   [-*-----]
xxx           [----------*----------]
xxx           [----------*--------------------]
xxx                      [----------*---------]
xxx     [-------------------------------------*-------------------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [-*-]
xxx [-*-----]
xxx [-*-------]
xxx     [-*-----]
xxx                      [----------*---------]
xxx           [---------------------*--------------------]
DMa [=====*===========================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.01                                                                    35
~~~

~~~
Item no.:  19 Item name: 19 Scale: uni
Expert
xxx    [-----*----------]
xxx          [----------*----------]
xxx          [----------*---------------------]
xxx          [---------------------*---------------------]
xxx                                           [----------*--------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [--*------------]
xxx    [-*------]
xxx      [---*----]
xxx  [-------*---------------------]
xxx      [--------------*--------------------------------]
xxx                     [----------*----------]
DMa [========*=======================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.4                                                                     35
~~~

~~~
Item no.:  20 Item name: 20 Scale: uni
Expert
xxx  [-*---]
xxx    [---*-------]
xxx    [---*-------]
xxx    [---*-------]
xxx [---------------------*--------------]
```````````````````````````````````````````````````````````````````````````````````
xxx  [-*]
xxx [--*-----------]
xxx [------*-------]
xxx        [----------*-----------]
xxx    [--------------*------------------]
xxx                   [------------------*------------------------------------]
DMa [=======*=================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     0                                                                     100
~~~

~~~~
Item no.:  21 Item name: 21 Scale: UNI
Expert
xxx    [--*-------]
xxx    [--*-------]
xxx    [----------*------]
xxx           [-------*----------]
xxx               [----------------------*----------]
```````````````````````````````````````````````````````````````````````````````````
xxx   [*-]
xxx [-----*--------------]
xxx       [-------*------]
xxx    [---------------------*------------------]
xxx                      [----------------------*----------------------]
xxx                      [----------------------*-----------------------------]
DMa [==========*===============================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                     100
~~~~

~~~~
Item no.:  22 Item name: 22 Scale: uni
Expert
xxx    [--*-]
xxx   [---*-----]
xxx   [---*-----]
xxx       [-----*------------]
xxx           [-------*------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [*]
xxx  [----*-----]
xxx [-----------*------------]
xxx             [------------------*------------------]
xxx       [------------------------*------------------------------]
xxx       [------------------------*------------------------------------------]
DMak [===================*==============================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     0                                                                      60
~~~~

~~~~
Item no.:  23 Item name: 23 Scale: UNI
Expert
xxx      [---*-]
xxx  [-------*--------]
xxx    [-----*--------]
xxx    [-----*--------]
xxx    [--------------*------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [*-]
xxx  [-------*--------]
xxx          [--------*---------]
xxx      [------------*----------------------------------------------]
xxx                   [------------------*------------------]
xxx      [-------------------------------*------------------------------------]
DMake [================*===============================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     0                                                                      40
~~~~

~~~~
Item no.:  24 Item name: 24 Scale: uni
Expert
xxx  [*]
xxx    [---*-------]
xxx    [---*-------]
xxx        [---*------]
xxx            [------------------*----------]
```````````````````````````````````````````````````````````````````````````````````
xxx [-*]
xxx [--*-----------]
xxx [------*-------]
xxx        [-------*------]
xxx    [------------------*----------------------]
xxx    [---------------------------------*------------------------------------]
DMa [=======*==================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     0                                                                     100

Item no.:  25 Item name: 25 Scale: uni
Expert
xxx    [--*-------]
xxx    [--*-------]
xxx       [---*---]
xxx       [---*-------]
xxx       [------------------------------*------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx    [--*---]
xxx [-----*--------------]
xxx       [-------*------]
xxx    [-------------------------*----------]
xxx                   [------------------*------------------------------------]
xxx                      [----------------------*----------------------]
DMa [===========*=============================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                     100


Item no.:  26 Item name: 26 Scale: uni
Expert
xxx    [-*---]
xxx   [--*-----]
xxx   [--*-----]
xxx  [---*-----------]
xxx      [-----*-----]
```````````````````````````````````````````````````````````````````````````````````
xxx  [*]
xxx  [---*-----]
xxx [----------*-----------]
xxx      [-----------------*--------------------------------------------------]
xxx            [----------------*-----------------]
xxx      [----------------------------*----------------------]
DMak [=======*===================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     0                                                                      65
~~~~

~~~
Item no.:  27 Item name: 27 Scale: uni
Expert
xxx    [-*---]
xxx   [--*-----]
xxx   [--*-----]
xxx  [---*-----------]
xxx   [--------------*----------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [*]
xxx  [---*-----]
xxx      [-----*-----]
xxx            [-----------*----------]
xxx      [-----------------*--------------------------------------------------]
xxx    [------------------------*-----------------]
DMa [=======*====================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.01                                                                    65

Item no.:  28 Item name: 28 Scale: LOG
Expert
xxx                                      [-----*---]
xxx [-------------------------------------------------*-------------------]
xxx                                                   [-*------]
xxx                                                [-----*------]
xxx                                                      [---*]
```````````````````````````````````````````````````````````````````````````````````
xxx                                         [----*-]
xxx                               [----------------*------]
xxx                               [-----------------*-----------]
xxx                                                [-----*-]
xxx                                                [---------*---------]
xxx                                                       [------------*------]
DMaker 1                           [======================*==================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.0001                                                                2740


Item no.:  29 Item name: 29 Scale: LOG
Expert
xxx                                      [-----*---]
xxx [-------------------------------------------------*-------------------]
xxx                                                   [---*-----]
xxx                                                [---------*------]
xxx                                                      [----*]
```````````````````````````````````````````````````````````````````````````````````
xxx                                         [----*-]
xxx                               [----------------*------]
xxx                               [-----------------*-----------]
xxx                                                   [--*--]
xxx                                                   [--------*---------]
xxx                                                    [-------------------*--]
DMaker 1                           [======================*===================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.0001                                                                2740
~~~

~~~
Item no.:  30 Item name: 30 Scale: LOG
Expert
xxx [----*-----------]
xxx                        [-----------------*----------------]
xxx                                          [---------*------]
xxx                                               [-----*---]
xxx                                               [-----*-----------------]
```````````````````````````````````````````````````````````````````````````````````
xxx      [-----------------*--------------------------------------------------]
xxx         [---------------------*-------------]
xxx                        [-------*---]
xxx                             [-------------*----]
xxx                               [----------*-------]
xxx                                    [-----*--]
DMaker 1     [============================*=========================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.5                                                                   8000
~~~

~~~
Item no.:  31 Item name: 31 Scale: LOG
Expert
xxx [----*------------]
xxx                        [------------------*-----------------]
xxx                                           [----------*------]
xxx                                                [------*---]
xxx                                                    [-------*--------------]
```````````````````````````````````````````````````````````````````````````````````
xxx      [------------*------------------------------------------------------]
xxx         [------------------*------------------]
xxx                        [--------*---]
xxx                              [------------*----]
xxx                                     [--------*---]
xxx                                     [--------*---------]
DMaker 1    [===============================*======================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.5                                                                   6000
~~~

~~~
Item no.:  32 Item name: 32 Scale: LOG
Expert
xxx                   [-------*------------------]
xxx                   [-------*------------------]
xxx                           [--------*---]
xxx                                              [-------*--------]
xxx                                                                   [-----*-]
```````````````````````````````````````````````````````````````````````````````````
xxx [-----------------*----------------]
xxx                   [----------------*-----------------]
xxx                           [------------*-----]
xxx                           [------------------*-------]
xxx                                    [-----------------*------------]
xxx                                              [-------*------------]
DMaker 1 [====================================*======================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.001                                                                  0.6
~~~

~~~~
Item no.:  33 Item name: 33 Scale: LOG
Expert
xxx         [--------*-------------]
xxx         [-------------*---]
xxx         [-------------------*--------]
xxx                                                          [--------*----]
xxx                                                          [--------*-------]
```````````````````````````````````````````````````````````````````````````````````
xxx [-------*--------]
xxx                  [----------------*-------------------]
xxx                             [-----------------*-------]
xxx                                      [--------*----------]
xxx                                      [----------*--------]
xxx                                      [-------------------*--------]
DMake [========================================*==================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.005                                                                    2
~~~~

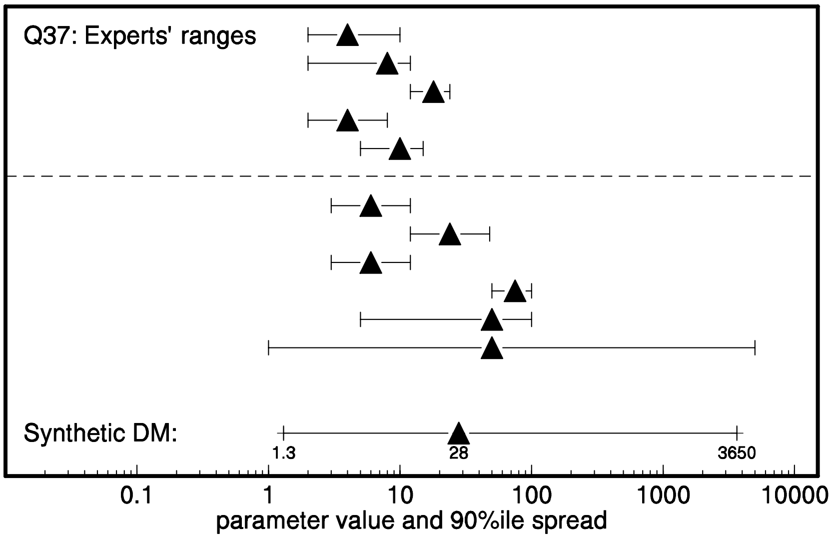
~~~~
Item no.:  34 Item name: 34 Scale: LOG
Expert
xxx                                    [-----*------------]
xxx                                        [-*--------------]
xxx                                              [-*-]
xxx                                                    [----*]
xxx                                                               [-----*-----]
```````````````````````````````````````````````````````````````````````````````````
xxx [-------------*------------]
xxx                            [-------*---------]
xxx                                    [-----*------------]
xxx                                          [-----*--------]
xxx                                          [---------*-----]
xxx                                                         [-----*-----]
DMake [=========================================*======================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.001                                                                    4
~~~~

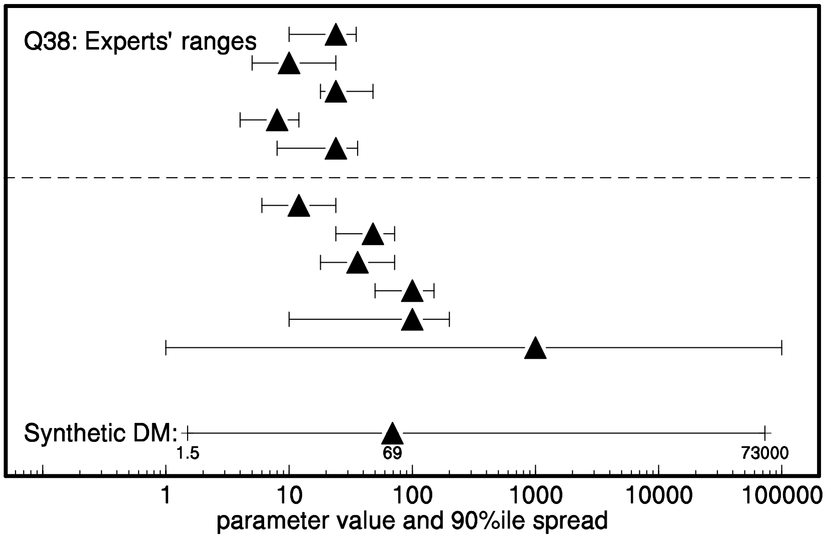
~~~~
Item no.:  35 Item name: 35 Scale: LOG
Expert
xxx                             [---------*--------]
xxx                                       [--------*---]
xxx                                       [--------*------]
xxx                                                [------*----]
xxx                                                               [------*----]
```````````````````````````````````````````````````````````````````````````````````
xxx [-------------*-----------------------]
xxx                                [------*----------]
xxx                                [---------------*--------------]
xxx                                       [--------*------]
xxx                                         [-------------*-------]
xxx                                                    [-------*---------]
DMake [===========================================*====================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.005                                                                    7
~~~~

~~~
Item no.:  36 Item name: 36 Scale: LOG
Expert
xxx                               [-------*--------]
xxx                                       [----*---]
xxx                                             [--*------------]
xxx                                             [-------*]
xxx                                                                [------*---]
```````````````````````````````````````````````````````````````````````````````````
xxx [--------------------------*-------------------]
xxx                                       [--------*----]
xxx                                       [--------*-------]
xxx                                       [----------------*----------]
xxx                                                [-------*----------]
xxx                                                [-------*--------------]
DMaker  [============================================*==================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.02                                                                    10

Item no.:  37 Item name: 37 Scale: UNI
Expert
xxx |
xxx |
xxx |
xxx |
xxx |
```````````````````````````````````````````````````````````````````````````````````
xxx |
xxx |
xxx |
xxx []
xxx *]
xxx *-------------------------------------------------------------------------]
DMa *=====================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                    5000

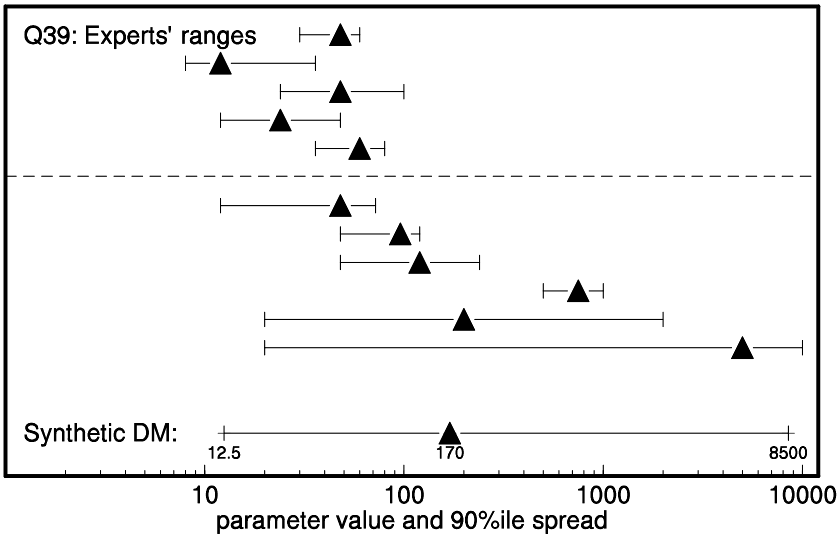

Item no.:  38 Item name: 38 Scale: UNI
Expert
xxx |
xxx |
xxx |
xxx |
xxx |
```````````````````````````````````````````````````````````````````````````````````
xxx |
xxx |
xxx |
xxx |
xxx |
xxx *-------------------------------------------------------------------------]
DMa *=====================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                     1E5
~~~

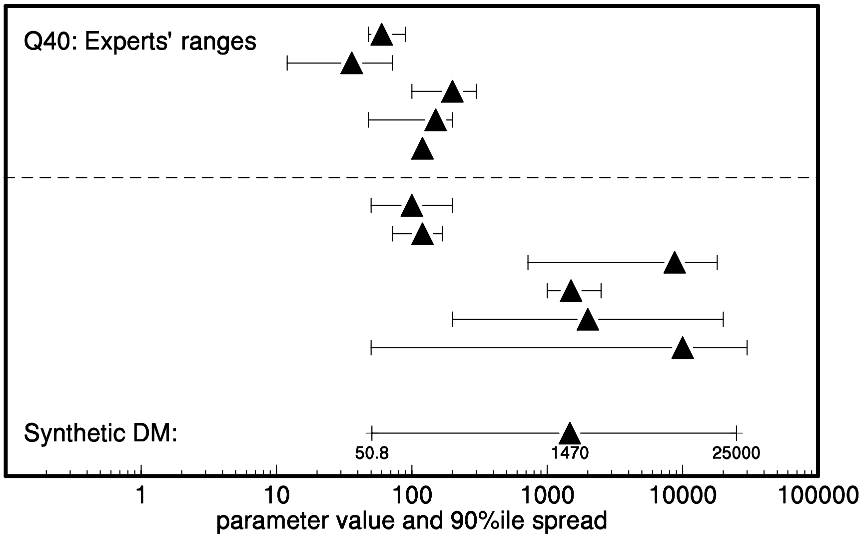

Q37: Experts' ranges
Synthetic DM:
1.3
28
3650
0.1
1
10
100
1000
10000
parameter value and 90%ile spread


Q38: Experts' ranges
Synthetic DM:
1.5
69
73000
1
10
100
1000
10000
100000
parameter value and 90%ile spread

~~~~
Item no.:  39 Item name: 39 Scale: UNI
Expert
xxx |
xxx |
xxx |
xxx |
xxx |
```````````````````````````````````````````````````````````````````````````````````
xxx |
xxx |
xxx *]
xxx [*------------]
xxx    [-*-]
xxx [------------------------------------*------------------------------------]
DMa [*=============================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     8                                                                     1E4
~~~~

~~~~
Item no.:  40 Item name: 40 Scale: UNI
Expert
xxx |
xxx |
xxx |
xxx |
xxx |
```````````````````````````````````````````````````````````````````````````````````
xxx |
xxx |
xxx   [*--]
xxx [---*--------------------------------------------]
xxx  [-------------------*----------------------]
xxx [-----------------------*-------------------------------------------------]
DMa [==*==========================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    12                                                                     3E4
~~~~
```

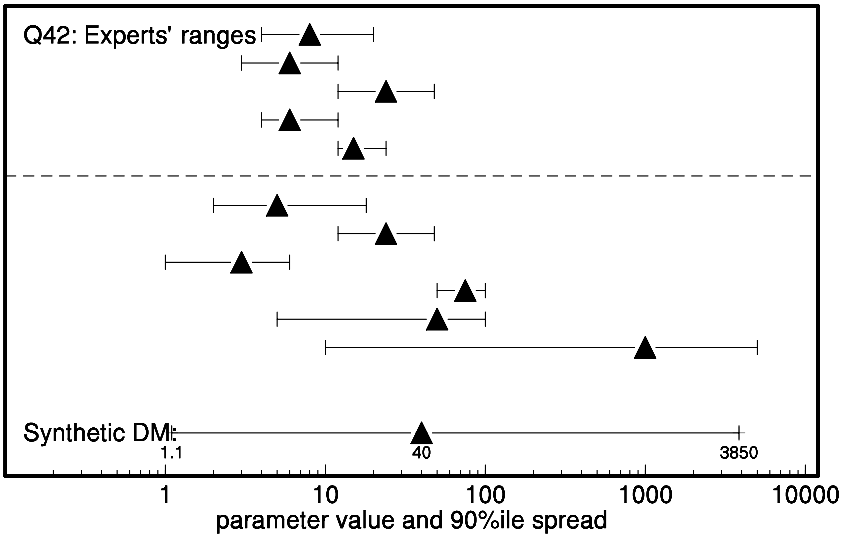

Q39: Experts' ranges
Synthetic DM:
12.5
170
8500
10
100
1000
10000
parameter value and 90%ile spread

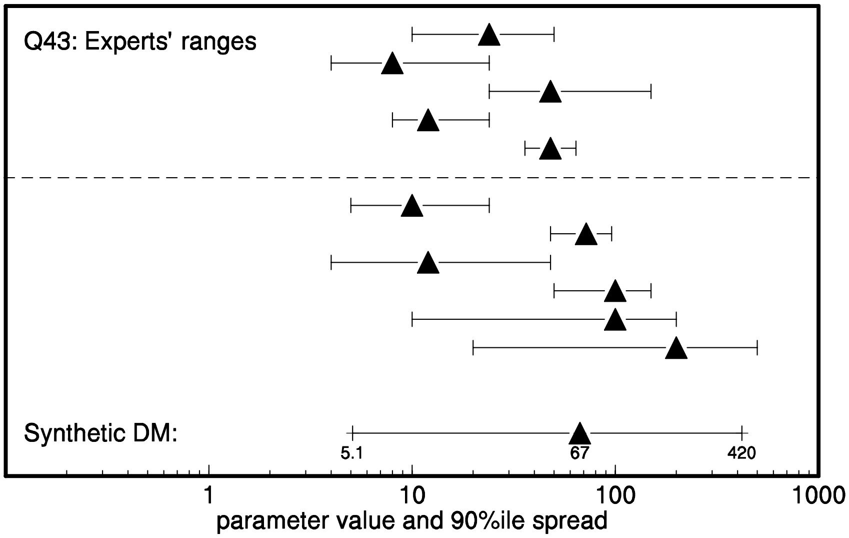

Q40: Experts' ranges
Synthetic DM:
50.8
1470
25000
1
10
100
1000
10000
100000
parameter value and 90%ile spread

~~~
Item no.:  41 Item name: 41 Scale: LOG
Expert
xxx [-----*---]
xxx    [------*------]
xxx           [--*--------]
xxx                  [----*---]
xxx                              [------*--------]
```````````````````````````````````````````````````````````````````````````````````
xxx         [--*--]
xxx       [---------------*------]
xxx                              [------*------]
xxx                                     [----------------------*--------------]
xxx                                 [---------------------------------*------]
xxx       [-------------------------------------------------------------*-----]
DMaker 1    [================================*================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    50                                                                     1E5
~~~

~~~
Item no.:  42 Item name: 42 Scale: UNI
Expert
xxx |
xxx |
xxx |
xxx |
xxx |
```````````````````````````````````````````````````````````````````````````````````
xxx |
xxx |
xxx |
xxx []
xxx *]
xxx [-------------*-----------------------------------------------------------]
DMa *========================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                    5000
~~~

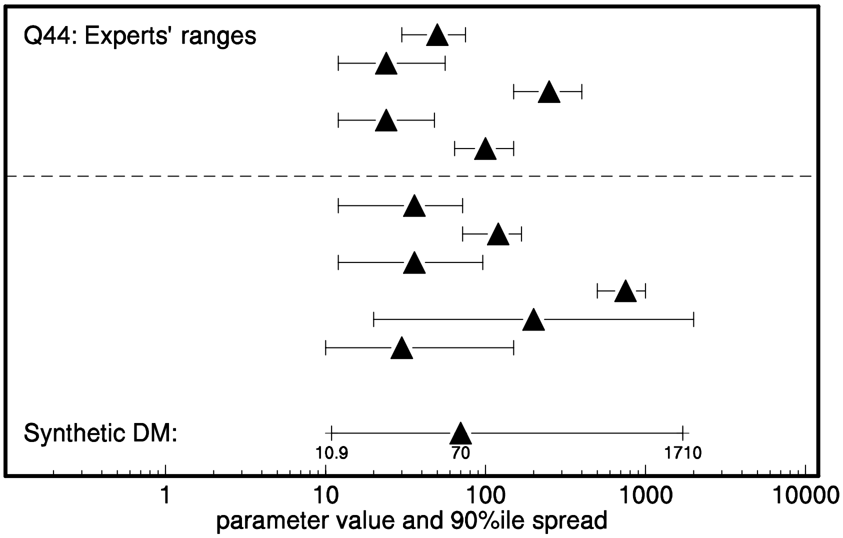
~~~
Item no.:  43 Item name: 43 Scale: UNI
Expert
xxx *--]
xxx [*-]
xxx [--*--]
xxx     [-*--]
xxx    [--*---------------]
```````````````````````````````````````````````````````````````````````````````````
xxx *--]
xxx [*----]
xxx       [---*--]
xxx       [-------*-------]
xxx [-------------*--------------]
xxx   [--------------------------*--------------------------------------------]
DMa [========*====================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     4                                                                     500
~~~

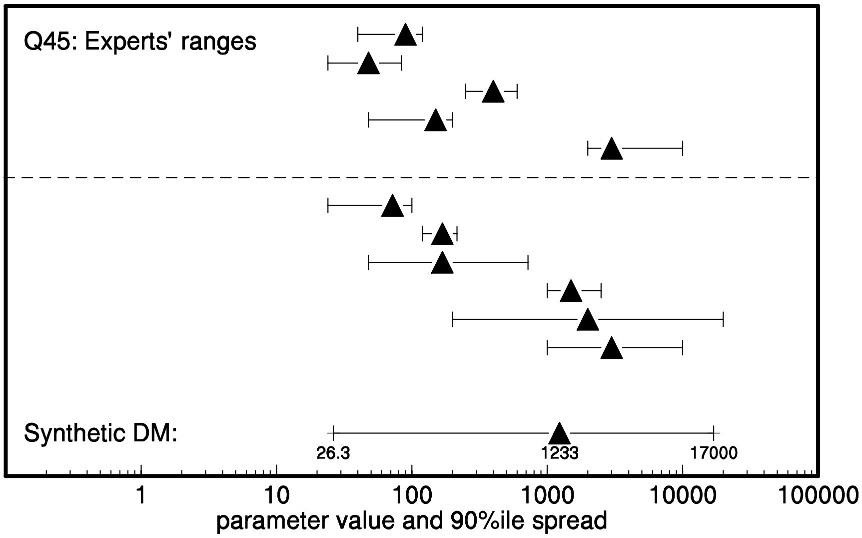

Q42: Experts' ranges
Synthetic DM:
1.1
40
3850
1
10
100
1000
10000
parameter value and 90%ile spread


Q43: Experts' ranges
Synthetic DM:
5.1
67
420
1
10
100
1000
parameter value and 90%ile spread

```
Item no.:  44 Item name: 44 Scale: UNI
Expert
xxx *]
xxx *]
xxx [*]
xxx   [*-]
xxx      [---*----]
```````````````````````````````````````````````````````````````````````````````````
xxx *-]
xxx *--]
xxx *----]
xxx   [-*]
xxx [------*--]
xxx   [--------*---------]
DMa [=*==]
    ~~~~~~
    10   2000
```

```
Item no.:  45 Item name: 45 Scale: UNI
Expert
xxx |
xxx |
xxx |
xxx [*]
xxx        [---*-------------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx |
xxx |
xxx *-]
xxx   [-*---]
xxx [------*--]
xxx   [-------*-------------------------]
DMa [===*===]
    ~~~~~~
    24   2E4
```
```


Q44: Experts' ranges
Synthetic DM:
10.9
70
1710
1
10
100
1000
10000
parameter value and 90%ile spread


Q45: Experts' ranges
Synthetic DM:
26.3
1233
17000
1
10
100
1000
10000
100000
parameter value and 90%ile spread

~~~
Item no.:  46 Item name: 46 Scale: LOG
Expert
xxx      [--*------]
xxx           [--*-------]
xxx                [--*-------]
xxx [------------------*-----------------------]
xxx                         [---*---]
```````````````````````````````````````````````````````````````````````````````````
xxx                 [-*-]
xxx          [-----------*--------]
xxx              [---------------*---------]
xxx                                 [------*-----]
xxx                                        [--------------------*-------------]
xxx                                           [----------*------]
DMaker 1       [================================*===========================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    27                                                                     1E5
~~~

~~~
Item no.:  47 Item name: 47 Scale: UNI
Expert
xxx [--*-----------]
xxx [--*-----------]
xxx [------*-------]
xxx    [-------*-------]
xxx    [-----------*-------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [--*----------------------------------------------------------------------]
xxx   [--*-----]
xxx  [-----*-------------------]
xxx [------*---------------------------]
xxx    [-------*---------------]
xxx      [---------*---------]
DMa [=======*=======================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                      20
~~~

~~~
Item no.:  48 Item name: 48 Scale: UNI
Expert
xxx [*---]
xxx [--*--]
xxx [----*--]
xxx  [---------*-------------------------]
xxx       [-------*----------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [--*--------------]
xxx [--*--------------]
xxx [--*----------------------------------------------------------------------]
xxx [----*------------]
xxx    [--*-------]
xxx       [---*---]
DMa [====*=========================================================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
     1                                                                     100
~~~

```
Item no.:  49 Item name: 49 Scale: UNI
Expert
xxx           [-*]
xxx       [------*---------------]
xxx       [--------------*-------------------------------------]
xxx              [---------------*--------------]
xxx              [------------------------------*-----------------------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [*----]
xxx   [---*--]
xxx   [*---------------]
xxx   [-----------*-------]
xxx   [-------*-----------------------------]
xxx   [---------------*--]
DMa [==================*===]
    ~~~~~~
    0.1   5
```

```
Item no.:  50 Item name: 50 Scale: LOG
Expert
xxx                                          [*--]
xxx                                         [----------*------]
xxx                                                [--------*---]
xxx                                                [--------*------]
xxx                                                [--------*------]
```````````````````````````````````````````````````````````````````````````````````
xxx [------*--------]
xxx   [-------*---]
xxx   [*------]
xxx   [--------*------]
xxx   [-----------*------]
xxx   [---------------*----------]
DMake [==*=================]
    ~~~~~~
    0.02   30
```

```
Item no.: 51 Item name: 51 Scale: LOG
Expert
xxx [---------------------*-------------------------]
xxx   [-------*---------]
xxx   [--------------*----------------------]
xxx   [--*-----------------]
xxx   [-*------]
```````````````````````````````````````````````````````````````````````````````````
xxx                       [--------------*----------]
xxx                              [---------------*--]
xxx                                      [----------*-----------]
xxx                                                 [------*----]
xxx                                                 [------*----------]
xxx                                                        [----*-------------]
DMaker 1                   [========================*======================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.05                                                                     5
```

~~~~
Item no.:  52 Item name: 52 Scale: LOG
Expert
xxx                     [-------*---------------------]
xxx                                            [--*---]
xxx                             [---------------------*---------]
xxx                                                   [---------*--------]
xxx                                                   [-------------*---------]
```````````````````````````````````````````````````````````````````````````````````
xxx *-------------]
xxx   [----------*-----]
xxx   [-----*----------]
xxx   [----------*-------------]
xxx   [----------------------*-----------------]
xxx   [--------------------*-------------]
DMa [==*========================]
    ~~~~~~
    0.079   10

Item no.: 53 Item name: 53 Scale: LOG
Expert
xxx   [----*-------------------]
xxx   [---------*--------------]
xxx   [--*--]
xxx   [--------*-----]
xxx   [------------*-----------------]
```````````````````````````````````````````````````````````````````````````````````
xxx [-------------*------]
xxx                 [--------------*--------------]
xxx                                [--------*---------]
xxx                                [--------*------------]
xxx                                  [------*---------]
xxx                                         [---------------------*-----------]
DMaker 1            [==========================*============================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.1                                                                     25


Item no.:  54 Item name: 54 Scale: LOG
Expert
xxx                                    [-*---]
xxx                                    [--------------*-------------------]
xxx                                    [--------------*-----------------------]
xxx                                    [-----------------------*----------]
xxx                                    |
```````````````````````````````````````````````````````````````````````````````````
xxx [-------------------*---------]
xxx   [--------*-----]
xxx   [--------*-------------------------]
xxx   [--------------*---------------]
xxx   [----------*-------------------]
xxx   [--------*-------------------]
DMaker 1 [=======================================*========================]
    ~~~~~~
    0.2   6
~~~~

~~~
Item no.:  55 Item name: 55 Scale: LOG
Expert
xxx                               |
xxx                               [----*---]
xxx                               [--------------------*--------]
xxx                                        [-----------*--------]
xxx                                                          [--*-]
```````````````````````````````````````````````````````````````````````````````````
xxx [-------------*------------]
xxx                               [--------*----]
xxx                               [--------*--------]
xxx                               [-----------*-----------------]
xxx                                    [---------------*--------]
xxx                                        [--------------------*-------------]
DMaker  [====================================*======================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.1                                                                     30
~~~

~~~
Item no.:  56 Item name: 56 Scale: LOG
Expert
xxx [-------------*---------------------------]
xxx                             [--*-]
xxx               [---------------------------*-------------]
xxx                             [---------------------*-----------------------]
xxx                                                   [---------*------]
```````````````````````````````````````````````````````````````````````````````````
xxx               [--------*------------]
xxx                  [----------*------]
xxx                             [-------*-----]
xxx               [---------------------------*-----------------]
xxx                             [-------------*-----------------]
xxx                                [----------*-----------------]
DMaker 1           [=====================*======================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.25                                                                    10
~~~

~~~
Item no.:  57 Item name: 57 Scale: LOG
Expert
xxx             [--------*---------]
xxx                      [---------------------*---------]
xxx                                [-----------*------------------]
xxx                                     [----------------*-------]
xxx                                                      [----*---]
```````````````````````````````````````````````````````````````````````````````````
xxx [-----------*-----]
xxx                      [------------*------------------]
xxx                                [-----------*---------]
xxx                                [-----------*------------------------------]
xxx                                     [----------------*--------------------]
xxx                                            [------------------*--------]
DMaker 1          [==============================*=========================]
    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    0.2                                                                     50
~~~

~~~
Item no.:  58 Item name: 58 Scale: UNI
Expert
xxx [------*----]
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APPENDIX F : POSSIBLE TECHNIQUES FOR EARLY DETECTION OF INTERNAL EROSION

F.1 Introduction

This section describes the results of the review of possible techniques, including consultation with manufacturers.

Relevant textbooks on the subject include

		Title	Remarks
Dunnicliff	1988	Geotechnical Instrumentation for monitoring field performance	Provides a good summary of the range and capabilities of conventional instrumentation.
ICOLD	2001	Bulletin 118 Automatic dam monitoring systems	
ICOLD	1993	Bulletin 90 - Dams and Environment geophysical impacts	
ICOLD	1992	Bulletin 97 - Improvement of existing dam monitoring Recommendations and case histories	
Bedmar and Araguas	2002	Detection and prevention of leakage from dams	The use of natural and artificial tracers to detect foundation leakage is described in a textbook by (2002, Balkema).

Sampling of the dam can be subdivided into two main groups; “point samples” and “volume samples”. Common problems with most forms of volume, or “zonal”, sample are

a) the fact that data is generally obtained by readings taken along linear “runs”; whereas the reality of performance of the dam may be strongly three dimensional.
b) Although the parameter can be measured fairly easily, it is often difficult to interpret the significance of the readings to dam performance

Thus although in many cases obtaining data is relatively straightforward the difficulties come in interpretation of the readings; particularly where a number of parallel sets of readings are taken to provide a 3D picture. This is particularly true of geophysical techniques. Summary comments on possible zonal techniques are given in Table F.1, with more detailed comment in the following sections.

The section is ordered into

a) geotechnical instruments
b) survey techniques
c) tracers, including temperature sensing
d) geophysical techniques

Table F.1 : Summary of techniques which sample internally more than a single point (Zonal techniques)

Name (listed alphabetically)	Description of technique Principle	Equipment	Typical applications? Remarks	Applicability to internal erosion			Remarks
				Seepage		Int erosion	
					Min detectable		
Acoustic emission	Noise generated by leakage	Microphone	Identification of leaks- through face of concrete faced rockfill dams; -water mains (technique pioneered by WRc - Sahara)	Possibly			With dams problem will be separating out background noise e.g. water down spillway, waves, wind etc
Electromagnetic	Measures electrical conductivity: based on induction of electric currents in the ground by the magnetic component of electromagnetic waves generated at the surface		Poor repeatability (in relation to dam materials)	No			
Gravimetric	Differences in Earth's gravitational field across site	Highly sensitive spring balance.	To detect large voids at depth	No			
Ground probing Radar	Electromagnetic (Radar) waves reflected back where it encounters significant contrasts in dielectric properties. Lowest frequency c. 25MHz gives greatest range but poorest resolution. Highest frequency 400Mhz. Greater reflection for higher moisture content. Equipment power limited by legislation to avoid interference with radar	portable equipment which travels across surface	Locating services (Approved by Dept of Transport), shallow buried foundations.	No			a) Range below ground surface less than 1m in clay; maximum range in granular soils 8m if low frequency. Range also limited where water high in dissolved minerals
			Can be mounted on car/ railway carriage and used at normal speeds (50mph)				b) However developing cases/ cable for use with CCTV camera surveys to detect voiding above sewers, so may be of use to detect voids along outside of culverts; c) work by BRE reported in Matthews, 1994, 1995; d) has been used to investigate voids below a service reservoir base slab
Magnetic	Passive method based on the measurement of localised perturbations in the earth's magnetic field caused by the presence of buried ferrous objects	Portable magnetometer; gradiometric surveys determine the vertical gradient of the magnetic field					
Resistivity	Measure electrical resistance to AC current, which decreases with water saturation (by a factor of 2 to 10). Charge successively passed though outer two electrodes, and current read in two central electrodes to give resistivity. Relative position of current and potential electrodes gives varying position of best resolution. By using source electrodes at increasing distances apart can probe deeper (45 degree dispersion assumed); max depth 40m? Resistivity is strongly dependent on moisture content and pore water chemistry	Array of shallow (0.1 - 0.25m long) electrodes, e.g. 64 at 5m centres (320m length) pushed into ground (can also get arrays of 32, 128 electrodes, with electrode spacing varied down to 1m; closer spacing gives better resolution but shallower depth).	Definition of geological boundaries.	Possibly			a) Outer ends of array only probe ground at 45 degree slope in towards main array, so on steep abutments there would be a window between end of the array and resistivity (although electrodes could be carried up abutment)
			Have been permanently installed around landfill to monitor seepage through perimeter.				b) Unlikely to detect air void (reduced resistivity) smaller than 0.3m dia at 5m depth. May be better at looking for preferential flow paths (increased resistivity)?
			May have been used/ tried on dams to monitor seepage (US, Germany, Spain)				c) Resistivity will change seasonally; d) comparing surveys at different times may reveal more about potential leakage e.g. Loke (???)
Seismic reflection/ refraction	detects variations in seismic velocity	Poor repeatability		No			
Streaming potential (Self-potential)	Uses natural voltages generated by flow of water with water acting as electrolyte (groundwater flow, due to mineral deposits and chemical diffusion); expressed relative to a "reference" electrode at that site		Leakage from landfill; large ore bodies.	Possibly			Payne & Corwin (1999) report a trial on a BC Hydro dam, where SP survey was conducted at high and low reservoir level, and the difference used to infer there was no concentrated seepage
Thermography (Surface temperature)	Tedd & Hart, 1985, 1988		Used to look at insulation standard of buildings	Not normally			Inappropriate where varied vegetation, or obscured by trees. Cannot be used on sunny days because surface temperatures governed by solar gain from sun. Surface temperatures also depend on solar history (e.g. duration exposed to sun); solar absorbance and thermal mass of object
Temperature sensing	Dornstadter, ICOLD 1997 Q73 R7. Measure temperature of reservoir and embankment; use difference to detect leaks (areas where dam temperature is similar to that of reservoir imply "percolating water".) Interpretation complicated by seasonal change in temperature of both reservoir and embankment, with embankment lagging reservoir and reservoir temperature being constant with depth in winter, but stratified in summer.	19mm ID hollow cylinders (+ solid base) vibrated in with hand held machines (and pulled out with no backfill at end). Reported can be vibrated up to 30m depth in alpine soils; typically used for canals and small embankments i.e. up to 10m deep Then lower in cable into dry tube with temperature sensors at 1metre spacing. Spacing is common practice; in Germany 20m, in UK 10m	1. Need full reservoir (which is tracer). 2. Ideally done in peak winter when reservoir coldest (<8°C) and water at constant temperature for full depth. 3. Cost for one off of order of £3k mobilisation plus £20/m (0-6m depth) say £9-10k for small dam. 4. Can get temperature profile in piezometer tube etc, but convection currents within tube may distort temperature	Yes	pore velocity 10^{-6} m/s	Not directly	a) new seepages and changes in flow rate can be detected by looking at amplitude and phase lag of seasonal temperature change; b) it may be possible to detect internal erosion by lowering other readout units down the probe e.g. gamma rays. c) Unclear if this only detects zones of seepage, or whether it would be effective at picking up concentrated leakage at **a point**

Notes

1. many of surface techniques can also be used down boreholes e.g. cross-hole resistivity; cross hole GPR

F.2 Geotechnical Instrumentation

This is adequately covered in Dunnicliffe.

The following comments were provided by Prof Vaughan
"Measurement of seepage pressure in a permeable upstream shell may indicate the position of a leak through a core. This method was utilised at the Balderhead Dam (Vaughan, Kluth, Leonard & Pradoura, 1970) When the leak developed suddenly by hydraulic fracture, existing piezometers in the shell upstream of the leak, which hitherto had measured reservoir level, started to measure below reservoir level. This indicated flow through the upstream shell. A second leak occurred when the reservoir was refilled (Lovenbury, 1973). Additional piezometers were installed and measurements of head loss made. The location of the leak was identified with sufficient accuracy that it was sealed by the sleeve grout of the first treatment tube-á-manchette. The method would be much more difficult to interpret if there were head loss in the upstream shell when there was no leakage through the core."

F.3 Leakage and Turbidity

These are deemed to be relatively standard items, developed in other industries. Details of an installation recently used for checking that there was no pollution arising from a foundation grouting contract to a concrete dam was

"The equipment we are using is a pHOX 200 series, model 201v multi-parameter Water Quality Monitor. The monitor is powered using an internal 12 volt battery and can be trickle fed from either mains 110 or 240 volts or by using a solar panel.

The 201 has an out put socket of 0 - 2.5 volts for connection to a data logger.

The pHOX 201 measures the following parameters:

- *Temperature*
- *pH*
- *Dissolved Oxygen*
- *Turbidity*
- *Conductivity*
- *Ammonium NH4*

pHOX are no longer in existence therefore the monitor is no longer produced so any spares that are unique to this instrument are quite hard to find and fairly expensive.

The people who built the 201 have moved on to other things and two new water quality companies have been formed since the demise of pHOX. pHOENIX instrumentation Ltd., based in Shefford, Beds. and Eauxsys UK Ltd. (pronounced "O" sis) based in Camelford, Cornwall. Both pHOENIX & Eauxsys produce a newer version of the 201.

The loggers being used are Technolog 8 channel, 0 - 2.5 volt data loggers Types 3.21 & 3.23) The data is being recorded every 10 minutes which can be altered to suit any requirements by changing the configuration files using a PSION organiser or a Lap top PC. The channels however are being monitored approximately every 30 seconds in order to detect alarms ASAP.

Alarms have been set on pH, Dissolved Oxygen, Turbidity & Conductivity only.

(as per the contract spec)

The parameters are validated every site visit with a multi-parameter water quality monitor covering Temperature, pH, D.O. & Conductivity, this validation meter is produced by a German company called WTW. They have a UK distributor called CA Clase.

Turbidity is validated using an Eauxsys 3300P Turbidity monitor. Ammonia if required would be validated using a Palintest 5000 Photometer."

Comments from Prof Vaughan are:
"*Turbid seepage water may well indicate erosion. However, turbidity may not be pronounced when the rate of loss is low. Some caution is required as seepage discharge may become turbid for other reasons. A continuous turbidity in dry weather when a reservoir is full and clear water when the reservoir is drawn down is a clear indicator of possible seepage erosion. Information on typical flow and turbidity from dams which are known to have been eroding would be useful*."

Available techniques are summarised as follows

Technique	Test method	Principle of measure	Remarks
Suspended solid determination on water sample		Evaporate sample and weight residue	Require water sample
Turbidity	BS6068-2.13:2000	a) Scatter of light by suspended or colloidal matter in the sample; light being measured at 90° to the incident light and compared to light scattered by standard formazine solution b) Test results expressed in formazine turbidity units (FTU) (approx equal to mg/litre for low turbidity)	a) Routine water quality test for water and sewage treatment works. b) Glass becomes obscured with time; requires cleaning between daily and weekly c) Limit of visual detection is 5 FTU, technique can measure down to 0.1FTU. Normal river water say 100FTU; rivers overseas in Africa 1000 to 10,000ppm
Particle counting	Various e.g. ISO/TR 16386:1999; BS 3406	Various light based e.g. photon correlation (BS3406-8:1997); optical fibre (Zhang et al, 2000)	a) Historical use in evaluating contamination of hydraulic fluids e.g. BS5540-5: 1987 b) Increasing use in water industry in response to need to remove pathogens such as Giardia and Cryptosporidium from water supply c) Need to decide which size particles are being counted d) Use as alternative method to turbidity

F.4 Topographic Survey

Conventional ground based survey is used regularly for monitoring settlement of dam crests. In addition the following information has been forwarded via Defra:-

Company	Technique	Remarks
NPS	Satellite radar interferometry (InSAR)	a) Measurements taken to radar corner reflectors from every satellite pass (24 days for RADARSAT, 35 days for ERS) b) Claims "millimetre" accuracy c) Claims used at Wraysbury reservoir (six one metre reflectors around reservoir perimeter, with a 7th unit on stable ground as control d) British Geological Survey in association with NPS and TRE of Italy are seeking the commitment from a variety of stakeholders to fund (£5M) the development of a "National ground movement information service NGMIS"

F.5 Tracers

F5.1 General

The use of natural and artificial tracers to detect foundation leakage is described in a textbook by Bedmar and Araguas (2002, Balkema). A natural tracer which is becoming well established as a technique is the difference in temperature between the reservoir and embankment fill.

F5.2 Temperature differential between reservoir and embankment

The technique is described in Dornstadter (1997) and Dutton (2000), with the key points summarised in Table F.2.

It is noted that Dornsatdter (1997) describes the measurement of gamma ray activity changes as fines are washed away as a "promising" technique for detecting internal erosion (envisaging that these measurements could be made down the temperature probes). However, a caveat that is near surface reading affected by cosmic rays

Table F.2 : Principles of the use of temperature anomalies in seepage flow.

Principle of detection	a) The technique measures temperature of the ground which has changed due to the flow of water at a different temperature (advection). b) In winter the reservoir temperature is constant with depth (typically 4^{o}C i.e. maximum density; although the surface may drop to zero when the lake freezes over. In summer there is stratification, with an upper warmed zone (max in UK say 24^{o}C), and a lower zone still at the winter temperature i.e. not as good for temperature sensing c) 19mm internal diameter probes are driven into the ground, and cables with sensors at 1m centres are then lowered into the ground. As the act of installing the probes generates heat, and the sensors are at different temperature to the ground it is necessary to leave the sensors to stabilise with the adjacent ground after dropping cable into hole (typically ¾ hour, for probes to cool down, plus10 minute for sensors to stabilise) d) On completion the probes are withdrawn, allowing the hole to squeeze shut

	on its own
Ground temp	This varies seasonally with depth; down to about zero change at 6 to 10m (variations go deeper in gravel) There is also an increasing time lag with increasing depth, relative to both the embankment and reservoir surfaces (about 3 months for the latter)
Interpretation	a) It is understood this is currently done manually i.e. it requires expert interpretation rather than being automated through a computer programme. b) It is based on comparing the temperature of an "unpercolated" section with other sections, both in horizontal and vertical sections. c) in theory could relate magnitude of temperature anomaly (and/or radius of anomaly) to quantity of seepage, but in practice this is not done i.e. only use to identify location of leak
Limitations	a) only tells you about seepage, not internal erosion b) less effective where reservoir is not full c) probes generally limited to 10m depth d) small flow and particularly small concentrated flows may be impossible to detect (i.e. measurements are normally made at 10m centres) e) "sterile" times of year when reservoir water is same temperature as dam (although may be counterbalanced by time history of leak area remembering being at different temperature from adjacent ground). This "sterile" time varies with depth e.g. at 1m depth is weeks 16-24, at 6m depth is later (plus shorter duration) f) There is little information on potential long term drift of temperature sensors; it may not be important if assessment is to compare the temperature at one probe to other sensors, but could be important if looking at long term phase and amplitude
Variations to overcome "sterile" periods	a) heat pulse – not done in UK; uses rate of cooling to assess seepage velocity. Have to get whole probe to same temperature. Need a lot of energy (over 12 hours heating to get stable). b) In principle could do the same with "Frost pulse". Tried in UK – used liquid CO2. Difficulties in getting to constant cold temperature
Changes in leakage	a) Change in amplification and lag will allow an estimation of change in leakage (although monthly readings are required i.e. a permanent monitoring system). Leakage is increasing where increasing amplitude and reduction phase shift. It is understood that there is German PhD which covers the relevant theory b) This is useful where on permeable foundation, and seepage does not emerge at the surface
Permanent installation	a) Not done in UK yet. Have quote for one dam? (£40k for 220m long x 13m deep, 20m spacing) b) Differentiate those where probes permanently installed, but still manual reading, and those where sensors cables up to remote readout (this would be a lot of sensors!! E.g. 10 probes at 10m deep = 100 sensors) c) Would need to develop software to do automatic interpretation e.g. "base" is average of all readings at a given depth?

F5.3 Other tracers

Comments from Prof Vaughan are:
"*Measurement using tracers and chemical analysis of seepage water has been used intermittently. Dilution and mixing of flows can make interpretation difficult. A relatively new development is the adoption of synthetic tracer chemicals which do not occur in nature. These are non-toxic and self destructive so that they disappear in a*

few days. Such a tracer was used to investigate the origins of seepage below the membrane at Roadford. The whole reservoir was dosed."

F.6 Geophysical methods

F.6.1 General

These measure different properties, including

a) Electrical resistance
b) Electrical conductivity
c) Seismic velocity
d) Background potentials e.g. natural flow of ions

The viability of any of these methods is thus determined by the extent to which the properties are affected by the presence of concentred leakage, and/or any voids. The method most sensitive to changes in moisture content is resistivity, whilst the only method that detects fluid flow are self-potential methods.

This section is based on research including

a) a visit to a Geological Society Geophysics open day at Leicester on 27th June 2003
b) discussions with the Geophysics section of STATS
c) email correspondence with members of BC Hydro in Canada, on their research work on zonal techniques

Copies of the latter are included in the first sub-section, followed by comments on uncertainties in use of resistivity methods. At the time of writing this report it has not been able to find any precedent for use, or trials, of acoustic methods in detecting internal erosion.

F6.2 Research programme by BC Hydro, and others

Emails in late October 2003 relating to this include:

From Gary Salmon
"*Our Geophysical Research included activities in seismic, resistivity, streaming potential and temperature. This research cost about $1.6 million CAD. It is the DSIG's intention to sell the results of this research with the exception of temperature. For temperature we paid to have an existing computer code transcribed into a user-friendly program. The sponsors have the right to use this code but not to sell or distribute it. It belongs to Sam Johansson of HydroResearch:* <sam.johansson@hydroresearch.se>.

We have not completed all of our research project and we haven't decided on a sale price nor printed sales copies of the portions that are completed. I suggest you contact the Project Manager, Ken Lum of BC Hydro, to get more detail on what will come available. <Ken.Lum@BCHydro.bc.ca> *(604) 528-2406. You may be interested in the four or five year monitoring program of two Swedish dams with resistivity and streaming potential partly funded by our research.*"

From the Project Manager, Ken Lum
"*The research will likely continue at least to the end of 2004 and possibly into 2005. Therefore I suspect that the reports would not be available for sale by CEATI until 2005 at the earliest. Costs are to be determined at a later date by the project sponsors when the products are available.*"

From Des Hartford

"last summer, we partnered with ELFORSK (Sweden) and EBL (Norway) to perform an independent "blind field test" of SP Resistivity and Temperature methods. This is independent of DSIG (joint sponsorship of CD$1.6 M) and our other research into SP (BC Hydro CD$0.8 M). The "blind field test" (CD$ 0.2 M) involved creating zones of high seepage into a 5m high dam at the EBL test site near Mo-I-Rana. An independent contractor with no knowledge of the locations of the zones of high seepage was then sent to site to monitor the seepage during staged filling.

The test has been reported on and I am now setting up an independent analysis and interpretation of the field data. I am presently preparing a laboratory testing proposal to perform an identical blind test in a laboratory on a 1:5 (preferred) or 1:10 scale model using two independent contractors. We will then be in a position to do some serious analysis of the laboratory and field test data. Funding is obviously a big issue as I estimate that to do the laboratory test well we will need about CD$ 0.5 M. This next step is in the early stages of development and I am particularly interested in seeing if I can put together a consortium to fund the work. If you are interested, please let me know and I will send you details as soon as they are ready (hopefully within two weeks)."

F6.3 Resistivity methods

Variables that will affect the results obtained include

a) electrode arrangement e.g. Dipole- dipole; Schlumber, Wenner
b) electrode spacing, and overall length of array
c) position of electrodes relative to dam crest
d) reservoir level
e) time of year (i.e. general moisture level)

In regard to 'c' the charge from the source electrodes would be expected to create an asymmetric equipotential distribution along the traverse, and spherical charge normal to the traverse. However, the high air resistance means that the equipotentials normal to the line of the traverse would be expected to be almost exclusively within the embankment body. The significance of this may be that traverses along the embankment faces are effectively normal to the dam face (rather than vertical), although this would need testing to see how it was affected by the presence of the reservoir. This might be a technique to obtain a more three dimensional image of any leakage.

Two major water companies are known to have trialled resistivity, with reasonable results (e.g. see case History A in Appendix D); although it is acknowledged that they were used to provide information on location of the leak through dam where a concentrated leak had been detected by surveillance.

APPENDIX G : OPTIONS AND COSTS FOR REMOTE MONITORING

Publications relevant to this issue include

Author		
ICOLD	2000	Bulletin 118 : Automated dam monitoring systems

Features relevant to this project are summarised as follows

Table	
G.1	Data Collection Systems
G.2	Power Supply Systems
G.3	Instrumentation

Table G.1 : Descriptions of Data Collection Systems

System	Solution for All Users	Alternative Solution for Major Users Only	Comments
Manual Downloading	The data is stored on a data logger at the dam and the dam is visited periodically, data is downloaded and the collected data taken to a central location for analysis.	As for All Users	Low tech solution. Major disadvantage that any problems with the dam, or the monitoring system, would not be found until after the following visit. Labour intensive. Capital cost up to £2k, operating costs dependant upon labour rates.
Land line (PSTN or Private Data Cable)	Each dam is connected to the Public Switched Telephone Network (PSTN), data is collected on a data logger at the dam and transmitted to be analysed centrally by a service provider who sends alarms and information to the user by e-mail, web, text or voice message.	Each dam is connected either to the Public Switched Telephone Network (PSTN), or to the user’s own telemetry system, data is collected on a data logger at the dam and transmitted to be analysed centrally by the user’s own computer system centre to initiate alarms, etc.	Very reliable solution utilising well established technology. Preferred solution for “critical” dams. Capital costs dependant upon the length of the required telephone type cable between the dam and the existing local PSTN system, operating costs up to £200 p.a.
Mobile phone (GPRS Data System)	Each dam is linked to the General Packet Radio System (GPRS) using cellular telephone technology, data is collected on a data logger at the dam and transmitted to be analysed centrally by a service provider who sends alarms and information to the user by e-mail, web, text or voice message.	As for All Users, but the data is collected and analysed centrally by the user’s own computer system centre to initiate alarms, etc.	Reliable solution utilising established mobile telephone technology. Not suitable for areas with no cellular telephone coverage. Network provider contract and SIM card required. Capital cost up to £1k, operating costs up to £100 p.a.
Radio System	Only appropriate for Major Users.	Each dam is linked to by radio to the user’s system centre, data is collected on a data logger at the dam and transmitted and analysed centrally by the user’s own computer system centre to initiate alarms, etc.	Reliable solution utilising established radio technology. Geography may limit use in some areas. Frequency allocation and radio transmission licenses required. Technology limits this solution to Major Users who already have an established radio network. Marginal costs on an established system are negligible.
LEO Satellite System	Each dam is linked to the Low Earth Orbit (LEO) satellite system, data is collected on a data logger at the dam and transmitted to be analysed centrally by a service provider who sends alarms and information to the user by e-mail, web, text or voice message.	As for All Users	The only solution for remote locations outside the mobile telephone coverage areas. Contract required for satellite links resulting in higher operating costs. Satellite communications can be adversely affected by rain, snow, etc. Capital cost up to £3k, operating costs up to £300 p.a.

Table G.2 : Descriptions of Power Supply Systems

Power System	Solution for All Users	Comments
Rechargeable or Replaceable Batteries	The instrumentation, data collection and/or transmission systems are powered by one or more rechargeable or replaceable batteries. Each dam is visited regularly and the batteries are replaced with recharged or new batteries.	Low tech solution. Disadvantages are the labour and materials requirements for replacing batteries and the possibility of loss of data due to premature battery failure. Suitable for electrical loadings up to around 30mW. Not suitable for dams with large numbers of instruments, or for dams with instruments having high electrical power requirements (such as rain gauges, some water quality analysers, etc.). Labour intensive. Capital cost up to £500, operating costs dependant upon labour rates.
Mains Electricity Supply	Each dam is connected to the mains electricity supply. Small rechargeable batteries would be provided to cover for short periods of mains power supply failure.	Very reliable solution. Suitable for all electrical loadings. Preferred solution for “critical” dams. Capital costs dependant upon the distance between the dam and the existing mains power supply. Operating costs up to £100 p.a.
Solar Panel	Each dam is provided with a solar panel array linked to rechargeable batteries to cover the night-time and periods of low sunlight.	Reliable solution utilising established technology. Suitable for electrical loadings up to around 20W. Not suitable for dams with instruments having high electrical power requirements, such as rain gauges, some water quality analysers, etc. Solar panel may require protection against environmental damage or vandalism. Capital cost up to £6k, operating costs negligible.
Wind	Each dam is provided with a pole or mast mounted wind turbine linked to rechargeable batteries to cover periods of low wind speed.	Reliable solution utilising established technology. Suitable for electrical loadings up to around 40W.Higher power output than solar panels, but may not be suitable for dams with instruments having high electrical power requirements such as some water quality analysers. Applicability dependant upon wind profiles in the local environment. May require planning approval. Wind turbine may be subject to environmental damage or vandalism. Capital cost up to £10k, operating costs negligible.

Table G.3 : Descriptions of Instrumentation

Parameter	Typical Instrument Types	Instrument capital cost	Comments
Pore Pressure;	Vibrating Wire Piezometer	about £500	Instrument power consumption about 0.3W.
Temperature	Resistance; Thermocouple; Thermistor	about £50	Instrument power consumption negligible.
Water Level	Ultrasonic; Float; Hydrostatic Pressure	about £750.	Instrument power consumption up to about 3W.
Precipitation	Tipping Bucket	about £300.	Requires a heater with power consumption about 20W if it is necessary to correctly measure precipitation falling as snow. Instrument power consumption negligible.
Flow	Ultrasonic Head over Weir; Ultrasonic Doppler	about £2000.	Instrument power consumption about 3W.
Turbidity	Optical	about £750.	Instrument power consumption about 1W. Instrument capital cost
Closed Circuit Television	Fixed Camera; Remotely Controlled Camera	about £1000.	Not effective during hours of darkness. Instrument power consumption about 5W (fixed camera).
Data Converter and Recorder	Data Logger	£2.5k to £10k.	Data logger power consumption ranges from negligible (for single instrument with local data collection) up to about 20W (for multiple instruments with remote data transmission).