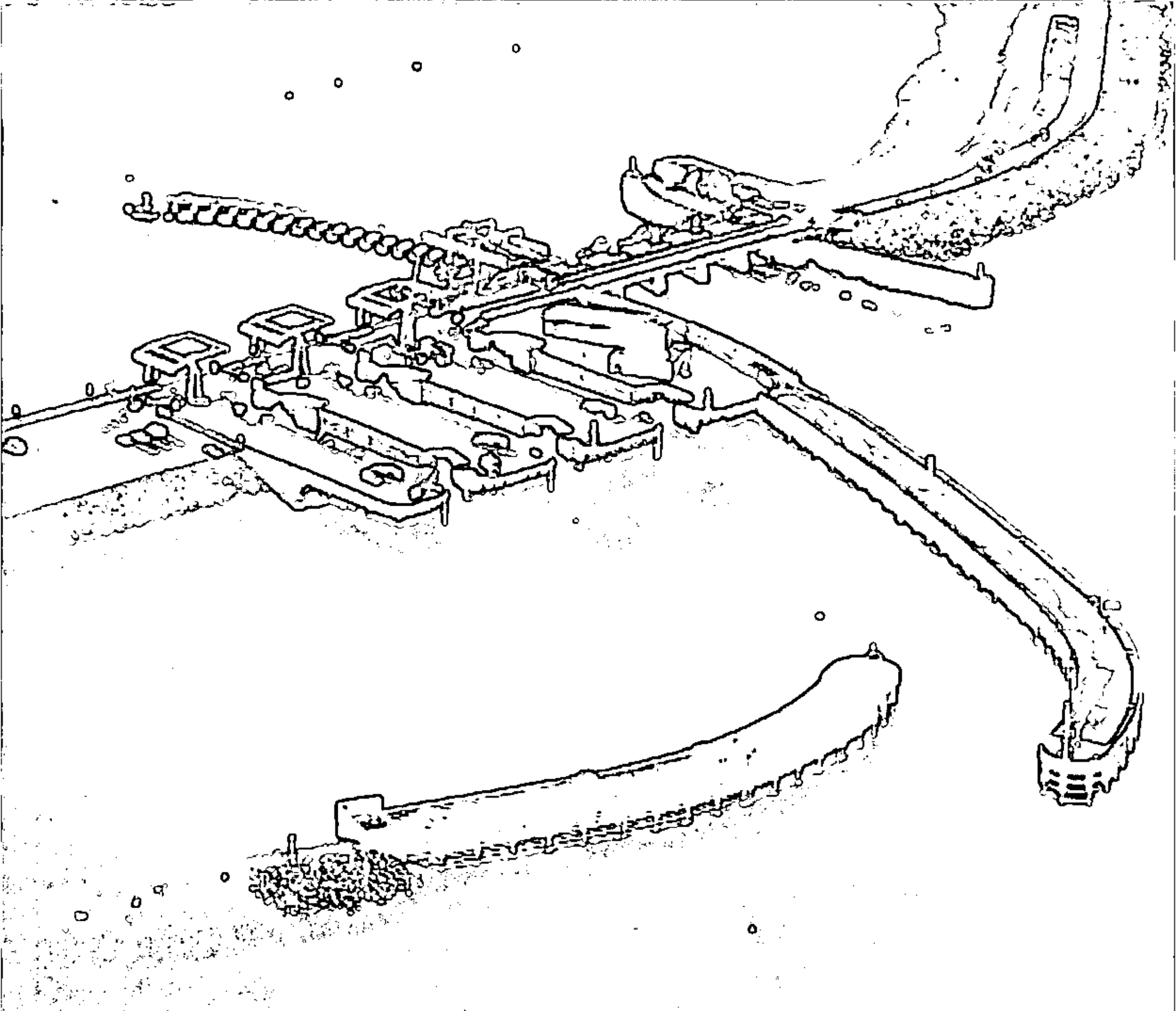

DAMS 2000

DISCUSSION

BDS

BRITISH DAM SOCIETY

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Dams 2000

DISCUSSION

Edited by Andrew Robertshaw

Published by the British Dam Society at the
Institution of Civil Engineers, Great George Street
London SW1P 3AA

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PREFACE

This volume contains the complete record of discussions from the Eleventh Conference of the British Dam Society entitled "DAMS 2000" which was held at the University of Bath on 14-17 June 2000.

The Conference papers are in a separate volume published by Thomas Telford Services Ltd and available from the bookshop at the Institution of Civil Engineers, Great George Street, London SW1P 3AA.

VOTE OF THANKS TO BRISTOL WATER

by Mr. R. C. Bridle, Chairman of the British Dam Society

Ladies and gentlemen, I would like to say thank you to the Bristol Water Company, particularly Colin Hunt and Barry Straughton, for arranging these visits for us. Visiting Barrow No. 3, Blagdon and Chew Valley reservoirs in one afternoon is a real treat, a voyage through some fascinating and important milestones in dam development.

Barrow No. 3 was in the "news" at the last conference when John Beaver reported on recent grouting and Neil Swannell reported on seismic stability checks there. I know from working on it before that this is a reservoir redolent with history. James Simpson, a predecessor of Taylor's, now Hyder, was the Engineer responsible for the reservoir originally, but after repeated slips of the embankments, Bristol approached Mr Thomas Hawksley ("old" Thomas), who had a high reputation for making dams stand up. He found it necessary to reduce the slopes to as flat as 1 in 12, unique for the time. Even then there was instability, necessitating local "poultices" (we would say berms nowadays) and it was fifty years between impounding commencing and the issue of a Final Certificate allowing filling to top water level. The reservoir is a monument to the persistence and teamwork generated in Victorian times between Owners and their Engineers. Peter Horswill, Chief Geologist at Montgomery Watson, composed the history of Barrow No. 3 in 1982, using the Bristol Water Company Board meeting minutes and other records. The fundamental reason for the problems at Barrow No. 3 is that it is founded on the debris from landslips on the hills above the reservoir. The wooded land below the reservoir still shows the characteristic disturbance exhibited by landslip debris and on large scale maps it is still called "The Wild Country".

Now Blagdon, isn't it the prettiest dam you've ever seen? It is the acme of the Victorian/Edwardian puddle core embankment dam. I have a very nice photograph of the spillway with water flowing over those beautiful steps on my wall at home. The quality of the stonework, the width of the crest, the generosity of the proportions are all evidence that this was a prestige project of its day, executed by engineers confident of their knowledge.

I was intrigued during the 1992 inspection to read some correspondence from Mr T E Hawksley ("young" Thomas). He inspected the reservoir on the 17th May 1972 and wrote a letter regarding construction drains in the dam to Tom Braid (Bristol's Reservoir Engineer, Colin Hunt's job, in those days) on the 20th July 1972. Sadly, he died just a few days later, on the 2nd August 1972. His letter was written in an amusing vein. He said he was very glad to have investigated the matter of the drains because it made him go into the attic at home and search through old correspondence from the construction period (60 years earlier!). The result was that "he could clear out 90% of the bulk of it as it was no use at all". Although Thomas was only moderately dilatory in completing his report (May to July), Bill Dyer, his partner, who took on doing the inspections after Thomas' death, inspected and sent in his report on the 7th of September, only five weeks after poor Thomas had died. An interesting contrast in the speed at which people do their reports.

Then we come to another Hawksley dam, Chew Valley, an early example of a modern embankment dam. It has no filters, but Michael Kennard reported on the first foundation sand drains in UK here and there may be internal drainage blankets in the fill. It is interesting how masonry in pitching and wave walls was replaced here by precast concrete. It was well disguised and it is difficult now not to be taken in! The wave protection blocks were 2ft (600mm) deep. After the 1987 tornado, we found that the depth of block required to resist overturning by the different water pressures in front and behind was, yes, 2ft! Had we forgotten something the older engineers knew? A paper in our Dams 2000 conference proceedings describes some of the environmental aspects of Chew Valley Lake. These too were forward thinking for their time.

Thank you again to Bristol Water, Barry Straughton, Colin Hunt and all the Bristol Water staff who have shown us round.

CONFERENCE OPENING

INTRODUCTION

by Mr. R. C. Bridle, Chairman of the British Dam Society

Thank you to all delegates for coming. Welcome to our 12th Biennial Conference. I know it's not always easy to find the time or to persuade employers to find funds for conferences. We very much appreciate how many of you come regularly and it is nice to see some of those who come less regularly, and we hope that they will transfer into the "regulars" category in future. There is a renewed emphasis on professional responsibility and the maintenance of professional standards through Continuous Professional Development today. For UK dam professionals, attendance at the BDS conferences and meetings is an essential part of the CPD process.

I would like to thank all the authors for their work on the conference papers collected together in the splendid conference volume. Giving praise where praise is due, I would like to single out Binnie, Black and Veatch whose authors have produced more papers than any other groups. I can also apologise to two of the authors, Fiona Tarrant and Andy Rowland, as the last page of their paper on dam breaks was omitted. Perhaps the shock of reading about the impact of dam breaks rattled the printers! What should have been page 42 has been inserted near the back of the volume. Thank you also to the reviewers of the papers, and particular thanks to the editor Paul Tedd. I know he really enjoys editing but it requires much time and the quality of the papers as presented owes much to Paul's diligence.

Our Conference will be looking ahead. We are concentrating on new methodologies, on keeping dams safe and bringing other up to standard. We are looking at the applications of new technologies, including risk management and other "softer" technologies on dam safety. We are looking at environmental issues and maintenance and rehabilitation technologies for the future. Our prestige Binnie lecturer is Alan Johnston The lecture title is "Taken for Granted", and we can all wonder what it is that's being "taken for granted". We are very pleased to welcome Achim Steiner, a Commissioner and the Secretary General of the World Commission on Dams, who will be addressing us tomorrow morning. The work of the World Commission is also looking ahead and we hope it will help us to produce better dams, particularly, by managing the social and environmental consequences of dams more effectively and perhaps more fairly, than we do now. We hope that Achim will give us an insight into the content of the

WCD's reports which are to be published later this year.

Professor Cliff Burrows, Dean of the Faculty of Engineering and Design here in Bath University, will be welcoming us to the University and to Bath. He is a top engineer, a Fellow of the Royal Academy of Engineering, as I am pleased to say are a few of our Dam Society members. When not engaged on Dean's duties, he is Professor of Systems Engineering. He is also Director of the Centre for Power Transmission and Motion Control and Director of the Engineering Design Centre of Fluid Power Systems. One of the departments in the Faculty of Engineering and Design is the Department of Architecture and Civil Engineering. I know that although Bath is a relatively young University, it already has an awesome reputation. We remember the late Professor Ted Happold who started a centre of excellence here in Bath on tensioned structures. The Greenwich Dome and the Pavilion at Lord's are structures made possible by early work here.

Enough from me, if I can now hand over to the Dean of the Faculty of Engineering and Design, Professor Cliff Burrows.

REMARKS

By Professor C. R. Burrows,
Dean of the Faculty of Engineering and Design,
University of Bath

Well thank you chairman for that introduction and welcome to Bath. I must say its quite a novel sight this, it's a nine o'clock lecture and it's full. Although it's a great pleasure for me to be here to welcome you may I first of all apologise for the fact the Vice Chancellor can't be with you. He, like most of us nowadays, has to be in about three different places at once, but he has asked me, on his behalf, to welcome you.

We have been very fortunate this year in Bath to have a number of major conferences in the University. A few weeks ago we were able to host the wide-span enclosures meeting and that of course reflects our specialisation here in the Civil Engineering Department in lightweight structures and that, of course, links with Architecture. I'm indeed proud of my colleague's contributions to the Millennium Dome and let me underline after the Chairman's remarks that we had nothing to do with the Millennium Bridge. We don't have any specialists in Dam design but let me just pause there and say if we have any suitable sponsor in the audience then I'm quite happy to consider a chair in that particular specialisation. I'll let that message sink in just in case the sponsors didn't hear it.

I note that this is the eleventh biennial conference in the series organised by the British Dam Society and I applaud you for that. One of the first things that I did when I first came to Bath in 1987 was to inaugurate a series of annual workshops in fluid power. This year it is our thirteenth and, apart from the benefits of the technical sessions, many friendships have been established over that period. I echo what the Chairman said and I hope that many of you are going to enjoy meeting old friends and, of course, making new friendships. I have noticed that now we have no problem at all getting people to return to Bath. My wife makes sure that she lets all the wives and partners know when the next meeting is to be and then I sit back and it all happens. We find that people are quite happy to return to what is a beautiful City and those of you who feel a little guilty about being here this morning with your partners in Bath, you can relax. There are plenty of shops and they all take credit cards so it will be fine. Then of course this evening we can look forward to enjoying the city together at the Pump Room and of course the Baths.

I think I should at this point note the sponsors, the Hydropower and Dams magazine and the Water Power and Dam Construction magazine and I'm sure you would like me, on your behalf, to thank them for that support. A glance at the list of your conference topics indicates that, as a Society, you are not complacent in spite of the many attractive features of hydropower and the human need for storing water. The topic in your programme about risk assessment seems to raise issues at the heart of most engineering disciplines. We take the benefits as given and try to assess potential liabilities. We are concerned about the impact of our work on the environment and its impact on future generations and I see that this is another of the topics in the programme. That type of ethical concern can never be set aside, neither can risk assessment. We hear frequently about medical ethics but the ethical dimension of our profession is no less real. I am aware that we do not always give weight in our courses to the factors involved in risk assessment. I am particularly fortunate here however because the Chairman of my Faculty Advisory Board has nuclear interests and I'm glad to say that we actually use him to teach our students the elements of risk assessment.

I think it is right and proper that we should be self critical about the impact of our professional activities and I pick up that concern in several of your conference papers and topics. Items like learning lessons from past incidents, the need to monitor structures, the need to manage risk as well as assess it. I note too the concern to assess the dis-benefits of reservoirs. You function in a world where people want water and they want flood control but they want none of the environmental impacts. Having said all of these things we should never let self-criticism blind us to the benefits of our work. I read the other day of a vacation student on placement in India who reported, and I quote, "water distribution in India is focused on providing basic drinking water" rather than "luxuries such as electricity". That story reminds us, that as specialists, each of us must be aware of the contributions made by other specialists. It is all right to store the water but of course the water has to be treated and that brings us to Chemical Engineers and the list could go on.

Mention of India draws attention to another of your sessions on lessons learnt from overseas experiences. Nowadays the ease with which information and experience can be exchanged globally puts us at a tremendous advantage compared with the engineering pioneers. They achieved miracles using basic analytical tools allied to insight and the willingness to build on experience which would probably have been limited to the family or the firm. I return to that story of the student in India. I wonder how the British public would react to the need to choose between water for drinking and electricity. Water and electric power are taken for granted. Your work is taken for granted until there is either a shortage or a catastrophe. Perhaps I am thinking along the same lines as the Geoffrey Binnie lecturer who has an intriguing title for his lecture "Taken for Granted".

That reminds me too of the Millennium Bridge and some of you will have seen the television programme the other evening when an Architect and an Engineer were being interviewed. The Architect was saying just how beautiful the bridge was and well, of course, all the problems were the Engineers. It is so easy to have the problems downloaded. But I hope this conference will provide a shop window for you to impress the public about your successes, perhaps through your sponsors' magazines. I hope too it will provide you with happy memories of friendships; friendships renewed and new friendships made. Memories of a city where it is a privilege for us to live and work. Memories for your partners of friendships made outside the meeting, but within the accompanying person's programme. Above all I hope you will carry away with you memories of an exhilarating conference held in a University that is delighted that you have chosen us as a venue. It is certainly a privilege for me to welcome you and I hope you have a tremendous conference in every sense.

Thank you very much indeed.

RESPONSE

Thank you Professor Burrows for your amazingly insightful speech.

I suppose we perhaps tend to forget that all Engineer's, give or take, have similar concerns. You will be very interested to know that, in our particular case, the question about our concern for what happens after the dam is there and for future generations and so forth has to some extent been forced into the open. A body called the World Commission of Dams has been formed to decide on whether "dams is good or dams is bad" in the crudest possible sense and we will be having Aachim Steiner the Secretary General of the WCD addressing us tomorrow morning so make a note.

Thank you very much anyway professor for your welcome.

SESSION 1
DEVELOPMENTS IN RESERVOIR HYDROLOGY

Chairman	Jim Claydon
Technical Reporter	Ian Scholefield

Papers presented

1. Revised design storm rainfall estimates obtained from the Flood Estimation Handbook (FEH)
   D E MacDonald and C W Scott
2. Reservoir inundation studies: a concrete dam owners perspective
   K J Dempster, A MacDonald and L A Cowan
3. CADAM: A European Concerted Action Project on Dambreak Modelling
   M W Morris

Papers not presented

1. Design floods for UK reservoirs - a personal view of current issues
   D E MacDonald and C W Scott
2. Bohernabreena Reservoirs, Dublin: the impact of Hurricane Charlie
   A Rowland
3. Prediction of downstream destruction following dam failure: no quick solution
   F R Tarrant and A Rowland

Andrew Robertshaw (Yorkshire Water Services)
In an attempt to place the discrepancies between the Flood Estimation Handbook (FEH) and the Flood Studies Report (FSR) into a business context, Figure 1.1. shows the number of reservoir flood improvement schemes either completed or planned by Yorkshire Water Services Ltd over the period 1981 to 2004: -

The key points to note from the graph are as follows: -

1. Since 1981 YWS has spent almost £25m on improving reservoir flood capacity to FSR design standards. This sum is based on costs at the time of construction and therefore does not take into account inflation over that period, i.e. the investment represents considerably more than £25m at current costs. Any upward revision of flood standards brought about by the adoption of FEH design standards would have major financial implications if it resulted in requirements for further capacity increases on recently improved reservoirs. Taking

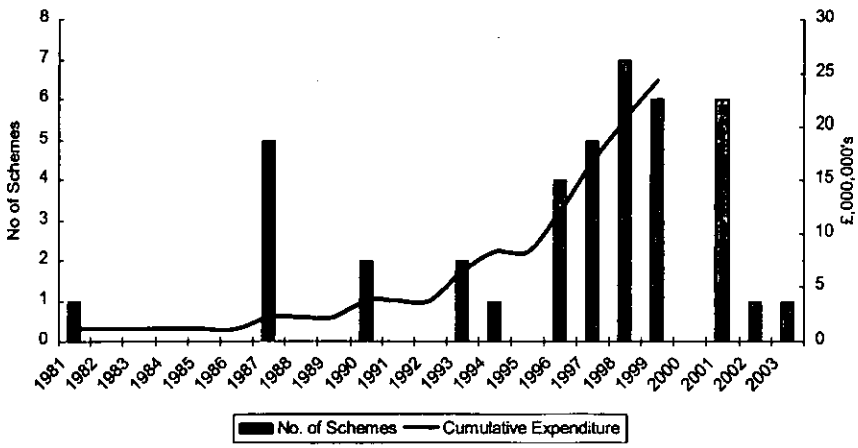

Figure 1.1. Yorkshire Water Reservoir Flood Improvements

into account the extreme return periods of the design events it would be very difficult to justify to senior management that any additional expenditure was required.

2. The graph also shows that there are no flood improvement schemes planned for 2000 and this is because two major schemes, each of which is estimated to cost approximately £1m, have had to be deferred until the current ambiguity is resolved. This has had a significant effect on the YWS Capital Programme both in terms of cash flow and also potential increased workload in the future. In addition it should be noted that the potential increased Capital requirement in respect of these improvements has not been recognised by the Director General of Water Services in his AMP3 determination.

The above points are presented to illustrate that the somewhat academic debate between the two methodologies has significant potential financial implications to reservoir owners that should not be overlooked.

Chris Scott (Binnie, Black and Veatch)
Andrew Robertshaw is quite right to draw our attention to the implications of the revised rainfall estimates produced by the Flood Estimation Handbook (FEH). As a profession we need to be very much aware of all of the elements of the dam, outlet, overflow and reservoir perimeter as a system to contain the reservoir water; the system only being as strong as its weakest element. Additional expenditure on overflow arrangements seems to me to be difficult to justify unless we are positive that overtopping due to inadequate spillway

capacity is the weak point in the system. With a dam stock dominated by embankment dams built without filters it seems to me that other areas are likely to present greater hazard than overtopping, particularly considering the work that has been undertaken to upgrade spillway capacities since the publication of the FSR.

Alex MacDonald (Babtie Group)
I would like to outline the work currently being undertaken by Babtie Group in association with CEH-Wallingford and Rodney Bridle Limited on an initial review of the differences between the Flood Estimation Handbook and Flood Studies Report methodologies in respect of reservoir flood assessments. The project has been commissioned by DETR in answer to concerns from reservoir professionals on the impact of FEH. The study includes the provision of advice to DETR on guidance, which can be issued to Panel Engineers.

The work to date is showing that certain areas of UK, particularly the South East of England and the North West Highland areas, could exhibit FEH rainfall predictions of between 1.5 and 2 times those from FSR. However, the study has only recently commenced, with the draft report to be submitted to DETR by the end of July 2000.

Chris Scott
In response to Alex MacDonald's remarks, I note that the rainfall figures referred to are point rainfalls whereas the work in the published paper refers to catchment rainfalls. I would also point out that the worked example of a reservoir flood calculation quoted in Example 8.1 in Volume 4 of the FEH uses the new rainfall prediction method described in Volume 2 to estimate the catchment rainfall. I look forward to the results of the DETR research contract and hope that its findings will be made generally available.

Ernest Taylor (Consultant)
I make a plea that realistic scenarios are used in dam breach analyses. A dam breach is an extreme event but, nevertheless, the parameters used should be within the bounds of credibility. This is what is done when considering other extreme events. For example, the maximum probable flood is used rather than the maximum possible flood, similarly the maximum creditable earthquake rather than the maximum possible earthquake.

The peak flow from a dam breach depends upon the time that it takes for the breach to develop, also upon its size. The breaching of embankment dams is reasonably well documented and commonly the scenarios used in dam breach analyses, where embankment dams are involved, reflect this information. I believe that similar considerations are appropriate when gated concrete dams are involved. Guidance on suitable parameters can be obtained from actual failures.

I have investigated the breaching of two dams that had gated spillways. In both cases, the failures occurred because the gates were not opened. One of these dams was a mass concrete hydro-electric dam of the Dundreggan type, although about twice the discharge capacity. It was built in 1935 and had six vertical lift gates each 7.5m high (4 of 16m span, 2 of 5m span) with a total discharge capacity of 3760m^3/s. Just before the dam was overtopped in a flood, one of the gates collapsed and this temporarily lowered the reservoir level, but as the flood increased, the reservoir reached a higher level and a second gate collapsed. This failure mechanism was repeated with a third, then a fourth gate collapsing as the flood flow into the reservoir increased. The gates progressively failed over a period of 8 hours, each at a significantly higher reservoir level than the previous one. The last of the four gates to fail did so before the peak of the natural flood. The concrete structure survived. The flows released by the gate breaches were less than that of the subsequent natural flood peak.

Large dams often have a considerable height difference between the top of the gates and the crest of the dam, in which case the gates will fail under comparatively shallow depths of overtopping of the dam crest, or even before it is overtopped. This is simply a consequence of the increase in hydrostatic pressure and the factors of safety used in the design of the gates. Concrete dams have a good resistance to overtopping and the gates will almost inevitably fail first. The gates will not fail together, one of them will collapse first. There is sufficient variation in the fabrication to make a difference between new gates, and with old gates corrosion makes a pronounced difference to the collapse load. The failure of a gate temporarily lowers the reservoir level, so there are time delays between the progressive collapses of the gates.

Kenny Dempster (Scottish and Southern Energy plc)
Scottish and Southern Energy have a majority of concrete dams, 16 of which are predominantly gated structures and, in such cases, add to the difficulties noted over the dam breach formation mechanisms. We seek to provide inundation maps that show the worst case scenario but equally want to present the emergency services and our operational control engineer's with credible

scenarios that they may have to deal with. Hence the modelling of a range of failure types and at different flows. More specifically regarding flows, we estimate that a gate failure would result in flows of the order of a 150 year return period event, so we are dealing with relatively low return period flooding events in the wider context. The structural integrity of gate structures under extreme loading is another matter and is receiving ongoing attention.

Mark Morris (H R Wallingford)
I think I would agree with some of the things that have been said but the point is that our ability to determine or predict the way in which the dam will fail or a gate will fail or a breach will form is quite poor. The solution to this is that when you are doing a dam break study you should do a range of tests - a sensitivity analysis as it were - so that you can look at one gate blowing to the complete destruction of a dam and get a feel for the range of flood conditions that you may get downstream.

Ian Gowans (Cuthbertson Maunsell)
The attached sheet shows a comparison of the FSR and FSH flood peak inflows at two reservoirs in Scotland which we have studied. Harperrig is in south-east Scotland, and Loch Bhraomisaig is in north-west Scotland. The differences between the two results vary depending on the return period.

Some of the differences will arise from the following factors:

Calculation of UH Tp
SAAR from different Standard Period giving different storm duration
Use of HOST soil classification rather than WRAP
Use of BFI rather than ANSF for base flows

The FEH gives a significant increase over the FSR, particularly in the 10,000 year flood. At Harperrig, the difference is 27% higher. At Loch Bhraomisaig, the increase is 11%.

There are also noticeable differences in the 1,000 yr and 150 yr floods although they are inconsistent between the two locations. At Harperrig, the FEH value is 20% higher than the FSR for the 1,000 yr flood, and 16% higher for the 150 yr flood.

Comparing 10,000 yr storm depths, at Harperrig the FEH rainfall depth for the 12.5 hr storm is 190 mm which is 20% higher than the FSR depth. At Loch Bhraomisaig, the FEH depth is 221 mm compared with the FSR depth of 162 mm, but the durations are not the same because the FEH duration is based on a much higher Standard Average Annual Rainfall (SAAR).

There are differences between the FEH and the FSR methods which could result in significant variations in flood estimates between the two methods. Not least of these is the effect of SAAR on storm duration. Other variations can be expected to arise from differences in catchment parameters between digital and manual data acquisition.

	Inflow (m3/s)			
	Loch Bhraomisaig		Harperrig	
	FSR	FEH	FSR	FEH
PMF (summer)	49.47	43.5	145.02	147.4
PMF (winter)	42.54	38.79	118.97	122.33
10000	26.21	29	52.61	66.7
1000	15.67	16.16	31.71	37.92
150	10.82	10.44	21.96	25.46
100	-	9.84	-	23.62

Note:
FSR - inflows calculated using 1975 Flood Studies Report method
FEH - inflows calculated using 1999 Flood Estimation Handbook method

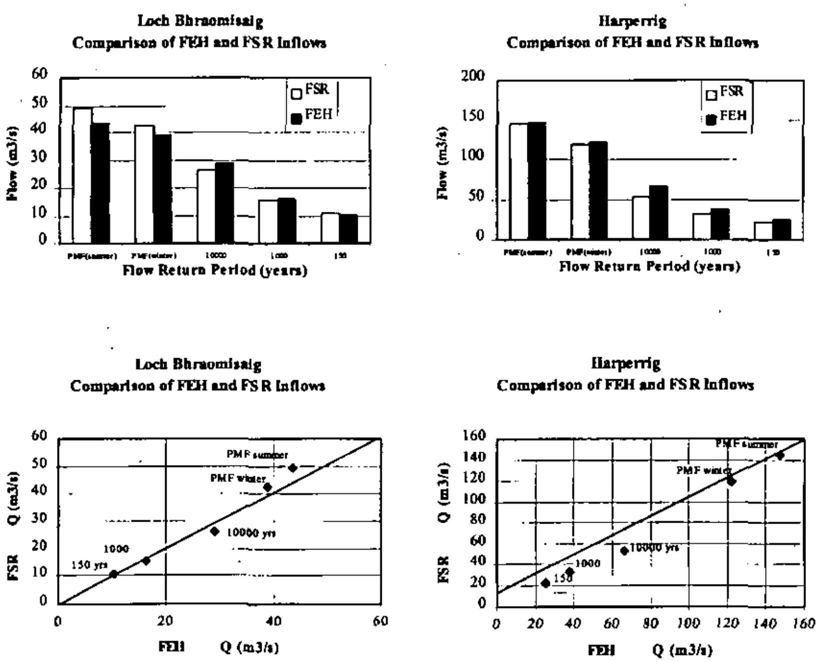

Figure 1.2. Comparison of inflow peaks

Chris Scott
I have some comments on Ian Gowans' interesting contribution. The FEH does not change the Probable Maximum Precipitation (PMP) estimates in the Flood Studies Report (FSR). Thus the differences in results between the FEH and FSR quoted for the PMF for Loch Bhraomisaig and Harperrig reservoir relate to changes brought about by the differences in the parameter estimation equations for the Standard Percentage Runoff (SPR) and the Time to Peak of the Unit Hydrograph (Tp (0)). The published paper restricted itself to a comparison of FEH and FSR catchment rainfall.

Derek Knight (Consultant)
We have just had presented some disquieting comparisons between the 1975 Flood Studies Report and the 2000 Flood Estimation Handbook - the FSR and the FEH respectively. In some parts of the country there are apparently, significant increases to the applicable design flood, whilst in other parts there are equally significant decreases. Half a century ago the Institution of Civil Engineer issued, I believe, guidance to dam engineers on floods for spillway design. A quarter of a century later the FSR resulted in major works and expenditure to bring spillway capacities "up to standard". Now, a further quarter of a century on, it seems that some of the upgraded spillways are inadequate again, whilst others were satisfactory after all, and - it seems reasonable to infer - need not have been modified after all.

It should be realised that references to so-called 1 in 2000 or 1 in 10 000 year floods are really numbers to describe an annual exceedance probability. The question needs asking, what is the date of the oldest actual data? Extrapolation beyond that must be speculative. What however, is not now speculative is that about every 25 years for the past half century flood estimation guidance for a particular part of the country has resembled a train announcer at a railway station: "Cancel that last announcement - the timetable and platforms have just been changed; please wait for a further announcement". We look forward to that announcement later this year (2000). Meanwhile it seems reasonable to conclude that dam engineers may expect significant ups and downs in flood estimation guidance at least twice, and possibly three times, in a professional life-time.

Jim Claydon (Yorkshire Water Services)
Yorkshire Water Services has recently taken over York Waterworks Company, a very old established company and in looking through the archives in their basement at Lendal Tower we found their flood records which went back to 1253. I'm not sure if these are of any use to us at the moment as one did say

something like 'Ye greatest flood in living memory'.

Chris Scott
I would just like to clarify something. The figures that I have published and talked about were rainfall figures and not flood figures. I think that Ian Gowan's figures were flood figures rather than rainfall figures. You have not only got the differences in rainfall estimates you are also then involved in the differences in the parameter estimation equations which may have other effects which we decided not to look at. We just solely concentrated on what was happening to rainfall and what the different approaches implied in terms of that input factor.

Chris Binnie (Binnie Black and Veatch)
I think it is now generally accepted that we do not have climate stationarity. The question then comes as to whether we should apply this, or rather its projection, in our design process. As dam designers, when we design or upgrade a spillway it is not economic to go back every decade or so to change the spillway because of marginally changed flood conditions. We need to do this in step changes of several decades, keeping ahead of climate change so that the standards of protection for the public are not jeopardised.

The recent October 1999 report of the Hadley Centre on "The greenhouse effect and climate change" shows the current estimate of change in short term rainfall. For instance a winter daily rainfall event of 1 in 10 years which was previously about 22mm could well become by say 2050 about 30 mm. This is an appreciable increase in rainfall, and proportionally a bigger increase in runoff. One would expect longer return period rainfall and runoff to increase also. If we are designing long life structures such as spillways then should we be incorporating such climate change conditions into our designs?

Neil Sandilands (Scottish and Southern Energy plc, UK)
I would like to comment on the short presentation by Ernest Taylor. The history of disasters shows that they usually occur from a series of very highly improbable events occurring together. As an example, the Herald of Free Enterprise sailed very many times with its bow doors open before it actually sunk one night. In the example of floodgates whilst it is very unlikely that floodgates would fail concurrently I think we should be extremely careful about totally discounting that because if the event does occur we will be held accountable for it.

Iain Moffat (University of Newcastle-upon-Tyne)
Just a quick point with regard to the inundation mapping in relation to concrete dams. It seems rather a hard definition to talk of either full breach, 10 blocks going or 1 block going. There is only one known instance of a gravity structure failing completely and that was because of particular foundation conditions. If you take the most critical mode of failure of a gravity dam as being sliding then I would suggest that the probability is that 1 or perhaps 2 blocks will slide forward and therefore you do have an attenuated outflow in the first phase.

I was fortunate enough to go to Malplasset dam shortly after the failure in 1960. The dam was a double curvature arch dam and the reason for failure was that the left abutment moved on first filling by nearly a metre I think. This led to the very rapid failure of about 3/4 of the dam. As a young dam designer it was very instructive to see such a failure with blocks of concrete the size of a house that had made up the dam lying 400m downstream. My memory is that many people were drowned in the town of Frejus several km downstream.

The erosion from the valley sides was appreciable. At the end of the valley by the sea there were several metres of silt. When considering what the flood water levels are going to be in a dam break, can the current computer models calculate the erosion which is increasing the valley cross section in some places and take account of the deposition that is raising the water level at other locations?

Kenny Dempster (Scottish and Southern Energy plc)
I think that the last two speakers demonstrate the complexities of concrete dams in relation to breach formation. We don't really know the exact mechanism and are addressing this issue from the perspective of sensitivity analysis, hence the single block, 10 spillway blocks, which essentially equated to the spillway of that particular gravity dam. The worst case for inundation mapping would of course be entire dam failure and perhaps echoing what Neil Sandilands said about accountability, if the entire dam was to fail we would be held responsible and so we wish to know what the potential consequences would be in that particular scenario.

The easy answer to sediment transport is that no, we have not made any real assumptions and think that this is not a major issue in the Scottish Highlands, although Mark Morris did touch on this area further.

Mark Morris

In my presentation I showed a picture of the St Francis dam in the US that failed. You will notice that there is a "tooth" of about a third of the dam left standing in the middle of the dam and it seems impossible to understand how it has stayed in place. This is just to emphasise that when trying to predict dam failure modes we are ranging from one small segment to the entire dam - or somewhere in-between - and our ability to define this is quite poor. Yes - it depends on the particular type of dam that we are talking about to some extent but still the uncertainty is wide. On the issue of sediments, research in Belgium comprising academic flume work is looking at movement immediately downstream of a dambreak flood wave and is suggesting that for a flood wave approximately 20m high you are looking at a potential 5-10m change in bed level from erosion / deposition. Some case studies in the US from past failures have also shown instances where bed levels have risen through deposition by 5-10m. There was also a situation where a very large stone bridge trapped debris up to a depth of 15m. With this magnitude of sediment / debris build up and scour, the water levels are also going to vary by similar amounts.

Iain Moffat

If I may just make this point about the mode of failure of a concrete dam. St Francis was a curved gravity dam but was not built in blocks. In the cases of the Mohne and Eder dams in Germany, there was no progression of the failure once the initial breach had taken place as a result of the bombing. The same is evident in the remains of the little dam a where they experimented with the bombs for the raids on Germany. There is also the classic case of Bousierre dam in France, a gravity structure, where the entire structure initially moved forward bodily and the dam did not in its first failure collapse in total.

Dominic Molyneux (Binnie Black and Veatch)

I am interested by comments from the audience that imply that sediment deposition and erosion caused by the dambreak wave could have a significant effect on the results in the field. Figures of 5 to 10 m of deposition and 5 to 10 m of erosion were mentioned. Mark Morris admitted that none of the codes tested during the European CADAM project could begin to allow for these factors.

In my paper to this conference 'Monitoring and planning mudflow control works following Mt Pinatubo eruption, Philippines', I present work carried out to control lahars on the Pasig Potrero River on Luzon, Philippines. A lahar is defined as a rapidly flowing mixture of rock debris and water, other than normal stream flow, from a volcano. Lahars differ considerably from normal flow events due to the extreme sediment concentrations and increased erosiveness of the flow. Volumetric sediment concentrations of between 50 and 75% have been recorded.

A lahar was described graphically by Rodolfo, a local geologist, in 1996: 'Pulses or surges of muddy streamflow were the precursors of incoming lahars. These surges had minimal sediment concentrations, generally less than 15 per cent by volume. A gradual increase in flow depth and increased surge frequency signalled the onset of hyper-concentrated flows, accompanied by strong lateral erosion at typical rates of 0.5 to 3 m per minute and the formation of standing waves as high as 2 to 3m and 15 to 20 m long. As a hyper-concentrated lahar progressed in intensity and discharge, its standing waves started to break, roaring continuously like ocean surf and the flow became very turbulent and erosive. The flow no longer cut sideways so strongly; instead it cut downward into the channel bed. The material eroded from the bed became part of the lahar, making it more dense and energetic, so it could flow faster. The increased density and speed of the lahar allowed it to incise the channel more deeply. Velocities at this stage ranged from 3 to 6 m/s.' During the course of the work at Pinatubo, carried out in conjunction with the Japanese, we witnessed deposition of 8 m of sediment followed by 16 m of erosion at one point on the river during a three day period. The erosion occurred over one night.

Lahars can be triggered by a number of mechanisms one of which is sudden breakout of lakes formed behind volcanic ash dams in the headwaters during tropical cyclones.

There are obvious parallels between lahars and dambreak modelling. I suggest that future researchers who might follow up the CADAM project to investigate the influence of erosion and deposition would do well to look beyond the borders of Europe. During our work in the Philippines, the Japanese presented results from a two-dimensional model that they had developed to look at erosion and deposition during lahar events. Other countries with similar problems from volcanoes may also have developed models or researched this problem.

Geoff Sims (Brown and Root)
Just to add to what Iain Moffat said. I think that the complexity of failure of a concrete gravity dam is more apparent than has been revealed so far. I do

not think the Mohne and Eder dams had joints across the structure. The photographs that I have seen in connection with the damage in wartime show that the bombs made a big hole in the middle and you are quite right that it did not spread to the side. The example that I have seen and used before is one called Tigra in India and I have the impression that was constructed with vertical joints and indeed one element did move by sliding independent of all the rest. I think that if we are going to make assumptions on floods on the basis of an assumed failure mode we do have a little more work to do.

Peter Mason (Binnie Black and Veatch)
Two notable cases of damage to concrete dams are the Koyna dam in India and the Sefid Rud dam in Iran. Both suffered structural damage during earthquake.

In the case of the Koyna concrete gravity dam, the body cracked through its entire depth over a considerable length and at an elevation 27 m below the prevailing water level. In spite of this, the dam did not fail. Similarly the Sefid Rud buttress dam cracked through structurally below water level, but again did not fail. Repairs were later carried out in both cases.

Cases of concrete dam failure have tended to be foundation failures, which accounts for examples where some sections of dam have remained standing while sections either side have failed.

Statistically concrete dams are about 2 to 3 times safer than embankment dams in terms of failure frequency but where failures have occurred, the loss of life has tended to be higher due to the more rapid nature of the collapse.

Jack Meldrum (Mott MacDonald)
For our first speaker, if I understood correctly, there were 3 scenarios put up as to the correctness of the methods. Either one was right the other one was right or both were right but there is a fourth alternative and I do not think we should lose sight of that. I think that was the sentiment of Derek Knight's comments. My second point is how bad was the Perth flooding? Has one of these really extreme events occurred and how does this compare with the dam break scenario?

Chris Scott
Jack Meldrum slightly misrepresents my comments. Both the FEH and FSR

present statistical models for the estimation of extreme rainfall and flood events. As such no claim to being 'right' can be made for either of the approaches. The highest claim is to provide a better model of reality. What we as dam practitioners require is a method that produces consistent estimates that can be adopted for assessing the risk of overtopping and the required overflow capacity. There seems to have been reasonable contentment with the FSR approach over the past 25 years, particularly among Consulting Engineers! What the paper seeks to highlight is the differences in the design rainfall totals obtained from FSR and FEH methodologies. We, as a profession, need to decide what course of action we should take given this and any other significant change.

Kenny Dempster

Our dam break modelling has considered both a PMF routed safely through the reservoirs and dam break at peak PMF levels, with modelling downstream to Perth. To all intents and purposes, the PMF plus a dam break would generate the same levels of inundation as the PMF alone, due to the attenuation effect of the 56 km of river. So under the PMF event alone we would be faced with a very serious situation to which dam break makes little difference in the downstream reaches, this will of course not always be the case and will definitely not the case in the upstream reaches. We have not yet fully modelled the 1;10,000 or 1:1,000 year return period events to allow comparisons to be made. What we do know by modelling is that a gate failure is comparable to the 1 : 100 or 150 year events, which in turn is comparable to the 1993 Perth flood. So if we were to have a gate failure we would yet again have flooding in Perth to the levels seen in 1993 although flood defence works are now nearing completion to protect against this level of flooding.

Rod Bridle (Consultant)

With regards to FEH versus FSR, I am very pleased to see that Andrew Robertshaw has not rushed into doing anything and is holding his horses for a little while and I would advocate that course of action to everyone. Our project will be giving some interim advice before very long but it is likely that there will be some further research so there might be an initial holding period until we can progress further.

In relation to Fiona Tarrant and Andy Rowland's paper on dam breaks, I endorse what they said. As Mark Morris' paper has also demonstrated, there is no quick solution or precise means of evaluating dam break floods, but current methods do give us an approximation to what might happen should a dam breach. The Tarrant & Rowland summaries show us that dam break floods would have devastating impacts.

The impact is largely proportional to the speed at which the breach occurs. Our models normally predict time to maximum breach size of less than 30 minutes (see "Inundation mapping for dam failure - lessons from UK experience", Tarrant, Hopkins and Bartlett, Reservoir Safety and the Environment, 8th Biennial Conference of the British Dam Society, Exeter, pp 282-291, Thomas Telford, London, 1994). This may appear a short period but Walder and O'Conner (in 'Methods for predicting peak discharge of floods caused by failure of natural and constructed earthen dams', Paper 97WR01616, Water Resources Research, Vol. 33, No10, pp 2337-2348, October 1997) quote times to maximum breach of natural failures. These were one hour for a water level drop of 97.5m at Birehi Ganga in India; less than one hour for 90m at Isfayramsay in the former Soviet Union and 0.67 hours for 9m at North Fork Toutle River in USA. They also give times to maximum breach of well-known dam failures. Teton breached to 67m in 1.25 hours, and Baldwin Hills, 12.2m high, failed in 0.33 hours.

The velocities of the dam break waves are high and the distance that the flood waves travel can be vast, up to 50 km or more. The effect of ground slope is marked; in steep catchments the flood wave travels further with velocities often high enough to cause risk to lives over long distances from the dam. Our dam break technology, however approximate, serves to demonstrate that we must take every step we can to guard against the occurrence of dam breaks and the uncontrolled release of water from our reservoirs.

I note that most of the tables in the paper refer to the extent of the zone of structural damage, not to the extent of the total damage zone, in which it is normally assumed that lives would be at risk. Could the authors confirm that they are using the structural damage zone as a convenient indicator and that it encompasses the total destruction zone? They have defined the zones of total destruction in the three case histories cited. These range from 8km to 82km downstream of the dam, although in the 82km case, the initial zone extends for 37km continuously from the dam. It would be useful, perhaps at a future conference, if they could present plots of the extent of zones of total destruction.

Fiona Tarrant (Binnie Black and Veatch)
In answer to your question, Rod, the partial structural damage is the

intermediate stage between total structural damage and inundation damage only. It was used as an indication to illustrate how far downstream you could actually get such damage. You will see that the paper talked about total structural damage and partial structural damage. We have given illustrations of the distance downstream that you can find each of these types of damage indicating in terms of total structural damage that it could be some distance downstream - one example quotes 80km downstream of a dam. The other point to make is that the total structural damage could be in sections down the valley not just a continuous section just below the dam. These are two fairly important points to make.

Jim Findlay (Babtie Group)
Just a couple of points, one on the floods and one on the dambreak.

In Chris Binnie's question, should we not be trying to predict the higher return periods for the climate scenario in the future and that is part of the DETR research. I will be making a short statement this afternoon on where we have got with the implications for reservoir safety of climate change and we will be highlighting the considerable uncertainties that there are in predicting climate change, even for the most basic parameter like precipitation. I think we are currently a long way away from predicting changes in return periods.

Going on now to dambreak for concrete dams and the work we have being doing for Scottish and Southern Energy. References have been made to full breaches, 10 block breaches and single block breaches. Obviously in developing these we have wanted to demonstrate the full envelope of potential breach consequences. However, in preparing an input statement to Scottish and Southern Energy we have been very keen to demonstrate that what we focus on is a credible dam breach and that we take account not only of the generally good foundation conditions that Scottish Hydro's concrete dams are based on but also the available energy to precipitate a failure and to maintain it. We heard about very large storage volumes in some of the reservoirs and that leads you to believe that they could sustain a progressive failure. However, we have to bear in mind that sometimes the driving head reduces very quickly on formation of the initial breach and we must not get too carried away looking at the extreme total failure and end up with an unrealistic scenario where there is virtually no driving power left in the reservoir to produce the total failure.

Peter Kite (Environment Agency)
The Environment Agency has 106 reservoirs registered under the Reservoirs Act. There are massive works and financial implications for flood defences and flood retention reservoirs if the FEH produces significantly higher flows than those forecast by FSR as indicated. It is not only those reservoirs that are affected in terms of the standard of protection they provide but also all the connecting infrastructure of thousands of kilometres of flood defences.

Additionally whilst increased flood flows may be forecast using FEH the implications need to be followed through and impacts built into flood warning and emergency planning arrangements.

Andrew Thomas (Independent Supervising Engineer)
I am very appreciative of the openness here today about what I call the fantasyland of the 10,000 year storm and the uncertainty that goes with it. It seems to me that we get in a rather silly situation when we have arbitrarily said that we should design for a 10,000 year storm. If there is any reason behind it we might have said 5000 or we might have said 937 so we took an arbitrary figure of 10,000 and we are taking an imaginary storm. I am beginning to think just what we are doing in reality is trying to give ourselves a comfort, a consensus that this is something that we all feel comfortable with. So what I am suggesting is that if we find we prefer to use the FEH then it is quite reasonable to go back to basic assumptions as to what a reasonable frequency is, and if there is a consensus of opinion, then we will settle for, say, 9000 years. The danger is that all we are trying to get is something that people feel happy about and we make all these calculations when it really is quite simple. We may as well just say let's just take 1,000 times the annual flood as long as everybody is happy with it.

Chris Scott
Andrew Thomas' point is an interesting one. To design or evaluate any structure one needs to determine the forces that have to be resisted and the events that must be survived. The ICE's Floods and Reservoir Safety guide suggests that flood provision for reservoirs should reflect the risk that the dam represents to downstream dwellings and property; with decreasing probability of occurrence (measured by increasing flood return period) being required for increasing downstream vulnerability. As noted earlier, we should be aiming for a constant level of hazard across all threats to the integrity of our structure. The use of extreme return periods allows us to have a measure of the probability of the events for which we are designing. Adoption of a crude multiplier on a shorter return period event would result in different

levels of hazard at different locations around the country. The current approach is certainly not perfect but it is, in my opinion, better than the suggested alternative.

Mr Thomas' comments have lead us to investigate what return period the FEH would suggest for the FSR 10,000 year event at sites around the country. Looking at our small sample of 10 reservoirs, the FSR 10,000 year return period catchment design rainfall total was found to have an FEH return period varying between 1,800 and 5,000 years.

Martin Brumby (RJB Mining)
If the Conference will accept a contribution from a designer of tailings dams rather than a "proper" Dam Engineer, I would like to agree with the previous speaker who pointed out that, irrespective of whether the FSR or FEH methodology was used, the "10,000 year flood" was itself an entirely arbitrary standard. Of course, it is important that hydrologists and statisticians use their best endeavours, the most complete records and the latest techniques to predict the outcome of these extreme events. It is in turn our duty, as engineers, to ensure that the best available prediction methods are used as part of the design process for new works and that the fullest account is taken of the consequences of failure. But the potential cost of upgrading every existing dam spillway is likely to be enormous, certainly many tens of millions of pounds.

I suggest we consider what the man in the street would expect. He would expect a dam to be "absolutely safe". This is unachievable. Were a more sophisticated approach to be urged on the public, a probability of "one in 10,000 years" may well only be generally accepted provided the storm which could lead to overtopping isn't expected to occur until year 12,000 AD. This isn't how it works! In fact there is a danger that the man in the street, or at least, the man living immediately downstream of a large dam, if confronted by the type of discussion on dambreak and inundation we have had this morning, would start to smoke an extra 20 Woodbine every day to cope with the stress!

It is easy for statisticians, for whom an extreme "one in 10,000 years" event is an "everyday" concept, to forget that, this level of probability (or rather, improbability) is entirely arbitrary. But dams can also fail for various reasons other than overtopping, notably internal erosion but also foundation or gate failure, instability, seismic effects or even the impact of a hypothetical meteorite or jumbo jet. If a reservoir spillway has in "absolute" terms the capacity to pass only a "one in 8,000 year" flood rather than 10,000 year but is otherwise satisfactory, I very much doubt that the sum of human happiness would be more effectively increased by spending millions on enlargement works rather than (for example) a similar amount on hip replacements for pensioners.

Jim Claydon (Yorkshire Water Services)
I think Martin actually summed up a lot of the dilemma here. There is a perception amongst some funder's for this that this is a wheeze dreamed up by engineers to create yet more work and we have to be very careful about that perception. So I am very pleased with the short time-scale which Alex Macdonald and Rod Bridle have given for this interim guidance and I look forward to reading it when it comes out. I would like to thank all the speakers from the floor and our three presenters here.

SESSION 2
INNOVATION IN HYDRAULIC STRUCTURES

Chairman Peter Mason
Technical Reporter Neil Williams

Papers Presented

1. Dam innovation - a selection of innovative features and curiosities
   J C Ackers and C W Scott
2. Refurbishment of the scour facilities at Green Withens reservoir
   I C Carter, S C Dickson and M J Hill
3. Three cases of gate vibration
   M Noble and J Lewin

Papers Not Presented

1. Early Siphon Spillways
   J C Ackers
2. Towards total acceptance of fully automated spillways
   P D Townshend
3. Deterioration of pre-tensioned bars retaining radial spillway gates leading to failure and loss of tension - a case study
   P E May and G R Hallowes

William Hakin (Hydroplus International)
In 1998 the United States Corps of Engineers awarded Hydroplus Inc. a co-operation agreement for a study to investigate the viability of utilising 6.5m high concrete fusegates to increase the flood protection and storage capacity ability of Terminus Dam, California. Located on the Kaweah River near Visalia, the main purpose of the 38 year old dam is flood control and water supply for irrigation.

An exhaustive nine-month model-testing program was undertaken and successfully completed in June 1999. A large model (23m by 16m in plan) was constructed at Utah State University to analyse the extreme flows and operating conditions in which the fusegates would be required to work. After the continuous assessment of test results by an independent panel of experts, the U.S Corps of Engineers decided to proceed with detailed design and construction of the innovative solution offered by use of the system.

Six concrete fusegates, 6.5 m high and 12.0 m wide, will be installed in the spillway channel thereby increasing the storage potential by 50 million m^3 and improving the flood control capacity. Because the Corps were concerned that large debris might get caught on the tops of the wells (normally situated on the fusegate units), the design for Terminus dam calls for the wells to be remote from the units and situated in a separate control structure located near the embankment. From the intake structure, pipes which are embedded in the spillway sill lead into the base chambers of the fusegate units to provide the necessary uplift pressure under extreme flooding events. Due to unwanted water fluctuations experienced during extreme flood conditions the remote well structure is itself fed via a pipe from an intake located 300m upstream of the remote well structure.

The reinforced concrete units at Terminus Dam will be the same height as the highest currently installed in the world, (Shongweni Dam, South Africa, in 1995), but at 400t each they will certainly be the heaviest. The first fusegate unit will not tip before the 1000 year flood event.

The Hydroplus spillway represents a cost effective and a reliable engineering solution for increasing the reservoir capacity at Terminus Dam. The total project cost using the system will be US$ 33 million, which represents a US$ 20 million saving for the Corps compared to the traditional solution originally considered which involved a conventional widening and raising of the existing spillway.

Construction work on the dam is expected to begin during the summer of 2000 and should be completed by mid 2002.

Jack Lewin (Consultant)
The operation of the automatic gates described in the paper by Townshend (Towards Total Acceptance of Fully Automated Gates) results in coarse water level control, like all gates controlled by buoyancy chambers. They are also subject to an appreciable difference between opening and closing because the direction of the seal friction forces reverses. To prevent leakage at the breast seal, an accurate profile and face of the gate is required. A close tolerance of trunnion/skin plate radius is also necessary which is not always attained.

The radial automatic gate overcomes these problems. It has been used extensively in the UK and the Continent of Europe for about 60 years and in most cases it does not require raising the dam crest and, of course, venting of the nappe is not necessary. However, it requires relatively wide piers to accommodate the displacer chambers. On the River Avon in the centre of Bath, at Pulteney Weir, a radial automatic gate 15 m wide by 3.7 m high has controlled the flood flow of the river for 31 years. Water controlled gates at spillways are susceptible to wave action. Radial automatic gates can be damped but not entirely. There is always a risk of gate instability due to wave action.

The title of the paper is slightly misleading because many spillway gate installations are automatically operated by programmable logic controllers.

The case described by May and Hallowes (Deterioration of Pre-tensioned Bars Retaining Radial Spillway Gates) is a very difficult assignment - a bad design of the trunnion anchorage aggravated by unacceptable workmanship described in the paper as "unusual installation practice".

The authors are to be congratulated for solving a difficult problem. I will confine my contribution to a general observation. Except in a dire position, as in this project, pre-stressed strands and bars should not be used together. Strands have a lower modulus of elasticity than bars. Ordinary wire ropes have a modulus of about one third of solid bars, and strands formed with Lang's lay have a higher modulus but still significantly below that of bars. Therefore, the loads on the tendons can only be matched over a limited range of applied loading.

George Hallowes (Consultant)
In response to Jack Lewin I would say that I do not regard the replacement of a small proportion of the bars by strands as causing an undesirable situation. The difference between the elastic moduli of bars and strands was recognised and its significance is discussed in the paper (May & Hallowes). It should be remembered that there will be no extension of the anchors and, thus no significance in the different moduli, unless the thrust on the gates is such as to exceed the pre-stress load in the anchors. That situation should not be allowed even if the anchors are all bars or all strands because any movement of the trunnions risks causing the gates to jam. The prestress load gives a factor of safety of 1.4 over the thrust from the water when the reservoir level is at the top edge of the gates, and if the reservoir rises further the operating rule to pass floods through the reservoir requires the gates to be opened.

If the proposal was to replace nearly 50% of the bars with strands I would consider replacing the remainder, because if the gates are not opened when they should be, the effect of so many of the anchors having a different modulus might be significant for the behaviour of the gates. However it is not necessarily beneficial to ensure even stressing of the anchors while the gate is seriously overloaded. If all the anchors remain equally stressed as they extend, the (rockfill) dam will be overtopped before the load in the anchors reaches their ultimate strength even though there will then be 10m of water above the top of the unopened gates. Under those circumstances failure of a gate would be preferable to a continued rise in reservoir level leading to failure of the dam!

May I take the opportunity to draw delegates' attention to an error which I made in sketch C of the figure on page 109 of the proceedings, for which I apologise. The upper group of bars totals 18 as drawn, but there were only 16. The lower pair of the upper group shown in the sketch should not be there.

Ian Gowans (Cuthberston Maunsell)
May I inform the audience that the gates at Fontburn referred to in the paper "Dam innovation - a selection of innovative features and curiosities" are secondary gates to the main spillway which is a bellmouth "morning glory" of limited capacity. The gates were constructed some 40 years ago to meet flood standards but the Flood Estimation Handbook may further increase the design flood. The gates were model tested at Heriot Watt University and in their working life have been tested to full water pressure on several occasions and they continue to work well.

With regard to the paper on "Early Siphon Spillways" I recall working on the Tummel Bridge Aqueduct which was emptied at the time when Dunalastair Reservoir experienced an extreme flood. This resulted in the uphill wall section of the aqueduct failing at three locations during the event. I understand that the siphons at Dunalastair were designed to come into operation as a secondary spillway facility with the two main gates in the dam providing the main flood discharge. I can confirm that there was considerable vibration when the siphons operated but I do not know if this was anything to worry about.

I recommend reading the Institute of Electrical and Mechanical Engineers' papers on the siphon spillways at Laggan and Dunalastair. They prove immensely interesting reading, demonstrating the competition at the time in terms of the siphon design and construction.

My company is presently working in Thailand and a colleague of mine has prepared a video of a fuse plug constructed in an earth embankment that is capable of being washed out in an extreme flood. I hope that my colleague will be able to show this at the next BDS Conference in 2 years time.

Mark Noble (Scottish and Southern Energy)
I am not aware of any problems with vibration at Dunalastair but I have had little involvement with the dam. I believe however that the gates open to 20ft but have a stopper at 2 ft 6 inches to avoid flooding at Tummel Bridge. At that restricted opening no vibration is experienced. I have also witnessed the operation of the siphons and no vibration was experienced or ever reported.

Some vertical lift gates at the bottom of deep shafts do vibrate and I am due shortly to inspect one such site where gates of size 19ft by 12ft have been reported to be problematic.

Geoff Sims (Brown & Root)
I feel that Mr Ackers has not revealed the full extent of the Binnie family in the matter of siphon spillways, particularly those running with a mixture of air and water. It is difficult to model accurately the volume of air entrained in the water flow. I worked with A M Binnie at Cambridge between 1964 and 1967 in an attempt to improve the accuracy of modelling techniques of air entrainment into flowing water. The presence of a free water surface implies the use of the Froude scale law, but since the water sometimes entrains air as it enters the siphon this aspect of the flow must also be modelled. Viscous effects are not negligible, neither is surface tension.

An opinion frequently expressed at the time was that models of flows involving the entrainment of air should be made according to the Froude law, with the ambient atmospheric pressure reduced in the scale ratio. The concept was to find out to what extent the flow through an air-regulated siphon spillway is influenced by the time-dependent behaviour of the bubbles entrained in the flow. They thought in terms of the stiffness of the air bubble and to model the air pressure within it. Mr Binnie arranged for the purchase of an obsolete decompression chamber from the RAF to contain the experimental rig.

They found that the pattern of flow was not influenced by the reduction in ambient atmospheric pressure, provided that the effects of cavitation were absent. The estimate of the volume of entrained air was not improved by this technique.

Rod Bridle
In the paper "Three cases of gate vibration" by Noble and Lewin, the

castellated beams are fabricated with sharp corners and are generally of poor design. This compares against a patented castellated beam that has holes of hexagonal shape cut into the web.

Mark Noble
I agree that the design was poor but the gates are very robust and their stiffness is much greater than American type gates that more readily experience problems.

John Ackers (Binnie Black and Veatch) subsequently provided the following written clarification of his paper ' Early Siphon Spillways".

Figure 1 shows the full-size model undertaken by Crump and colleagues in the period 1925-29, but the barrel size of this model is actually greater than that of the siphons installed at Renala in 1922. According to drawings seen when I visited Renala in March 2000, the barrels are actually 40 inches square, rather than 4ft wide by 5ft high, which I stated in the printed paper.

Since writing the paper, I have read Crump's contribution to the discussions on a paper on the siphon spillway at Eye Brook reservoir (Oliver, 1958), in which he confirmed the barrel cross section at Renala as 40 inches square and provided further design and performance information, including the following:

"Misled into fearing the random occurrence of full-bore operation, the air-vent soffits were placed at five different elevations ranging from 1.0 to 1.4ft above crest level. As a further precaution, the outfall hoods were terminated at five different levels in order to delay priming until the outlet became sealed by the rise in tail water-level resulting from earlier units coming, supposedly, into full-bore operation."

From the behaviour of the Renala siphons I have learned that all those elaborate preferential measures were not only unnecessary, but positively ill-advised, and that it would have been far better to make all 35 units exactly alike. In that case all 35 units would have behaved alike, each passing smoothly from unstrangled weir flow to strangled flow, with the air-flow automatically adjusting itself to pass any discharge offered to the battery.

There was an event when the spillway was by mistake overloaded to the extent of 900 cusecs. The result was that all units passed only black water; so that, with no air passing, the upstream surface rose, breached the main canal, and flooded many acres of cropped land. The siphons should be designed to pass the design discharge with air-partialised flow, so that there is some discharge capacity in reserve.

SESSION 3, PART 1
DETR RESERVOIR RESEARCH PROGRAMME

Chairman	Andy Hughes
Technical Reporter	Andy Rowland

Presentations

1. Introduction
   R Vincent
2. Reservoir safety advice
   Dr A Charles
3. Upgrades to embankment dams
   J Findlay
4. Climate change
   J Findlay
5. Sedimentation in reservoirs
   Professor D Butcher
6. Seismic risk assessment research
   Dr W Daniell

Chairman

This is a session which is slightly different to our normal format but which fits in very well with the theme of this conference, namely looking forward. This session which is called DETR Reservoir Research Programme includes a review of a number of research projects which are being undertaken and the presentations we are about to hear will inform us of progress to date and the work yet to be done. However, to start the session we will first have an overview of the DETR reservoir research programme and I ask Richard Vincent now to make his presentation.

Richard Vincent (DETR)

The general objective of the DETR research programme is to ensure that authoritative and developing information and advice on reservoir safety is available to the Department and hence to Panel engineers, reservoir owners and the authorities which enforce the requirements of the Reservoirs Act. If you think that that objective is no longer appropriate or that we are no longer living up to that objective do please let us know.

Let's look at what's going on currently. There are five projects which the Department is funding completely and you are going to hear about four of them. The fifth one was discussed in Session 1. The projects have been placed with the organisations you see mentioned following a process of competitive tender:

- General advice (BRE)
- Upgrades to embankment dams (Babtie)
- Climate change impacts (Babtie/IoH)
- Sedimentation (Halcrow)
- Floods (Babtie/CEH-W/Bridle)

The Department also part funds two other projects both of which are drawing to an end:

- the CIRIA Risk and Reservoir Project, which you again will hear something of this afternoon so again I shall not say anything about that at this point,
- the CADAM project and we heard Mark Morris's very interesting account of that earlier today.

Clearly I am not going to give you a precise figure for how much we spend but it is of the order of £200 000 a year. A summary of the projects is given below:

General advice contract with BRE:

- work on the database,
- further continuation of work that has been done in previous years on embankments,
- the literature review - this is an innovation and I trust most of you should have seen the output of that in the December 1999 issue of Dams and Reservoirs,
- the work on seismic stability analysis and there is a demonstration of that in the exhibition area,
- TQM approach that Andrew Charles is going to speak about,
- ICOLD input,
- and, very importantly, advice at call. If something awful were to arise, then ministers would need advice very rapidly. I am certainly not technically qualified to do that, so we do need such people who are readily available to us.

Upgrades to embankment dams

The objectives are:

- devise and disseminate a system for assessing needs for improvements to embankment slope stability,
- draw up general specifications and guidance for slope stability

remediation,
- draw up general guidance on internal erosion remediation.

Work on climate change impacts.

The origin of the work which is going on is summarised by a direct quotation from the climate change scenarios published in 1988 by the UK Climate Change Impacts Programme:

> "Changes in mean climate will also be accompanied by changes in the frequency of extreme events. Intense daily precipitation events become more frequent, especially in winter ...... summer gales become a little more frequent as do very severe winter gales ...."

The Department wholly funds UKCCIP. That provides a very major contribution to both the national and the international debate on climate change issues of all sorts. With that quotation in mind it was felt appropriate to see what it might mean for reservoir safety. The current work is focussing on these two questions:

- what extremes of precipitation intensity and/or frequency would pose a serious risk of exceeding the capacity of reservoir spillways?
- what severity of gale might cause wave action to pose a serious risk to the integrity of dam crests?

Other questions have arisen in the course of this work and you will hear something of that shortly.

Sedimentation

There are two matters of interest in the work on sedimentation. One of course relates to the long term usefulness of reservoirs - is there a significant danger of the reservoir stock in this country becoming significantly devalued by sedimentation? Another issue which arose very largely by moves to modify the Reservoirs Act is the question whether sediment in reservoirs should not be taken account of in determining whether a reservoir should be within the ambit of the Act. These are the sorts of issues being looked at in this work:

- devise broad classification of British reservoirs according to sedimentation susceptibility,
- examine capacity, operational and environmental consequences at representative reservoirs,
- extrapolate findings,
- examine physical nature of sediments,
- consider how to reduce sedimentation,

- consider options for economically and environmentally acceptable sediment removal.

That is what is going at the moment but we are always open to suggestions for new pieces of work which it would be appropriate for the Department to fund either wholly or partially. It is very much up to the practitioners to suggest new lines which they would like to see researched to aid them in their various responsibilities and interests.

The reservoir safety research programme is funded by DETR but we do work very closely with our colleagues in the Scottish Executive and the National Assembly for Wales so that the reservoir programme remains wholly appropriate to Great Britain. We are anxious, despite devolution, to ensure that all matters to do with reservoir safety continue to have the essential coherence which they have enjoyed to this point and which is manifest in this gathering here today.

Presentations

Andrew Charles (Building Research Establishment)
Reservoir safety advice.
Dr Andrew Charles outlined some of the work undertaken by BRE including developments of the Database and the Seismic Software. He then introduced his paper "Reservoir safety and quality management"

Jim Findlay (Babtie Group)
Upgrades to embankment dams
Richard Vincent has already presented the objectives of DETR's reservoir safety research programme.

The brief provided by DETR for upgrades to embankment dams can be summarised as identifying the need for an assessment system for older embankment dams, focussing on the potential failure mechanisms of slope instability and internal erosion. One of the key definitions in this work is that of less modern embankment dams which has been taken as pre 1950's.

The research is still developing at this time and Babtie Group is being supported by inputs from Iain Moffat of Newcastle University (understanding of old embankment dams) and Murray Reid of TRL (degradation processes and literature searches).

The project will be completed in December this year and the team is currently compiling a first draft.

Principal activities to date have involved consultation with industry through a questionnaire and presentation at the AR Panel Forum held at ICE in November 1999, plus analysis of the BRE database and a literature search of topics relevant to embankment dam upgrades.

Initial findings suggest that there is little insight available from the industry on the assessment of instability and internal erosion on older dams where there are no external indicators of distress. Also, that there is little correlation of known problems to the characteristics of the dams concerned, based on published information. These issues raise the question as to whether there is a case to answer in terms of the brief i.e. is there a need to assess the integrity of older embankment dams. Certainly there is an imprecise understanding of the processes involved in the two mechanisms.

The research team recognises that there is some scepticism within the industry related to the nature of the guidance to be provided. To address that, it can be stated what the study is not doing.

- The guidance will not advocate more intrusive investigations (as an easy option to decision making) nor will it suggest that you can avoid a thorough investigation where this is merited.

In pursuing this middle ground of guidance the team together with Richard Vincent have given some thought to expressing the need of the industry for further guidance. In particular it is recognised that there is already much published guidance in relation to embankment dams, specifically the Guide to Safety.

DETR's objectives are reflected by the following aspects of the study (refer to figure 3.1):

- Recognising the changing environment within which reservoir safety inspections are carried out (the drivers affecting owners and engineers). This centres on the way in which we deal with the uncertainty between a dam clearly in an acceptable condition and one clearly in an unacceptable condition. This gap in knowledge is increasing due to a variety of effects, including the uncertainty of the dam ageing process. The study explores this uncertainty and will also deal with potential complacency and the

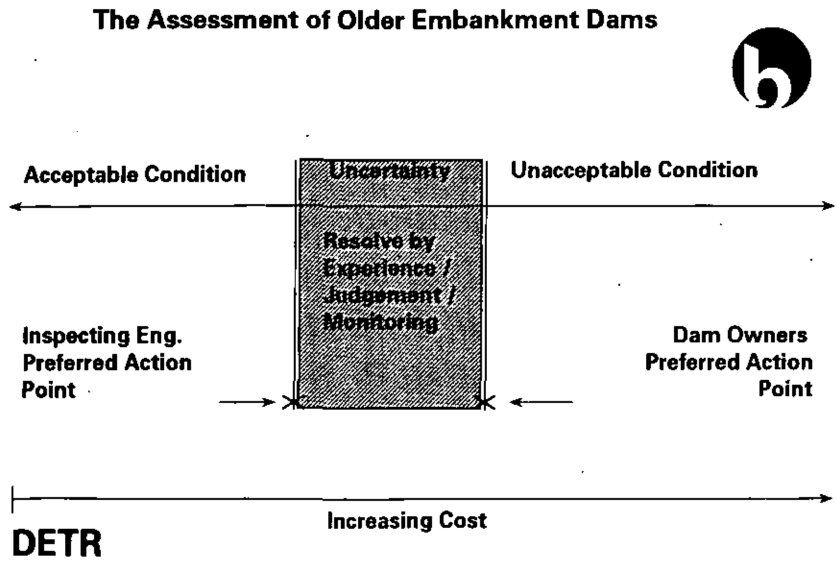

Figure 3.1

need to transfer knowledge to younger engineers.

- Providing support to experienced judgement to allow safety decisions to be transparent.
- Answering the question as to whether we should be doing more to understand older dams as a general case (the answer appears to be yes).

The guidance given will provide a chart-based methodology for expressing the potential for risk of internal erosion or slope instability. This will be an aid to understanding the mechanisms rather than a definitive numerical solution.

The document will also discuss appropriate standards to apply to acceptability of older dams while giving maximum scope for the application of judgement and experience.

The draft outline of the report splits the guidance into two quite separate parts:

1. Part A deals with the industry consultation carried out, why this justifies the need for an assessment system, and presents an appropriate methodology.
2. Part B presents the options available for upgrading works that deal with potential internal erosion and latent slope instability. This section will

provide reference to the published information available as well as highlighting the key technical criteria applying to the various options.

Jim Findlay (Babtie Group)

Climate change

The brief from DETR was to examine the impact of predicted changes in frequency of extreme events due to climate change and to consider the scale of precipitation and gale events that might cause risk of exceeding the capacity of existing dams.

Babtie Group is working with the Institute of Hydrology (now CEH Wallingford) on this project with the IOH team led by Dr Duncan Reid.

The work is well advanced with the various simulations run and a draft report largely complete.

It is important to understand the influences on climate change prediction, particularly the models used and the current state of knowledge in the field. The following points have a major influence on what the study can do:

- The global climate model (GCM) is the basis of the predictive work and is an international model. This uses a large scale grid of 250km with 15 layers and a large number of parameters and results in the UK being covered by only four grids.
- The basic driver for the model is CO_2.
- For the dam safety study a 10km grid has been derived.

There are considerable uncertainties in the application of current climate change scenarios. While there is high confidence in atmospheric CO_2 predictions, this confidence diminishes as the focus becomes more event specific, decreasing through regional seasonal precipitation estimates, eventually leading to low confidence in daily precipitation changes. There is thus a difficulty in downscaling global models, such that prediction of monthly rainfall averages is better than storm events. This presents problems in addressing storm driven impacts such as reservoir safety and care is needed in interpreting such predictions.

Access has been given to unpublished research data from the UK Climate Impact Programme (UKCIP) for this study. This has produced scatter diagrams giving envelopes of potential change in wind and rain for the four UKCIP98 scenarios on a site-specific basis.

The general trends emerging from the work show a NW/SE variation in increased rainfall (NW wetter) and also a distinct summer/winter difference with little change in Spring/summer rainfall but large increases in Autumn/ Winter figures. For wind speed, Autumn increases are predicted especially in the North.

The research project has to consider how these changes might affect reservoirs. Essentially, rainfall intensity, floods and winds impact on the available freeboard of a dam; this in turn being influenced by overflow discharge capacity.

The approach adopted has been to test the sensitivity of British reservoirs to climate-change driven total surcharge. To do this requires a sample of reservoirs that reflects characteristics such as geographic location, flood category, dam type, spillway type, catchment nature and reservoir area. Using these criteria, a representative selection of 14 reservoirs was chosen covering a spread of regions and characteristics. These reservoirs are semi-synthetic i.e. while based on actual reservoirs they are not precise replicas thus preserving a degree of anonymity. Also they are not regarded as typical, as that is an impossible objective given the variables involved. Rather, they are a broad representation of the major reservoir types in the UK.

The methodology used for the research was to plot incremental (percentage) changes in storm depth and windspeed for each representative reservoir based on multiple micro FSR runs to provide total surcharge values on a matrix (see figure 3.2). This was done for both summer and winter pmf events.

Overlaid on this basic matrix of surcharge values are a series of (parallel) sensitivity lines showing percentage increases in total surcharge for all combinations of wind and storm depth increases. The origin of the matrix axes represents the year 2050 zero point.

Superimposed on this reservoir specific background is a shaded zone that represents the boundaries of the four UK climate change scenarios for the region in which the reservoir lies. This is an expression of how significant the changes in total surcharge could be in the year 2050 if the most extreme outliers of the climate change scenarios are realised. It should be noted that these outliers may be well beyond the mean indications of change as represented by the centre of gravity of the scatter plots used as the basis for

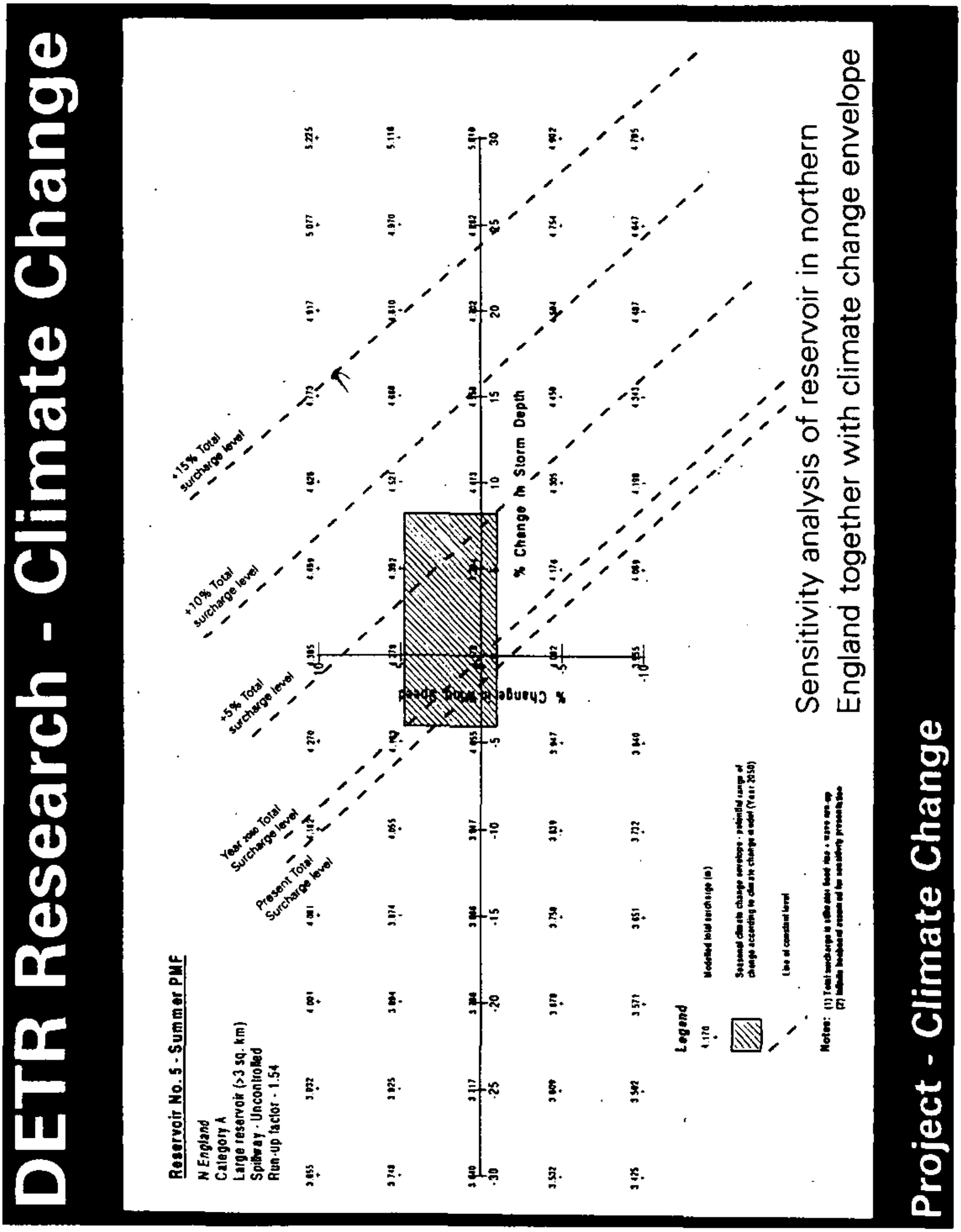

Figure 3.2. DETR Research - Climate Change

this presentation. They are thus a current worst case.

Looking at the results of this work for all the reservoirs, produces the following interim generalised findings:
Most reservoirs show approximately +5% sensitivity to the 50 year worst case prediction of storm depth and windspeed changes. This scale of response is considered to be similar to the error range of flood routing and wave run-up calculations due to the various input parameters, and therefore does not demonstrate particular sensitivity of UK reservoirs to climate change at this time.

This work comes with a health warning in respect of the climate change envelopes portrayed as rectangular zones in this study. These are not well defined at their outer limits and should be regarded as having fuzzy edges. The overall uncertainty of the climate change scenarios currently being presented is also highlighted.

The output of this study is primarily to brief DETR on the situation and may not be formally published as dam safety research.

Dave Butcher (Nottingham Trent University)
Sedimentation in reservoirs
A written submission from Dr J. Labadz, also of Nottingham Trent University, is included at the end of this Session.

Wendy Daniell (University of Bristol)
Seismic risk assessment research
Background to Study
As part of their asset management, Scottish and Southern Energy are conducting seismic risk assessments for all their dams and critical appurtenant structures. Recent experience indicates that most UK dams are unlikely to suffer any serious earthquake damage. However, appurtenant works are potentially more vulnerable. In the absence of comprehensive guidance on the seismic assessment of appurtenant works, this study was commissioned concentrating on the seismic performance of radial gates and intake towers. Case studies were carried out for Glascarnoch intake tower and the radial gate at Kilmorack Dam, both structures being typical for Scottish and Southern Energy dam sites. The outcome of the project has been the production of a guide for Scottish and Southern Energy for the seismic assessment of their dam appurtenant structures.

Dam Appurtenant Structures: Seismic Assessment Guide
The guide comprises four parts. An overview is provided for non specialists describing the seismic behaviour and vulnerability of intake towers and radial gates, a methodology for their seismic evaluation, and means of risk mitigation. More specific guidance is then given on the seismic analysis of general appurtenant structures for those carrying out seismic assessments. The other two parts provide particular information for intake towers and radial gates including specially developed analytical methods and other related issues. The guide draws on the findings of the case studies conducted as part of this project.

Seismic Study of Kilmorack Dam Radial Gate
Kilmorack Dam's radial gate, which was not designed for seismic loading, is 7.9 metres wide by 8.2 metres high and constructed from steel. The study on the gate included dynamic hammer testing of the prototype structure, to measure its dynamic characteristics, and a seismic analysis using two methods; the time history analysis of a 3-D finite element (FE) model and the equivalent-static analysis of 2-D models. The aims of the study were to establish the seismic vulnerability of a typical UK gate, and to determine a suitable method for its seismic analysis.

The study showed that the type of FE model employed could be used to predict the dynamic behaviour of a radial gate, as there was a fair correlation between the modes measured from the tests and those calculated from the FE model. The study suggests that this type of gate may be vulnerable to UK earthquakes for two reasons. Firstly, both the tests and FE model revealed that the gate had many modes of vibration in the frequency range excited by earthquakes. Also, both seismic analyses showed that the load during the Safety Evaluation Earthquake for the site almost doubled compared to the hydrostatic case.

A comparison of the two analytical methods demonstrated that the equivalent-static analysis of 2-D models is adequate for preliminary seismic assessments of this gate type. However, dynamic 3-D FE analysis must be used for gates with important 3-D effects, and when the seismic demand calculated from the preliminary analysis is close to or exceeds the capacity of the gate.

Seismic Study of Glascarnoch Intake Tower
Glascarnoch intake tower is constructed in reinforced concrete and has a complex structural arrangement. It comprises a tower supported on a

relatively rigid base structure with two flanking trapezoidal wing-walls supporting a curtain wall. The tower supports a gate house constructed from a steel frame encased in concrete with reinforced concrete slabs and infill walls. The overall height of the tower and base is about 24.5 m. Access to the tower from the reservoir shore is via a four span bridge.

The study on the tower included ambient vibration tests on the prototype structure, its linear-elastic seismic analysis, using a relatively simple 3-D FE model, and an equivalent-static analysis to estimate the seismic forces at the critical section of the tower. Similar to the gate, the aims of the study were to establish the seismic vulnerability of a typical UK tower, and to find a suitable method for its seismic analysis.

A relatively coarse mesh of solid elements was used for the FE model of the tower, as a stick model was unsuitable due to the complex geometry of the tower. The model was analysed with and without the bridge to study its effect on the seismic response. Dynamic properties of the FE model compared well with those measured from the tests, demonstrating that this relatively simple model could be used to predict the natural frequencies for this type of tower. The frequencies of the lowest modes of vibration for the bridge and the tower fell within the range excited by UK earthquakes, indicating that this type of tower may be vulnerable to UK earthquakes.

For the site's Safety Evaluation Earthquake, the equivalent-static forces, calculated by hand for the critical section of tower, were compared with those from the seismic FE analysis. It was demonstrated that the equivalent-static method can be used for a preliminary assessment of the seismic vulnerability of a tower. However, for complex structures like Glascarnoch tower, it will not give accurate results for the stress distribution across the section.

The seismic analysis of the FE model shows that the tower's concrete will crack and that a non-linear analysis is required to assess more accurately the seismic demand. However, for a reliable non-linear analysis, further research is required to characterise the non-linear dynamic behaviour of reinforced concrete towers. The required research should combine laboratory tests on scale models with analytical studies. In this way, the seismic capacity of typical intake towers can be evaluated, and currently available methods of analysis can be validated.

Discussion

Chairman

What I wanted the last presentation to show is that there is other research work going on other than that funded by DETR. There is longstanding research going on at Newcastle University. There is a whole wealth of research out there that perhaps we all don't know about. Part of the BRE contract is to keep us all informed but I wonder whether the British Dam Society can do more to collate that research and keep us all informed. That is something to think about in the discussion.

Foot Note: BRE has published two reviews of publications in Dams & Reservoirs, December 1999 and 2000. Every member of BDS has the opportunity of having their research and publications recorded in this review.

Jim Millmore (Babtie Group)

Richard Vincent asked if there were any points which we would like to bring to his attention for future research. It is glaringly obvious to me that there is one particular item which does need to be taken further. It is the matter in connection with FSR and FEH. Alex MacDonald said that he is working on a comparison of the two systems but I think that what has become quite apparent to me today, and before today, is that we need to go a lot further than simply a comparison.

We have heard about FSR and FEH. We've all been through PMPs and so on. We have talked about the 10,000 year return period flood and the uncertainty over this. What I can not get clear in my mind is whether the Noah's Ark flood was less than or more than a 10,000 year return period flood.

I think that what we ought to be doing as engineers is accepting that research is taking place and that it is introducing new standards of calculation of extreme events. What we need as engineers is an update on the guidance which the ICE has provided for engineers and owners on reservoir safety because we are seeing these new standards and because the Flood Estimation Handbook publicity says that this is the new standard which we are to follow. If anything goes wrong and we don't follow that, who is going to be in the court of law defending not having followed that procedure. I think that DETR should be considering the guidance for the standards we should be following as opposed to the theoretical standards that we can calculate.

George Hallowes (Consultant)
Can Dr Wendy Daniell or Neil Sandilands say how soon their work will be in the public domain? I got the impression from Dr Daniell's remarks that there is some hope that it will form part of a note but I think that is probably a long drawn out procedure. Might we as the public, rather than the people who commissioned this report, have access to this report earlier.

Neil Sandilands (Scottish & Southern Energy plc)
The guide will not be going into the public domain but it will be made available to appropriate people who have a use for it. I anticipate that will be in the next three months. It depends how it long it takes to clear up the present comments.

John Beaver (Consultant)
I wondered whether there was any likelihood that there will be a formal requirement of CPD for panel engineers to be used in the reapplication procedure. I think this is an excellent way forward to make sure that all panel engineers at least turn up to these proceedings.

I wanted to ask Wendy Daniell how the prototype tower was vibrated at Glascarnoch to determine the structural characteristics. Do you have to go round vibrating all different types of prototype to get a feel for the different intake towers that you are going to look at and then compare them with your finite element analyses?

Andrew Charles (Building Research Establishment)
The Reservoirs Committee are encouraging people applying for panel appointments to submit CPD. I think the only question is whether there will be a formal requirement. I am not sure that there is a formal requirement at the moment but the Reservoirs Committee certainly does want applicants for reappointment to present their Continuing Professional Development record.

Wendy Daniell (University of Bristol)
Wind was used for vibration and there was plenty of it at Glascarnoch. We do not have to test the structures for comparison with the models but as part of a research exercise it is very useful. I would also say that people who are assessing structures, and this applies to any seismic assessment, should go out and measure the natural frequencies of the structure to compare with models, because when you are dealing with models, especially for dams, you are dealing with very complex structures attached to a complex foundation about which you know very little. Also you don't know much

about the state or strength of the concrete in the dam, especially the dams we deal with in the UK. They are old dams and very often we do not have all the records on the concrete strengths. The ambient vibration testing is cheaper than doing a finite element analysis and I would recommend it.

Derek Knight (Consultant)
May I first of all answer Mr Jim Millmore's question about the flood in the time of Noah - whether it was the 10 000 year flood, or the PMF, or what? Noah's Flood was, in fact, a unique event of global extent and is fully described in Genesis Chapters 6 to 9 inclusive. It accomplished its designed purposes, after which God promised that never again would there be a flood to destroy the earth. As a token he set the bow in the cloud, so - the next time you see a rainbow, remember! The promise is to be found in Genesis Chapter 9, verses 11 to 13.

With that link to the present I should now like to comment on a point already made in this session, namely, that, because there is very little new dam building now taking place in the UK, it is becoming more difficult for future Panel engineers to gain experience in dam design and construction. Here are two suggestions:

1. There is much dam work going on overseas, and those responsible for Panel appointments will therefore be able to take such experience into account when assessing applicants whose UK dams experience is limited.

2. Most UK dams are embankment dams, and thus applicants with geotechnical experience should be welcomed.

Whilst no engineer now can have had experience of construction of the type of old dam typical in the UK, this obvious fact has not prevented engineers being appointed to the All Reservoirs Panel. The large variety of non-dam geotechnical engineering all over the country gives plenty of opportunity for today's engineers to see first hand the varied techniques which can now be applied to yesterday's dams.

Chairman
The benefit of the dam safety system in the UK is based on the panel engineer system that places responsibility on the individual. There is no doubt that he needs a supporting cast behind him to give the technical support that he needs. However, we do need to tighten up on the appointment and reappointment system for panel engineers and make it much more rigorous.

'DETR Reservoir Sedimentation Research Project

Presented by Prof David Butcher and written by Dr Jill C Labadz,
Dept of Land-Based Studies, Nottingham Trent University

Introduction

Walling and Webb (1996) noted that sediment transport by rivers has an important social and economic dimension related to the problems of reservoir siltation. The range of problems associated with reservoir sedimentation in Britain includes:

- Increased flood risk on influent streams, loss of flood storage for downstream channels and increased spillway flows.
- Loss of storage capacity with associated loss of reservoir yield and difficulties in storage recovery.
- Severe blockage of scour/drawoff works resulting in periodic reservoir drawdown to excavate sediment or abandonment of bottom outlet facilities.
- Build up of sediment against the upstream face of dams, adversely affecting the stability of certain dam structures.
- Sediment accumulations near power intakes, increasing the sediment load of the water passing through turbines, thereby accentuating turbine wear.

A research project on "Sedimentation in Storage Reservoirs" is currently being undertaken for the Water and Land Directorate of the DETR by Halcrow Water and Professor Butcher & Dr Labadz of Nottingham Trent University. The project commenced in May 1999 with completion due in December 2000. This research aims to review reservoir sedimentation in Britain and to provide guidance on the prediction of storage loss and the measures that can be taken to mitigate the associated problems.

The first element of the project brief was to devise a broad classification of British reservoirs according to the factors which are likely to determine their susceptibility to significant capacity loss through sedimentation. This paper includes a review of the available data for the assessment of sedimentation in British Reservoirs and the formulation of a proposed method of classification for susceptibility to sedimentation. The other stages of the project are:

- Additional reservoir surveys (bathymetry and sediment properties).
- Development and testing of a predictive technique to assess likely sedimentation rates in each reservoir class.

- Modelling of sediment release from reservoirs under dambreak conditions.
- Identification and review of the measures that can be taken to reduce sedimentation in reservoirs.
- Consideration of the options available for the removal of sediment from reservoirs and the associated environmental concerns.
- Consideration of the past and future consequences of reservoir storage loss.

British Sediment Yields in a Global Context

Sediment yield in Britain is known to be low by global standards. Mahmood (1987) gives the global average total sediment yield as 190 $t.km^{-2}.yr^{-1}$. There is considerable spatial variation in average suspended sediment yields: Walling (1987) gives 50 $t.km^{-2}.yr^{-1}$ as a typical value of suspended sediment yield for the UK and cites site specific yield measurements between 1 and 488 $t.km^{-2}.yr^{-1}$.

The factors which determine the sediment transport in a watercourse are well reported in general terms for Britain (DoE, 1995). The literature confirms that controls such as land use, management practices, vegetation cover, grazing intensity, soil type, channel steepness and length, flow convergence/divergence and surface roughness are all important. However it is only recently that a large-scale (regional) study of the processes has been undertaken in Britain. The Land-Ocean Interaction Study (LOIS) was launched by the Natural Environmental Research Council in 1992 and was completed in 1998. The 'river component' of LOIS focused on the Yorkshire Ouse and other principal rivers draining to the Humber Estuary, and on the River Tweed. In view of the general lack of information on suspended sediment transport by British rivers, particular attention was given to investigating the suspended sediment dynamics of the study rivers. It is important to note however that as LOIS aimed at a better understanding of the interaction between suspended sediments and nutrients and contaminants; bed load transport was not covered by the study. Suspended sediment yields within the Humber catchment gave figures of suspended sediment yield between 3.4 and 92.1 $t.km^{-2}.yr^{-1}$ with a mean value of 26 $t.km^{-2}.yr^{-1}$ (Waas and Leeks, 1999). The site with the highest mean suspended sediment yield (58 $t.km^{-2}.yr^{-1}$) was a steep upland catchment. The research found a positive relationship between suspended sediment yield and catchment area with the rate of increase tending to decrease with large catchments. It was considered that larger catchments are subject to lower erosion and depositions of sediment on the floodplains during overbank flooding events.

As well as there being considerable spatial variation, the sediment load can vary considerably with flow conditions at a site over time. Suspended sediment concentrations in British rivers have been recorded to vary by up to three magnitudes within a year. Newson (1986) pooled UK data for suspended and bedload measurements and found that bedload can exceed 50% of the total yield in small upland catchments whereas suspended sediment dominates in the larger lowland rivers where it typically represents over 85% of the total yield.

Given that there has been an absence of a national sediment monitoring programme in the UK, no definitive estimate for the average total UK sediment yield can be estimated. From the information available however, it appears likely that this lies in the range of 50 - 75 $t.km^{-2}.yr^{-1}$. Outside of the UK, reservoir re-survey data are available from a large number of authors for impoundments world-wide (White, 1993) and serve as a useful guide to global sediment yield figures. The majority of these data originate from the USA, with the remainder from India, Ecuador, China, Australia, Africa. These data have been broadly categorised on a continental basis in Table 1.

Table 1: Sediment Yield Data from Reservoir Surveys outside Britain (after White, 1993)

Region	Sediment Yield ($t.km^{-2}.yr^{-1}$)
Americas	1104
Africa	259
Asia	293

Care is required in interpreting the data in Table 1. The data are dominated by reservoirs from North America, with very poor representation from other parts of the world. Many of the data consist of individual studies in reservoirs where a severe sedimentation problem has been identified and these sediment yield data may misrepresent the general situation for the region from which they originate. In the same manner, care is needed when using British reservoir studies as a guide to national sediment yield.

Available data on reservoir sedimentation in Britain

The major owners of reservoirs in England Wales and Scotland have been approached as part of the study to obtain information on reservoir sedimentation that may be available, and to obtain additional characteristics of reservoirs that are kept in the Prescribed Form of Record for each reservoir. The information has been entered in a database initially based upon the information in the BRE dams database (Tedd et al, 1992) which covers all known reservoirs within the Reservoirs Act, and was supplemented with information derived from published literature sources, from unpublished research by the authors and others, and responses received from the various reservoir undertakers. The database is also geographically linked through the use of grid coordinates and can thus be used for geographical calculation of sedimentation rates etc.

The BRE dams data base contains over 2500 reservoirs but information on sedimentation was only available for very few of these. Where water undertakers did respond to the request for information it was most frequently to supply details of rainfall, land use and catchment areas of reservoir gathering grounds. Tables 2 and 3 indicate the variables included and the range of information obtained. Where available, other details have also been included to describe any factor which may influence the rate of sedimentation in a particular reservoir. This may include knowledge that there is another reservoir basin upstream, existence of any structure for managing sediment movement such as a bywash channel, or that there has been removal of sediment from the basin in the past.

In many cases the rates of sedimentation calculated are dependent upon the accuracy not only of a recent survey but also of the original survey at the time of dam construction and on comparability between two surveys. White et al (1996) have discussed some of the difficulties of this approach. Some of the information (such as that from He et al, 1996) uses isotope dating of sediments rather than direct volumetric differences between two surveys. This may be a preferable approach if a detailed study is undertaken and the sediments are relatively undisturbed but it has its own attendant difficulties, particularly if the number of sediment cores is limited and values obtained may therefore not be representative of the entire reservoir.

Table 2: Variables used in reservoirs database:

BRECAP	capacity of reservoir in BRE database (Ml)
DATEORIG	date of construction
ORIGCAP	original capacity (Ml)
DATEREV	date of revised capacity
REVCAP	revised capacity (Ml)

SAREA	surface area of reservoir (m^2 x 10^3)
HEIGHT	height of dam (m)
LENGTH	length of dam (m)
CATCHMNT	catchment area (km^2)
INDIRECT	indirect catchment area (km2)
CARATIO	capacity:catchment ratio ($Ml.km^{-2}$)
RAIN	annual average rainfall (mm)
M3YEAR	capacity loss ($m^3.yr^{-1}$)
M3KM2YR	capacity loss ($m^3.km^{-2}.yr^{-1}.$)
ANNPERC	annual loss of capacity (% of original)
MEANDBD	mean dry bulk density of sediment ($t.m^{-3}$)
SY	sediment yield to reservoir ($t.km^{-2}. yr^{-1}$)

Table 3 summarises the extent of the information available for reservoirs which have at least some direct catchment area (ie. excluding service reservoirs and those entirely used for pumped storage, since sedimentation is likely to be minimal in such cases):

Table 3: Descriptive statistics for British reservoirs:

Variable	Mean	Std Dev	Minimum	Maximum	No of cases	Median
BRECAP	8115.02	31907.63	25.00	382800.0	524	718.5
DATEORIG	1896.73	55.76	1725.00	1993.00	528	1901
ORIGCAP	3007.96	11259.61	.00	121020.0	209	551
DATEREV	1989.30	5.38	1967.00	2000.00	161	1990
REVCAP	3037.47	10454.03	8.20	116580.0	163	722.69
SAREA	1056.46	4207.72	2.00	74677.00	510	165.5
HEIGHT	16.17	12.99	.60	91.00	519	13.0
LENGTH	367.95	413.54	2.00	4420.00	419	266.0
CATCHMNT	33.42	124.96	.00	1810.00	473	4.69
INDIRECT	32.61	107.21	.00	989.81	209	1.78
CARATIO	579.72	3727.51	3.00	48286.00	177	183.0
RAIN	1114.81	408.64	450.00	2500.00	316	1003
M3YEAR	4530.98	18694.44	.00	185000.0	124	606.0
M3KM2YR	366.76	1021.10	.00	9339.50	100	139.1
ANNPERC	.13	.16	.00	1.01	123	.088
MEANDBD	.45	.19	.05	.93	75	.435
SY	84.29	78.36	3.69	389.11	107	48.11

It can be seen that the information available is sparse. Only 163 reservoirs actually have revised capacities available, the majority of which were surveyed by the authors (White, Labadz and Butcher, 1996 etc) for either Yorkshire Water or North West Water. Other clusters of reservoirs have been surveyed by Duck and McManus (1985, 1990 etc) for various water undertakings in Scotland, and by Foster and Lees (1999) as part of the NERC LOIS project. The remaining information is mostly for single reservoirs which have been the subject of an individual research project, or where sedimentation was of particular concern to the undertaker. These are summarised in Table 4. The final column in the table in Table 4 shows the "indicative" sediment yields suggested in a previous report to DETR as being typical of each situation. As a result of the limited range of individual studies which actually present sediment yields, data have been included in Table 4 (but not in the database) for a small number of natural lakes as well as reservoirs.

It was possible to calculate gross rates of infilling ($m^3 \cdot yr^{-1}$) for 124 reservoirs, and sediment yields ($t.km^{-2} \cdot yr^{-1}$) for only 107 reservoirs to date. The average sediment yield to British reservoirs for which information is currently available (only 107 reservoirs) is a little less than 85 $t.\ km^{-2}.yr^{-1}$.

The average loss of capacity from British reservoirs is perhaps best expressed by the annual percentage loss. The mean value here, derived from 123 reservoirs, equates to a loss of 13% of original capacity per century. As has been previously noted, this is a relatively low value compared to losses experienced elsewhere in the world but it may be of increasing significance as water resources in Britain become more pressurised.

The volumetric measure of capacity loss has a mean value of 4531 $m^3.yr^{-1}$ but the distribution is very skewed. The median value suggests that a typical British reservoir loses approximately 600m^3 to sedimentation each year. The volumetric measure of capacity loss per unit catchment area is also skewed, the mean of 366.76 being less "typical" than the median value of 139 m^3.km-2.yr^{-1}.

The median value for sediment yield for a sample of 107 British reservoirs of 48 $t.km^{-2}.yr^{-1}$ is close to the value proposed as typical for sediment yields from British catchments by Walling and Webb (1981). The mean sediment yield obtained is 84 $t.km^{-2}.yr^{-1}$, but with a standard deviation approximately equivalent to this value (78 $t.km^{-2}.yr^{-1}$) which again indicates a great deal of variability amongst the group. It was therefore considered instructive to try to divide the information according to anything known about the landuse of each catchment and the presence or absence of structures controlling sediment transport. The results are summarised in Table 4.

In general terms the values seem to confirm those previously suggested, but it must be noted that individual reservoirs sometimes produce anomalous results. Further investigation of the individual situation would be necessary in order to understand the relatively high sedimentation rate experienced. Rates for Stourton Lake (Somerset) and Wadhurst Park(Kent) given by He *et al* (1996) are higher than were generally expected for lowland pasture, although the precise nature of the landuse in these catchments is not clear from the paper. It may be that relatively steep slopes or soil types are conducive to catchment erosion.

The largest number of individual studies can be categorised as concerning reservoirs at "medium susceptibility" of sedimentation, by virtue of their being set within catchments dominated either by lowland intensive agriculture or by poor vegetation in the uplands. A good number of the studies fall below the suggested 25-100 t. $km^{-2}.yr^{-1}$ range, but the mean value for the 23 studies listed here is 37.7 t. $km^{-2}.yr^{-1}$ with a standard deviation of around 20 t. $km^{-2}.yr^{-1}$. It is suggested that this average figure is a good "first approximation" for reservoirs in these types of catchments.

The final land use class in the table is for those reservoirs set in upland peat moorlands. The majority of data here derive from studies by the current authors (White et al, 1996, Labadz *et al*, 1991 and 1995 etc) in the southern Pennines or from the work of Duck and McManus (1990, 1994) in Scotland. These are two areas where a perception of abundant rainfall on the hills led to development of water supply reservoirs in the 19th century to support industrial and urban developments further down valley. In Scotland there has also been development of reservoirs for HEP purposes. In both cases, sediment yields in excess of 100 t. $km^{-2}.yr-^{1}$ are commonly experienced. It must be noted that these rates are particularly important because dry bulk densities of peaty sediment can be very low, giving rapid capacity loss in volumetric terms. For example, the authors found that Wessenden Old Reservoir contains sediment at least 7m deep (Labadz *et al*, 1991) and both Strines and March Haigh reservoirs have been rodded and shown to hold at least 4m of sediment in places (White et al, 1997). Direct measurement of sediment depths at most other sites has been hampered by the inundation of the basin, with samples from the Mackereth corer only including the top metre of deposit.

The impact of sediment control structures upon measured rates of sedimentation is summarised in the table and is discussed in more detail by Labadz *et al* (1995) and White *et al* (1996). Residuum lodges and bywash channels do seem to be effective measures for reducing sedimentation, but variance within the samples was high. These measures were often deployed in situations where the original engineers anticipated very high sedimentation rates, meaning that direct comparison with other reservoirs lacking such structures may not be strictly appropriate.

Table 4: Sedimentation rates observed in British Lakes and Reservoirs:

Landuse etc	Impounding reservoirs with sediment control or another reservoir upstream	Impounding reservoirs with no sediment control or other reservoir upstream	Indicative sediment yields suggested in previous report to DETR ($t.km^{-2}.yr^{-1}$)
Lowland pasture		**Blagdon** = 121 $m^3.km^{-2}.yr^{-1}$ but no sediment density available (Bristol Water). **Chard**, Somerset = 29 $t.km^{-2}.yr^{-1}$ but catchment is 25% urban (He *et al*, 1996). **Chew Valley** = 314 $m3.km^{-2}.yr^{-1}$ but no sediment density available (Bristol Water) **Elleron Lake**, Yorks = 9.46 $t.km^{-2}.yr^{-1}$ (Foster & Lees, 1999). **Furnace Pond**, Kent = 11.6 $t.km^{-2}.yr^{-1}$ but 20% cultivated (He *et al*, 1996). **Seeswood Pool**, Warwickshire at end of 19th century = 8 $t.km^{-2}.yr^{-1}$ (Foster *et al*, 1990). **Stourton Lake**, Somerset = 29.6 $t.km^{-2}.yr^{-1}$ (He *et al*, 1996, says catchment undisturbed but doesn't give precise landuse). **Wadhurst Park**, Kent = 72.3 $t.km^{-2}.yr^{-1}$, catchment 95% undisturbed (He *et al*, 1996).	**Low 0-10**
Mixed arable, channels <1:1000		**Slapton Lea**, Devon = 16 $t.km^{-2}.yr^{-1}$ (Heathwaite, 1993). **Thoresby Lake**, Notts = 6.4 $t.km^{-2}.yr^{-1}$ (Butcher, Labadz and White, unpublished survey for British Coal, 1989).	**Low 0-25**
Upland less erodible soils or established forest		**Boltby**, Yorks = 19.57 $t.km^{-2}.yr^{-1}$ (Foster & Lees, 1999). **Fontburn**, Northumbria = 12.46 $t.km^{-2}.yr^{-1}$ (Foster & Lees, 1999).	**Low 10-25**

		Merevale Lake, Warwickshire = average 9.45 $t.km^{-2}.yr^{-1}$, varying 5-20. Deciduous woodland catchment (Foster *et al*, 1985). **Ponsonby Tarn**, Cumbria = 7 $t.km^{-2}.yr^{-1}$ before clear felling (Oldfield *et al*, 1999). **Trentabank**, Macclesfield Forest = 22.9-34 $t.km^{-2}.yr^{-1}$ (Stott, 1985, 1987).	
Lowland intensive agriculture or upland poor vegetation	**Holl** = 72.3 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1990).	**Barnes Loch**, Northumbria = 23.62 $t.km^{-2}.yr^{-1}$, mostly moorland (Foster & Lees, 1999). **Cameron, Fife** = 70 $t.km^{-2}.yr^{-1}$ (Al-Jibburi & McManus, 1993). **Catcleugh**, Northumbria = 43.1 $t.km^{-2}.yr^{-1}$ (Hall, 1967). **Cropston**, Leics. = 45.6 $t.km^{-2}.yr^{-1}$ (Cummins & Potter, 1967 and 1972). **Drumain**, Fife = 3.9 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1994). **Fillingham Lake**, Lincs. = arable, 16.49 $t.km^{-2}.yr^{-1}$ (Foster & Lees, 1999). **Glenfarg**, Tayside = 52 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1994). **Glenquey**, Tayside = 15.1 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1994). **Hopes**, East Lothian = 25 $t.km^{-2}.yr^{-1}$ (Ledger *et al*, 1974). **Kelly**, Renfrewshire/Ayrshire = 41 $t.km^{-2}.yr^{-1}$ (Ledger *et al*, 1980). **Llyn Geirionydd**, N. Wales = 6-18 $t.km^{-2}.yr^{-1}$, with higher values being due to mining rather than afforestation (Dearing, 1992). **Llyn Peris**, N. Wales = 5 -42 $t.km^{-2}.yr^{-1}$, increase associated with overgrazing, construction etc (Dearing *et al*, 1981). **March Ghyll**, Yorks. = 19.47 $t.km^{-2}.yr^{-1}$, mostly moorland (Foster & Lees, 1999). **Newburgh Priory Pond**, Yorks = mixed agricultural, 52.38 $t.km^{-2}.yr^{-1}$ (Foster & Lees, 1999). **North Esk**, Midlothian = 26 $t.km^{-2}.yr^{-1}$ (Ledger *et al*, 1974). **Old Mill Reservoir**, Devon = mean 54 $t.km^{-2}.yr^{-1}$ increasing from 20 to 90 $t.km^{-2}.yr^{-1}$ as agriculture intensified (Foster and Walling, 1994). **Pinmacher**, Ayrshire = 50.9 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1994). **Ponsonby Tarn**, Cumbria = 39.8 $t.km^{-2}.yr^{-1}$ after trees felled (Oldfield *et al*, 1999). **Seeswood Pool**, Warwickshire = 36 $t.km^{-2}.yr^{-1}$ after agricultural intensification. Effectiveness of grass buffer strip for reducing input from cultivated land was noted.	**Medium 25-100**

		(Foster *et al*, 1990).	
		Strines, Yorks. = 113.4 $m^3.km^{-2}.yr^{-1}$ according to Young, 1958, but no sediment density given. Later surveys suggest 70.1 to 115.6 $t.km^{-2}.yr^{-1}$ (White *et al* , 1997).	
		Strinesdale Upper, Lancs.= 39 $t.km^{-2}.yr^{-1}$ (Labadz, Butcher & White , unpublished survey for North West Water, 1993).	
		Wyresdale, Lancs = 41.5 $t.km^{-2}.yr^{-1}$ (Price *et al*, 2000).	
		Yetholm Loch, Northumbria = arable, 22.01 $t.km^{-2}.yr^{-1}$ (Foster & Lees, 1999).	
Upland peat/ Moorland	**Southern Pennine Reservoirs**: in a study of 77 reservoirs, those with residuum lodges or bywash channels in place experienced mean rates of capacity loss approximately 166-188 $m^3.km^{-2}.yr^{-1}$ compared to 213-219 $m^3.km^{-2}.yr^{-1}$ for unmodified reservoirs, although variance within the samples was high (Labadz *et al*, 1995, White *et al* , 1996). Effects of reservoirs upstream and catchwater interception were less clear. It is possible that any difference in the average rates is confounded by the preferential siting of chains of reservoirs in moorl and areas with relatively high erosion rates.	**Abbeystead**, Lancs = 192 $t.km^{-2}.yr^{-1}$ (Rowan *et al*, 1995).	**High (>100)**
		Chew Reservoir, Lancashire = 212.7 $t.km^{-2}.yr^{-1}$ (Labadz, 1988).	
		Carron Valley, Stirlingshire = 141.9 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1990).	
		Earlsburn, Stirlingshire = 68.2 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1990).	
		Howden, Peak District = 35.7 $t.km^{-2}.yr^{-1}$ from Severn Trent survey data, but 127.7 $t.km^{-2}.yr^{-1}$ suggested by Hutchinson (1995) from sediment cores.	
		North Third, Stirlingshire = 205.4 $t.km^{-2}.yr^{-1}$ (Duck & McManus, 1990).	
		Southern Pennine reservoirs 77 reservoirs = mean 124.5 $t.km^{-2}.yr^{-1}$ but with median value 77 $t.km^{-2}.yr^{-1}$ (Labadz *et al*, 1995, White *et al*, 1996).	
		Wessenden Valley chain, Yorks. = average for 4 reservoirs 203.7 $t.km^{-2}.yr^{-1}$ (Labadz *et al*, 1991).	

Using the information in the database, stepwise regressions were then performed to predict sedimentation rates with independent variables including:

a) *physical features of the reservoir:* date of origin, original capacity, surface area, length and height of the dam;
b) *catchment inputs;* average annual rainfall and catchment area;
c) *relationship between reservoir and catchment:* capacity to catchment area ratio.

These variables were selected on the basis of likely supply of sediment and the physical behaviour of the incoming sediment, such that a greater reduction in velocity will encourage more efficient settling and deposition (Mahmood, 1987). They were also selected as being those variables for which most information was available in practice. Brown (1944) used the ratio of capacity to catchment area as an empirical predictor of reservoir trap efficiency, and these data are more widely available than those for Brune's (1953) capacity : inflow ratio. Other variables such as land use, altitude and presence of sediment structures would have been informative but would have reduced the sample here to a very small size and so were not included.

The regression for the annual volumetric sedimentation rate per unit catchment area (m3.km-2.yr-1) used the capacity:catchment area ratio as the only significant independent variable. The coefficient of determination (R2) was 98%, suggesting a very good fit. However, this regression had only 52 degrees of freedom (because other reservoirs have incomplete data for the selected variables) and inspection of the chart indicates that two reservoirs are having an undue influence on the relationship.

A similar regression was produced for annual percentage loss of capacity. This time the variables selected as most informative were surface area, original capacity and rainfall. The rate of capacity loss was predicted with coefficient of determination 44% and 62 degrees of freedom. Whilst far from ideal, this may offer some potential for estimation of capacity loss in other British reservoirs since the variables included are readily available.

Results of a regression for sediment yield (in $t.km^{-2}.yr^{-1}$) were such that the two variables entered into this equation were rainfall and the height of the dam (perhaps a measure of trap efficiency of the basin). The coefficient of determination, however, was poor at 21%. Closer inspection also revealed that this equation had only 52 degrees of freedom. Many of the reservoirs have been omitted from the analysis because they are missing data for at least one variable. When the exercise to predict sediment yield is repeated using only RAIN and HEIGHT as independents, the coefficient of determination obtained was still only 21% although the degrees of freedom had now increased to 66.

In summary, then, the following variables have been shown to be of some benefit in predicting sedimentation in British reservoirs:

DATEORIG	date of construction
ORIGCAP	original capacity (Ml)
REVCAP	revised capacity (Ml)
SAREA	surface area of reservoir ($m^2 \times 10^3$)

HEIGHT	height of dam (m)
LENGTH	length of dam (m)
CATCHMNT	catchment area (km^2)
CARATIO	capacity:catchment ratio ($Ml.km^{-2}$)
RAIN	annual average rainfall (mm)
SUSCAT	sedimentation susceptibility category, based on landuse and sediment control structures

Conclusions

It is clear that the data currently available are not sufficient for a simple empirical prediction of sedimentation rates in Britain beyond the broadest generalisations. One possibility is to extend the current knowledge by further correspondence with water undertakers and selection of a number of reservoirs for bathymetric survey and sediment sampling. This would be expensive and time consuming, but it is the only way to increase the breadth of knowledge across the full range of situations. Ideally, full bathymetric surveys to determine change in capacity should be combined with sediment coring and isotope dating to give corroborative measures of sedimentation rates.

Another approach would be to purchase secondary data sources to extend the range of information available for statistical analysis, since the preliminary work has indicated that broad estimates of sedimentation can be obtained. One appropriate source would be the CD available from the Centre for Ecology and Hydrology (CEH) to accompany the Flood Estimation Handbook (1999). This would allow relatively speedy calculation of catchment area, rainfall, altitude etc for the entire range of reservoirs. Soil type could also be used as a predictor of erosion risk and therefore of sediment yield (Evans, 1990) and data are available in digital format from the Soil Survey and Land Research Centre at Silsoe. More detailed consideration and evaluation of the data already available for each reservoir, beyond the time resources of the current project, would undoubtedly improve the reliability of any prediction made. However, unless better data on sedimentation rates are also obtained (as mentioned above) the success of this approach is still likely to be limited.

Finally, where sedimentation is a particular concern it may be possible to develop a numerical or conceptually based model to predict the behaviour in an individual reservoir. This has been done for reservoirs overseas (Morris and Fan, 1998), as for example at Bhakra dam in India (Meadowcroft *et al*, 1992) and at Cachi reservoir in Costa Rica (Sundborg, 1992). It is likely, however, that the costs of such an approach in terms of time and resources would exceed those of the primary data collection described above and there is still a requirement to measure or model the sediment inputs to the reservoir before the impact of the basin itself upon sedimentation processes can be considered.

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SESSION 3, PART 2
RISK AND RESERVOIR SAFETY

Chairman	Andrew Charles
Technical Reporter	Ian Carter

Papers Presented

1. Risk Management for UK reservoirs
   A K Hughes, H W M Hewlett and C Elliot
2. Safety issues at small reservoirs
   J D Gosden and A J Brown
3. Emerging concepts in project risk management: some innovative suggestions and solutions for the dam industry
   M W Good

Papers not presented

1. A Guide to the Reservoirs Act 1975
   J D Gosden and A J Brown
2. Reservoir Safety and Quality Management
   J A Charles (presented in part 1)
3. Developments in the British national dams database
   P Tedd, H D Skinner and J A Charles

There was no discussion following this session.

SESSION 4
ENVIRONMENTAL IMPLICATIONS: BENEFITS AND DISBENEFITS

Chairman	Chris Binnie
Technical Reporter	Jim Findlay

Papers presented

1. Environmental assessment of reservoirs as a means of reducing the disbenefit/benefit ratio
   S Clifton
2. The potential for future dam construction in the United Kingdom: Appreciating the benefits and accommodating the impacts
   I Staniforth
3. Environmental evaluation of reservoir sites
   C Thomas, H Kemm and M McMullan

Papers not presented

1. Environmental implications - benefits and disbenefits of new reservoir projects
   E M Gosschalk and K V Rao
2. Environmental impacts of dams: the changing approach to mitigation
   T J Turpin

The session was preceded by the keynote lecture from Achim Steiner (Secretary-General) on the work of the World Commission on Dams (see page 111).

Derek Knight (Consultant)
As a very thirsty customer of Essex and Suffolk Water I should like to ask Sally Clifton whether Abberton reservoir in Essex is still being considered for raising.

Chris Binnie (Binnie, Black and Veatch)
I know the background to this scheme and it is still under consideration. The owner, Essex and Suffolk Water, has investigated several schemes and is currently promoting the reuse of treated sewage effluent in the Chelmer River. They will be making a decision on the promotion of the Abberton scheme in due course.

Derek Knight
My second question is to Mr C Thomas and his co-authors on the methodology used in their paper on the environmental evaluation of reservoir sites. Have they given equal weighting to the "site factors" in, for example, Table 11 on page 249? If so, why? Does this not introduce a considerable dose of subjectivism into the apparent objectivity.

Chris Thomas
Specialists in each field have provided the scales and the methodology of using 1-5 for assessment is considered valid for the level of detail needed on this comparative overview.

Jim Claydon (Yorkshire Water Services)
All of the speakers have based their presentations on the presumption that reservoirs are the chosen option. I would like to widen the topic to consider alternative water resource options to reservoirs.

The background is that Yorkshire Water has considered all conceivable water resource options including: importing water by tanker from Norway; desalination; groundwater development; groundwater storage; all possible undeveloped impounding reservoir sites; raising existing dams; bankside storage; additional river abstraction; import from Kielder reservoir in Northumbria into Yorkshire.

Kielder has over 300Ml/day unlicensed yield and transfers by river and pipeline have been considered. All the options were compared using a matrix of technical, financial and environmental considerations. The conclusion was that the preferred option was increased use of Kielder water. This raised fundamental objections from residents of North East England who regard Kielder as their water and wanted to keep it for future regional development. Another group of stakeholders did not want to reduce the amenity benefit of Kielder reservoir by lowering the water level.

In the event, demand has fallen in Yorkshire, largely because of leakage reduction and none of the resource options are needed. Nevertheless, can any of the speakers give an example of comparisons made between reservoirs and other non-reservoir options?

Ian Staniforth
All currently known resource options are considered on the basis that any

assessment would be challenged if options were excluded.

Tony Morrison (Halcrow)
I was interested to see the environmental ranking methodology presented by Mr Thomas, and compare it with the multi-criteria ranking system adopted at Initial Environmental Examination (IEE) stage on the ADB-funded Se Kong, Se San & Nan Theun Hydropower Master Plan Project. This project considered economic, social and environmental aspects of over 30 previously identified, but so far uncommitted, hydropower projects on major tributaries of the Mekong River in Laos, Vietnam and Cambodia, many of which involved large or very large reservoirs.

The methodology contained both similarities and distinct differences from that presented and included economic, social and environmental aspects in the same system for ranking potential projects in an appropriate order for development. The ranking followed a screening process, which eliminated any totally unacceptable developments. These included a potential scheme that flooded a provincial capital town and a development that would have caused major impacts on an internationally recognised bio-diversity reserve. A number of schemes were also eliminated on purely economic grounds.

Sector		Weighting by Factor	Weighting by Sector	Total weighting
	Factor			
Economic Evaluation			29%	29%
State of Preparedness			11%	
	Quality and status of technical studies	40%		4.4%
	Quality and status of socio-economic plans	30%		3.3%
	Status of national and power purchase agreements	30%		3.3%
Provincial and Regional Development			12%	
	Improved regional transport infrastructure	25%		3%
	Rural electrification	25%		3%
	Capacity of local provincial government	30%		3.6%
	Multi-purpose water resource development	20%		2.4%
Social			25%	
	Number of people affected	10%		2.5%
	Number of people resettled	20%		5%
	Ethnic vulnerability of affected people	20%		5%
	Nearness to provincial or administrative centre	15%		3.75%
	Access to improved health facilities	10%		2.5%
	Access to improved education facilities	10%		2.5%
	Improved water supplies	10%		2.5%
	Ease of consultation	5%		1.25%
Environmental			23%	
	Site (% of basin intercepted by dam)	15%		3.45%
	Reservoir surface area	5%		1.15%
	Percentage of catchment inundated	5%		1.15%
	Reservoir shape	10%		2.3%
	Energy intensity (energy per reservoir area)	10%		2.3%
	Degree of downstream flow disruption	25%		5.75%
	Potential synergy with protected areas	10%		2.3%
	Construction and access road impacts	10%		2.3%

The basis of the ranking system adopted was as follows
The various factors were ranked with positive factors high and negative factors low within the scale of the variations between the schemes. Scales were developed to guide marking of the more subjective factors and marking was checked by comparative marking by different people within the field of competence for the sector.

The criteria used in developing the ranking system were:
- The system should be robust and include practical processes that reflect the rural nature and the diversity of the scheme locations
- Subjectivity should be reduced wherever possible
- Assessments should be as transparent as possible
- The system should identify and assess key economic, social and environmental issues
- The system should help identify and assess parameters unique to each scheme

The ranking system, and in particular the weighting of the different aspects, was adopted only after extensive discussion both within the project team and in consultation with others, including at project workshops.

Other forms of comparisons were also used to review the high ranking schemes, including plots of energy/km^2 against energy/person affected and plots of the social and environmental rankings against economic parameters.

Jack Meldrum (Mott Macdonald)
Do the panel have any views or comments on planning blight as a result of early (premature?) notification of study intentions?

Chris Binnie
The question of potential planning blight is a serious one for any dam developer. After he has announced that he is investigating a particular scheme it will be much more difficult for the owner of any of the properties likely to be affected by it to sell his property. The developer is under moral pressure to announce his intentions as soon as possible. If he delays his announcement then he takes the risk that if his intentions are found out before he announces them then he losses much of the confidence of the people with whom he will have to deal during the promotion stage.

A few years ago the National Rivers Authority, Anglian Region, realised that there was likely to be a water shortage and following the publication of its water resources strategy it launched investigations of the most obvious new strategic reservoir site, Great Bradley. This was not a new site but one that had previously been investigated some 20 years previously and dropped because of lack of need at the time. Up to 100 properties could be affected by the scheme. Because the NRA was a national government body it considered it had to announce the investigations as soon as they started. The result was planning blight of those houses affected. Two of these were owned by elderly couples who wanted to sell the houses to pay for their time in retirement homes. Because of the blight they were unable to do so. Investigations went on for some 2 to 3 years at the end of which it was found that another scheme, raising Abberton dam, was more cost effective and had less environmental and social impact and Great Bradley was shelved again. The whole period generated much local ill-feeling. The conclusion is that it is best to complete as much of the investigations as possible before public announcement and if possible not before the need has been proved and the scheme has been selected. If one has to drill the dam site to establish engineering feasibility this is very difficult.

Written Contribution

Ted Gosschalk (Consultant)
Our paper ("Environmental implications benefits and disbenefits of new reservoir projects"; Gosschalk & Rao) is intended to present a review of the benefits and disbenefits of new reservoir projects and hence the case for or against the continued construction of reservoirs. We accept, however, that the paper can be criticised for being divisive. Certainly we have aimed at stimulating discussion and it is true that we feel that preservation of the environment has become an emotive subject and preservation has not lacked vociferous supporters. Strong objections to reservoirs readily appeal to the media, while advocating reservoirs does not. We therefore think that there is currently a gap to be filled and that the case for reservoirs merits strong support if only to find it a rational place in people's minds, though certainly not to the exclusion of consideration of environmental impacts.

A fundamental issue is the ousting of people by the construction of reservoirs. We have given a few figures to illustrate the scale of such problems but numbers can be small or vast. We think that this is not the real issue because many people in many categories leave their homes of their own accord at some stage or stages in their lives. The issue is whether finance can be made available to make their moves acceptable and attractive in the light of the benefits from the project to its owner or to the country and to those displaced. If it cannot, it means that the project is not justified.

Environmental impact assessments are and always should be fundamental to the evaluation of benefits and disbenefits and we have recommended (p 209) that the guidelines of ICOLD Bulletin No. 35 (1980) should increasingly be followed. They provide a matrix as an aid to thinking but not to replace a thorough ecological survey by specialists. We have outlined the method but it is necessary to refer to the description in the Bulletin. It is inevitably considerably subjective but following the method will help to achieve consistent evaluations for comparative purposes within a project and with other projects. It will be helpful if any delegates to this conference can table criticisms or suggestions for improvement of the method.

On page 204 we have indicated desalination of salt water as an expensive alternative to building more large reservoirs. In response to a query, we would like to quote the comparative cost of water prepared for public supply by these two methods but it is highly variable, depending very much on circumstances, not least on the potential for building reservoirs where the water is needed. The cost of desalination is reported to be reducing with advances in membrane technology but costs of the order of £2M to £4M per million megalitres per day have been quoted for desalinated water.

SESSION 5
LESSONS LEARNT FROM OVERSEAS EXPERIENCES

Chairman Paul Tedd
Technical Reporter John Falkingham

Papers presented

1. A few problems with Central Asia's large dams
   J. Halcro-Johnston and E A Jackson
2. New technologies to optimise remedial works in dams: underwater installation of water-proofing revetments
3. A M Scuero, G L Vaschetti and J A Wilkes
   Leakage investigations and remedial works, West Dam High Island Reservoir, Hong Kong
   D Gallacher (presented by R Mann)

Papers not presented

1. Dam safety in Kyrgyz Republic
   E A Jackson and J L Hinks
2. Monitoring and planning mudflow control works following Mt Pinatubo eruption, Philippines
   J D Molyneux

George Hallowes (Consultant)
With regard to the paper on Central Asia's large dams, as I understand it the cross section of one of the dams included a concrete grid to reinforce the crest against seismic effects. This appeared to include elements crossing the core from upstream to downstream below top water level, which would seem to introduce risks of increased seepage across the core. Can you say whether you were able to find out what measures were taken, in design and construction, to reduce the risk?

Jim Halcro-Johnston (Gibb Ltd)
We were simply unable to look into this in any detail at all. It is a very relevant point and I absolutely agree with you but no we don't know.

It is relevant to note that, justifiably, the seismic design of Nurek Dam was given considerable attention by the Soviet designers, including construction of a 6m high model which was tested using explosive charges. The concrete collars are reported to have been found to be a very successful solution to the problem of surface slippage in the top 10% of the height. It is possible that the collars do not extend significantly below the 10m height that is freeboard above normal top water level.

Jack Lewin (Consultant)
My limited knowledge of hydraulic structures produced by the Russians suggest that the reliability of their bottom outlet gates and valves is low.

When an earthquake occurs, the flow of water through the turbines cannot be relied upon as an outlet from the reservoir. My New Zealand clients state that under these conditions, the turbines are automatically tripped. This results in closure of the wicket gate and cessation of flow. In most hydro generating stations, the turbine inlet gates are also automatically closed to prevent surges in the reservoir affecting the wicket gates. The availability of the turbine flow to lower the reservoir level following an earthquake is therefore doubtful. (Williams, I.S : After the earthquake ensuring that the spillway can be operated when it really counts. 7th Hydro Power Engineering Exchange, Hamilton, New Zealand, Oct 1996).

Under flood conditions when there can be much debris, the discharge through the turbines can also be reduced due to the screens at the intake.

Jim Halcro-Johnston
I don't think I can add much in response, and I agree. Professor Lewin is perfectly correct in referring to the probability of the sets tripping in a major earthquake. I would add that any extreme climatic event, e.g. earthquake or major flood, would create conditions (e.g. landslides) that might put in jeopardy normal operation of the power station itself, the switchyard (located usually just below the dam) or the transmission line. The shutting down of any one of these would result in a loss of load and automatic closure of the wicket gates, preventing normal discharge through the power station openings.

I think one of the other main problems is the potential for blockage of the screens on a power station caused by the excessive quantities of trash and debris that are normally taken into suspension by a very large flood. The large low level outlets on Soviet dams are normally unscreened so they do not present the same obstacle to flow as the power outlets, although there is still a serious risk of blockage of the gate openings.

Jack Meldrum (Mott McDonald)
I had the opportunity to see one or two of the other dams in Kyrgyzstan as

part of a World Bank Strategy in Action Plan for their irrigation dams. I would endorse the comments by Mr Halcro-Johnston about different design philosophies and this is something which will create a lot of interest over the next few years as we discover more of what's being going on in the former Russian Republics. One observation I would like to make. There is a lovely bust of Lenin over one of the abutments of Kirov Dam which is lasting extremely well even if other parts of the dam are not.

Upstream of Kirov there is another dam called, I think, Karabura. It is a relatively small dam which is incomplete because they ran out of money. It is operated by waiting until the end of the snow melt and then closing the gates. If the timing is right the dam does not overtop, if they get it wrong - then that is what happens.

There is obviously a lot to be done in this part of the world and I just wondered what sort of method or approach they took to prioritising the work.

Jim Halcro-Johnston
I think that "ad-hoc" is the answer. As far as Karabura is concerned, you are perfectly right, it has actually been overtopped on four occasions as I understand it but it does not seem to do much damage. You are also perfectly correct about the statue of Lenin at Kirov. It is one of the finest parts of the dam.

As regards the prioritising of work on the Kyrgyz irrigation dams, the authorities are well aware of the many problems and appear to be anxious to undertake the full programme of rehabilitation works but are constrained by the available funding. The necessary works were originally identified during Jonathan Hinks' mission in 1997 and are being firmed up by more detailed dam examinations now being undertaken by Gibb and Temelsu. The initial priority was considered to be Orto Tokoi and Karabura dams and the rehabilitation programmes for these two dams were prepared in 1998. Work on Orto Tokoi is currently in progress but work on Karabura was suspended because the cost of completing the dam would have used up much more funds than were available under the World Bank's funding package.

The second level of priority is considered to be Papan and Kirov, both dams being of considerable height and located strategically above major population centres. Investigations to confirm the scope of work for Papan are currently in progress; the rehabilitation programme for Kirov has been determined but work has not yet started. The other dams that have been examined, but the rehabilitation programmes not yet determined, are Bazar Kurgan, Ala Archa and Spartak, all earth embankments without spillways. There are a further four dams that may be included if the funding permits.

Chris Peck (Thames Water)
This question is addressed to Ms. Vaschetti. You talked about the welding systems used on Carpi membranes. Could you please explain whether you used a double weld or a single weld? Thames Water has used a double weld system on HDPE membranes installed to reline sections of the "New River" to the north east of London which is then air tested.

Gabriella Vaschetti (Carpi)
We use both double and single weld depending on the configuration being dealt with. The double weld can be made only when there are no obstacles on the travel path of the automatic welding machine. If these obstacles are present, such as when the weld must be made close to a tensioning anchorage, then a single weld is made. The single weld can accommodate any type of configuration.

Carpi control both double welds and single welds by ASTM standards.

Cel Sutton (North West Water)
North West Water, when investigating uPVC as a solution for a water barrier, has been strongly advised against situations where the membrane can become exposed to the sun as the ultra violet (UV) rays cause significant and at times rapid degradation of the material. Would she care to comment?

We have considered uPVC as a waterproof membrane to concrete/masonry faces on the upstream but with summer draw downs it would become exposed to UV and we decided against the material.

Gabrialla Vaschetti
UV affects PVC which is why a PVC membrane has to be engineered. A PVC membrane is engineered against UV aggression by enriching its formulation with additives (stabilisers), and by producing membranes with high thickness. For example, in the United States, where the membrane is generally covered by a protection layer, the typical thickness is less than 1mm whereas in Europe, where the membrane is typically left exposed, the thickness is in the range of 1.5 to 2.5 mm.

A higher thickness protects the membrane from UV degradation because of the way this phenomenon proceeds: UV attack initially affects the surface layer, causing stabilisers to migrate towards the outside. Due to this migration, the surface layer becomes less susceptible to UV aggression, and the inner part of the membrane, which is homogeneous, is protected against alteration.

If anyone is interested in more details, I can provide some very interesting results published by the Italian National Power Board, ENEL, who has lined 11 dams with CARPI systems since the early 1970's. The PVC liners are exposed to UV and ENEL have been monitoring their behaviour by periodically cutting samples out and by testing them. The results that have been published by ENEL, for which I can provide references, show that there has been practically no alteration in permeability over 19 years.

Robert Mann (Cuthbertson-Maunsell Ltd)
I would like to point out that the position of pages 292 and 293 have been transposed in the Dams 2000 publication and that this should be added to the Erratum.

SESSION 6
INVESTIGATIONS AND REMEDIAL WORKS TO EXTEND ASSEST LIFE

Chairman	Geoff Sims
Technical Reporters	David Dutton (Part 1)
	John Sammons (Part 2)

Papers

1. The Future of Barcombe reservoir.
   J Hay, H T Lovenbury and D C Tye
2. Geotechnical investigations at Abberton Dam, Essex
   D J French, M J Woolgar and P Saynor
3. Ladybower Dam: analysis and prediction of settlement due to long term operation
   P R Vaughan, R W Chalmers and M Mackay
4. Investigations into seepage at Rotton Park reservoir using temperature distribution measurement
   M Andrews and J Dornstadter
5. Leakage investigations at Guide reservoir near Blackburn, Lancashire
   V G Over and F K Swettenham
6. Grouting of embankments at Cathaleen's Fall generating station on the river Erne
   B Casey and M Lowery
7. Reconstruction of Lednock Dam crest.
   C C Pasteur
8. Slurry trench cut-off walls in Embankment dams.
   P Tedd and S A Jefferis
9. Monkswood reservoir - the leaking Bath water
   A D M Penman, C Hoskins, P Tedd and G Harrison
10. Construction of a cement-bentonite slurry trench cut-off at Pebley Dam
    R Broad

George Hallowes (Consultant)
The assessment that the leakages through the embankments of the Cathaleen's Fall Reservoir were caused by high hydraulic gradients around the grout curtain in the foundation, reminds me of another situation where a design proposal would have resulted in high hydraulic gradients, if it had been accepted.

Part of the proposed Kalabagh dam in Pakistan, which was being designed by an international consortium led by Binnie & Partners, was to be constructed on a rollcrete slab foundation. The clay core of the dam, and the upstream and downstream sandstone shoulders, were to be placed directly on the slab. A visiting engineer attached to the World Bank, saw this design and said that to make it adequately watertight a key should be constructed to extend into the base of the core at the middle as shown beneath the letter C in Figure 6.1. Otherwise, he thought, there would be excessive seepage along the interface of the core and the rollcrete from letter A to letter B. This proposal was not accepted. If there was indeed a likelihood of greater seepage along the contact with the rollcrete, an effective key would cause pore pressures close to reservoir level upstream of the key and close to embankment toe level downstream of the key. These would in turn cause a high hydraulic gradient through the core above the key, as shown by the dashed line below letter C in Figure 6.1. In fact the way to guard against a risk of enhanced seepage along the interface of an embankment and a structure is to provide a suitable filter and drain at the downstream end (at point B in figure 6.1) to prevent internal erosion developing. Keys and collars are to be avoided in such situations because, amongst other reasons, of the high hydraulic gradients they may cause. Engineers who do not understand all the implications often propose them.

With respect to the embankments at Cathaleen's Fall, it appears that the grouting cured the leaks which had developed but did little to reduce the likelihood of similar leaks developing in the future. Was consideration given to a programme of grouting of the foundations upstream and downstream of the cut-off, along the length of the embankments, to reduce the permeability in those areas and thus reduce the hydraulic gradients past the cut-off?

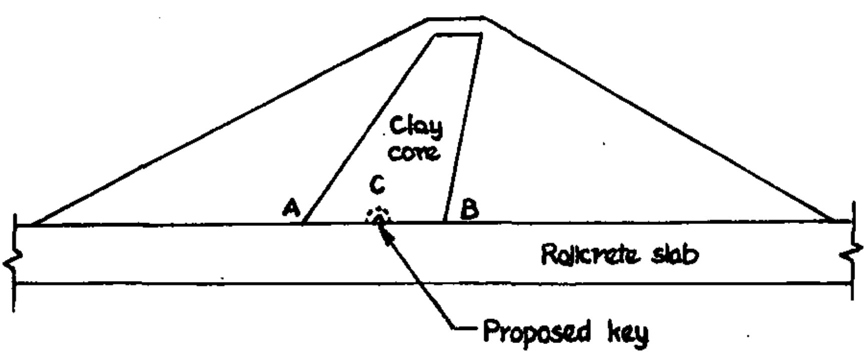

Figure. 6.1

Bernard Casey (ESB International)
George Hallowes has asked if we had considered grouting on the upstream side of the cut-off to intercept future problems. We have a view in ESB International that minor leaks are not altogether a bad thing because leaks give you the opportunity to monitor change. If you block up all your leaks you might be building up a problem that will hit you suddenly. We tend to focus our spring locations into channelled areas which are monitored daily. If our readings, over a long period of time, indicate that flows are increasing we know we are facing a problem where a channel is increasing in size and then we would target it with grouting.

Chris Binnie (Binnie, Black and Veatch)
I was the Panel Engineer for the Abberton Reservoir investigations. The object was to identify whether it was suitable for raising by up to 5 m. The reservoir had been completed and partly filled before the war. To stop German seaplanes landing on it the top water level had been kept down and floating mines had been put in the reservoir. This had been a problem in getting clearance to drill in the reservoir for fear of drilling into live ordnance. The top of the core had been covered by timber boards and these had ensured the puddle core had remained in excellent condition right to the top.

Although the zone upstream of the core had been made of clay there was little head loss through it. There was some evidence that the head loss through the core occurred almost entirely in the downstream half of the core. Has anyone else found a similar effect? The proposal was to raise the reservoir top water level so it was important to establish that this would not give rise to hydraulic fracture in the core. CPTs were put down and indicated that this should not be a problem.

Cel Sutton (North West Water)
In the North West of England it wasn't mines that were put into reservoirs but canal barges. During the last year we have had Warland Reservoir drawn down and we saw two 60 feet long canal barges put there to stop German seaplanes landing.

Derek Knight (Consultant)
Chris Binnie has raised the question of the fall-off of head across an embankment dam core with particular reference to the internal pattern in the downstream portion of the core at Abberton dam in Essex. With a narrow puddle clay core it is, of course, difficult to measure pore pressures across its width. However, there would appear to be no reason in principle why the

pattern should differ from that in a wider core. At El Chocón dam in northern Patagonia, Argentina the rolled silty clay core of this 92m high embankment dam was extensively instrumented, allowing the pore pressure pattern to be observed at three main cross sections in the wide river section of the dam during first impounding. A consistent pattern resulted in which half of the full pressure head reduction occurred in about the downstream third of the core's width at its base. Details were published in the paper by Marwick and Knight in the Proceedings of the 5th Pan American Conference on Soil Mechanics and Foundation Engineering, Buenos Aires, 1975 - "The early behaviour of the impervious core of El Chocón dam". See Vol. 2, November 1975, pp 351-360.

John Sammons (Consultant)
I remember discussing the concentration of head loss through the downstream part of a dam core some twenty years ago with John McKenna. We were examining the piezometer records from Gitaru Dam in Kenya. This is a rockfill embankment dam designed by EPDC. He suggested that the effect was probably due to the influence of effective stress on clay permeability.

At the upstream face of a core, pore water pressures match reservoir level; effective stresses are low. In contrast, pore water pressures are low and inter-particle pressures increase towards the downstream side of a core; there is a consequent reduction in clay permeability. This leads to concentration of head loss at the downstream side of the core. Seepage pressures through the core are thus higher than would be predicted based on an assumed constant permeability.

Professor Peter Vaughan describes this phenomenon in some detail in his Rankine Lecture, published in Geotechnique in December 1994.

Andy Hughes (RKL-Arup)
Resistivity sensors have been installed in the core of the new Audenshaw Dam as a control. Could Messrs Over and Swettenham please advise on the results of the analysis to date?

On the subject of hydraulic fracture we are just completing a study on hydraulic fracture for a major reservoir owner. The core has been modelled using finite element techniques from construction through a number of operating cycles and the results are fascinating. The results are shrouded in confidentiality at the moment but I hope to be able to present the results of our analysis at a future conference or BDS meeting.

Ian Moffat (University of Newcastle upon Tyne)
With regard to the apparent increasing loss of head in the downstream half of a core, I would suggest that this is less likely to be due to increased compressive stress there but rather more just to basic seepage theory.

Vic Over (Bolton Institute)
At Audenshaw we are looking at the resistivity profile through the core during construction and after commissioning. What we have found so far is a very uniform resistivity value: we have only had a 6 ohm-metre range in the core material during construction compared with, say, 250 on the downstream shoulder just behind the core on a Victorian dam. What we have noticed is that the resistivity profile is changing during consolidation; as water is draining out, the resistivity values are increasing and it may be that this gives a good pointer to moisture content changes and the degree of consolidation, showing it progressing with time.

Geof Sims (Brown and Root)
Could Vic Over and Myles Andrews comment on any comparison between the two methods which have been described here, resistivity and temperature measurements, to investigate seepage through embankments?

Vic Over
At the moment we are establishing a database of experience, but my belief is that this is not a one horse race. Maybe the future will lie in combining the two techniques; resistivity to give a broad view and then to go in with temperature measurements in any wet areas that the resistivity measurements have highlighted. One deficiency in our present investigation at Guide Reservoir is that we don't really know where the water has come from in the wet spot at 7.5m down: maybe water temperature measurements would help to clear that up.

Jurgen Dornstadter (GTC Kappelmeyer)
We tried to combine both methods about 5 years ago when we inspected the embankments along a 10km length of canal and compared the two sets of results. From time to time we were successful with both methods but we did get anomalies in the resistivity measurements which did not fit with the leakage pattern. The problem was that we couldn't distinguish between low resistivity values that were coming from a change in embankment fill materials and those arising from seepage. Your investigation was much better because you could make measurements with time and see the changes, so

you could separate out the low resistivity values arising from changes in materials from those due to seepage.

Myles Andrews (British Waterways)
With any geophysical technique you are measuring an anomaly in the parameter that you are monitoring and you then have to explain that anomaly. Vic Over has done that by monitoring over a period of time: the temperature based technique has done it by using a temperature signature of a body of water. The one thing you do have to have is a good ground model to compare it to and you can't work without that.

Ian Gowans (Cuthbertson Maunsell Limited)
Paul Tedd in his paper mentions Cod Beck and I thought I would take the opportunity to illustrate some of the problems associated with diaphragm wall cut-offs.

Cod Beck is an earth embankment dam in North Yorkshire with a central puddle-clay core. As the reservoir filled up, water was bypassing around the left hand bank coming out of the valley side at the bottom of the valley; the valley side was pretty well unstable. So drainage and a diaphragm wall were installed to support the side of the valley and connect into the puddle clay core. When the embankment dam was built they stopped work during the winter and exposure during that winter stop caused horizontal 'wintering' of the embankment. We also found problems below the puddle clay and jet grouting was used; the same mix was adopted at the connection between the diaphragm wall and the puddle clay.

The quality assurance that goes along with diaphragm walls is not often talked about. When the work at Cod Beck was carried out, about ten or twelve years ago, we had the usual computerised mixing and computerised records of the grout going in and also quite good control on the use of the digger. The wall was built in alternate panels using the panel system. Our concerns related to voids that might appear at the top of the jet grouting part of the job. There were also a few glitches that appeared on the computer records of the mix and the placing of the material during construction. On site there was concern about the accuracy the excavator.

So we carried out a series of Dutch cone tests to give us reassurance that everything was perfect. Unfortunately they did not give us that reassurance and so we ended up taking cores at four locations in the diaphragm wall. These showed some fall into the diaphragm wall from the adjoining material.

Using the Dutch cone tests we found four windows in the wall that we had to clean out and replace.

Jim Claydon (Yorkshire Water Services)
In response to David Tye's very interesting paper on Barcombe reservoir I would first like to reassure him that he is not alone in having to reconcile the requirements of different regulators. Yorkshire Water also has reservoirs which are SSSIs, with algal blooms requiring expensive treatment. This introduces another regulator, English Nature, and there is also the Planning Authority to consider. The algal blooms are largely caused by nutrients from migratory seabirds, which are the reason for the SSSI status, each seabird contributing as much faecal contamination as a person.

Mr. Tye clearly has cost estimates for the treatment works improvement and the dam repairs, but I would caution him that the costs of reservoir discontinuance can also be significant, and this would need planning consent. He will have to keep talking to all the regulators.

The improvements to the treatment works might be subject to an undertaking, recognised by Ofwat. Repairs to the dam will be base maintenance. In both cases the costs will be borne by the company and ultimately the customer.

David Tye (Consultant))
The references by Jim Claydon to the interpretation of cost allowances by Ofwat reflect a similar understanding to that held by South East Water. In the case of Barcombe reservoir and the Ouse catchment, a crucial issue, however, is whether the water supply customers should bear the full cost of investment that would be required in order to improve the river water quality at times of low flow. Expenditure on, say, phosphate removal, in respect of water supply only, paid for by a section of the community and without generating environmental improvements upstream, is surely less efficient and beneficial than expenditure that enhances the catchment as a whole through quality improvement of the waste water discharges, with the cost shared, in this particular case, between the customers of two companies? In spite of previous commitments and guidelines over the last twenty years or so, this aim has not yet been realised.

Chris Binnie (Binnie Black & Veatch)
Could I please ask Jim Claydon whether he believes the cost of upgrading spillways from the current FSR standard to the FEH standard, assuming it stayed the same and was implemented by the profession, would be allowable

within K in the AMP process.

Jim Claydon
Our understanding about cost of works needed to comply with the Flood Estimation Handbook is that changes to design floods are not a new obligation. They are not therefore eligible for cost pass through by Ofwat.

Chris Binnie
That means Ofwat would not allow funding and that the significant cost (maybe £ 20M for Yorkshire Water alone) would have to be paid out of profits. That being the case, water company clients will be reluctant to implement FEH.

Geoff Sims
I would like to ask Paul Tedd a question about his presentation on slurry trench walls. The table you showed from your paper includes reference to Earlswood. I know a little about Earlswood. We are aware there is a slurry trench installed there but have been unable to find any information about it. I wonder whether you could say where you got your data from and, if possible, could you also just expand on it. Could you hint at some generic factors that might explain why a slurry trench cut-off may not work? In your experience, what are the main danger factors?

Paul Tedd (Building Research Establishment)
With regard to Earlswood, I don't know where we got the information. With regard to slurry walls in the rehabilitation of dams, the only reasons I think that they would not work would be if the mix was wrong or if excavation did not fully cut through the part of the dam that was defective. I think a lot of the newer slurry walls using the single-phase method have been put in where the leakage is taking place towards the top of a dam. I'm not sure but I think this is probably the case. As far as I am aware all the slurry walls put in, and there are only five or six using the single phase method, have actually worked in the short term; in a hundred years time we will have to see again.

George Hallowes
At Afon-y Bala, the dam at the downstream (western) end of the lower reservoir for the Dinorwig pumped storage scheme, there was considerable difficulty in making an adequate junction between the base of the diaphragm wall cut-off and the rock in the sides of the valley at the two ends of the dam. The wall was required to cut off seepage through the outwash gravels overlying the lake sediments when the level of Llyn Peris was lowered during

construction and later during the twice-daily operational drawdown. Where the rock was shallow, an adequate cut-off required a positive connection with the hard bedrock, but the steeply sloping surface of the rock, particularly on the north side of the buried glaciated valley, required significant penetration on the uphill side of the panels for the wall to contact the rock on the downhill side. This was difficult to achieve, and careful grouting was required to avoid leaving a triangular area under each panel without a cut-off. Where a diaphragm wall is to make an impermeable connection with a hard rock layer, particularly one with a steeply sloping surface, it is necessary to have adequate contingency plans for where doubt arises, during construction, about the connection with the rock.

Paul Tedd
Achieving good contact is really a question for one of the specialist contractors. There are chiselling methods and rock cutters but whether or how much they have been used on dams for repair work I don't know. They have probably been used to install original cut-offs during construction of dams.

Alex Macdonald (Babtie Group)
I have yet another question for Paul Tedd about slurry walls. There is a tendency to believe that specialist contractors who install slurry walls know everything there is to know about the technique and sometimes we place over-reliance on them to design the mixes properly and to get the installation techniques correct.

There were very extensive slurry wall works undertaken to form a cut-off for the embankments of the Elvington Raw Water Storage Lagoons for Yorkshire Water. The bentonite cement slurry gave initial problems in achieving the specified design parameters. We were about six weeks into the slurry wall technique when permeability tests showed we were getting only 10^{-7}m/s instead of the specified 10^{-9}m/s. Investigations indicated that while the specialist sub-contractor had provided records from previous sites, using the same mix, which showed acceptable results in terms of the specification, it transpired that the oil industry OCMA Grade bentonite specified at Elvington performed differently to normal CE Grade bentonite. In addition, the contractor was using new plant which he stated 'flash mixed' and eliminated the need for hydration of the bentonite. Initial indications on site were that there was significant bleed water on the surface of the placed material after a short period of time. Various alternative mixes were used to try to eliminate this. The problem was ultimately shown to have been the lack of hydration of the bentonite with the new plant not performing in the way that the contractor had indicated. Subsequent trials with hydrated bentonite using both OCMA and CE Grade showed that the parameters in the specification could be met.

Paul Tedd

It is generally recommended that civil engineering grade bentonite should be used. However, at Elvington I think the main problem was that they were not hydrating the bentonite prior to mixing in with the cement; I believe even if they were using the OCMA Grade specified bentonite, providing it was being properly hydrated, there probably would not have been a problem.

Alex Macdonald

That was in fact the case and I think its just an example that in that particular case the contractor assured us that the techniques he was using to mix and to hydrate did not need long hydration periods. We very much initially relied on him and the fact that he was a specialist contractor. We believed he had undertaken this work before and it wasn't until we were some way into the wall construction when we saw we were getting problems with hydration and with excess bleed water on the surface that we started to question the contractors mix and hydration techniques. Even after we started to question him he said that it's all right, it's flash mixing, it's a new technique that we are adopting; it will work.

The implication of the above is that while contractors in this field sell themselves as "specialists", the principles of slurry wall design are still not fully understood. The ICE's specification for bentonite/cement slurry walls is now of considerable assistance to designers. However, based on the experience at Elvington, it is recommended that results from what would appear to be the same mix design on previous sites should not be taken as the likely outcome of the mix properties at another site.

Paul Tedd

This raises a number of important points. There is no doubt that the specialist slurry-wall Contractors have more experience in design and construction of slurry walls than most Consulting Engineers specifying their use. The desire to remove the bentonite hydration phase from the mixing process arises because of the considerable cost and timesavings that could be made, an outcome of the competitive tender process. The problems at Elvington and other sites in the early 1990's led to the preparation of the ICE Specification. The lessons learnt from the Elvington experience in 1994 have been included in the ICE Specification. In section 4.1 it states *"Bentonite powder and water shall be thoroughly mixed using high shear or colloidal mixing techniques and the bentonite mud allowed a minimum of 8 hours to hydrate (unless the contractor can demonstrate that a shorter duration is acceptable) prior to its use in the slurry mix"*. Quality control procedures specified in the ICE Specification are crucially important for successful production of cement-bentonite slurry. The Engineer should take an active part in these and make provision for their payment.

It is important to emphasise that the set properties of the slurry are dependent not only on the components and their proportions in the mix, but also on the mixing method and mixer type.

Geoff Sims
Is there also a message that a trial panel is a useful idea?

Alex Macdonald
There is certainly that message but in the case of Elvington, because it was a cut-off wall, it was the first activity that was being undertaken on site. The contractor provided test results of previous mixes using exactly the same mix technique, using exactly the same mix; what he did not tell us was that there was a difference in the hydration and there was a difference in the grade of bentonite. I think to be fair it was the Elvington wall that showed up the difference between OCMA Grade bentonite and CE Grade bentonite that is most commonly used.

Paul Tedd
If I may just make one final point on slurry walls, I think clients must be willing to pay for quality control and they have got to be partially responsible. They cannot rely entirely on the contractor. You need to have some independent quality control if you want to be happy that your wall is all right.

Ian Gowans
I agree about quality control. It was the quality control work at Cod Beck that found the windows and voids. We did extensive cone penetration testing to ensure that the wall was fully constructed; it is the quality assurance that one expects at the end of the job that does not always come through.

Geoff Sims
I have one question for Chris Pasteur. You spent quite a lot of money

replacing the top of Lednock dam and the concrete you replaced had suffered from freeze thaw deterioration and it appears it was not a very good mix in the first place. What measures did you put in place and what confidence do you have that the new concrete, apart from being strong enough, will have appropriate durability for what you need and also that it has sufficiently similar physical characteristics in terms of temperature and strain expansion that it won't just pop off like the other repairs.

Chris Pasteur
In the dam crest reconstruction we used a more modern concrete, a designed mix to BS 5328, having design strength of 40N in preference to the 30N of the original concrete. The reason for this uplift was to increase durability of the concrete not because of a need for any additional strength. In our experience and the experience of others at similar locations this type of concrete has proved to be durable.

Air entrainment and polypropylene fibre reinforcement were also considered as methods of increasing the durability of the concrete. These options were not pursued due to the logistical difficulties associated with the long transport time to the site and the placement of the concrete by pump. There was also little confidence that the benefit of these modified mixes would justify their additional costs.

The new crest concrete was dowelled to the original concrete below to ensure that the new and original concrete cannot separate. No specific measures were taken to accommodate differential movement between the original and new concrete. Inspections of the dam since completion of the works have not indicated any problems.

David Dutton (British Waterways)
The freeboard at a number of British Waterways' dams is of the order of 1 m or less, and crest widths are also quite small. Drawdown during the summer months can result in the upper layers of the crest drying out. Cement bentonite slurry is prone to drying shrinkage and cracking as shown by the plastic bag referred to by Paul Tedd that is sitting in my garage full of crumbs. Is it, therefore, a sensible precaution to install an impermeable membrane at the top of the slurry wall, as we did at Pebley, to ensure that there is no leakage through the upper layers of the crest when the reservoir returns to top water level?

Paul Tedd
Under the circumstances of small freeboard and narrow crest width, the top of the dam needs to be lowered to take the excavator, resulting in the top of the cut-off wall being constructed lower than TWL, as at Pebley dam. The use of a membrane at Pebley to obtain a positive connection from the top of the wall to the crest was a good engineering precaution to prevent leakage at the interface with the clay above. The interface between the clay cap and the top of the wall is potentially a plane of weakness and should be carefully considered. The use of clay above and to the side of the cut-off wall to prevent the top from drying is essential. Where the top of the cutoff wall can be completed above TWL and an engineered clay cap can be constructed to protect it, the benefits of using a membrane are likely to be marginal.

David Dutton
At Boddington north bank where we carefully put back a clay (puddle clay) at the top of the crest, we again got leakage through that clay. How certain can you be that clay at the top is not going to crack and let water through?

Paul Tedd
I'm sure there have been many cases where puddle clay has been added to the tops of dams and they have been satisfactory. However, I realise a lot of dams do leak at the top; this may depend on the quality of the workmanship and the clay that is going in.

Where leakage can be confirmed to be occurring through the dam near top water level, consideration could be given to a narrow shallow slurry trench incorporating a membrane.

Cel Sutton (North West Water)
We have worked on five or six reservoirs in the past ten years where we have put new clay onto old clay. I am only aware of one reservoir where there was a slight problem at a point where new clay was brought up against a concrete face. After some remedial work it shows no sign of leakage. So in all those half a dozen cases where we have added clay there has been no indication of leakage, although it should be noted that the reservoirs probably have not been at top water level much in the ten years.

John Sammons (Consultant)
In hotter climates where drying out of the top of a clay core is far more of a problem than in the U.K. a frequent design detail is to provide a layer of coarse sand or gravel above the core and beneath any surfacing. The aim is

to break the capillary action in the clay and so greatly reduce evaporation. You might alternatively wrap the top of a clay core in a membrane.

Alan Johnston (Babtie Group)
It is fairly common for an owner to express concern over expenditure that arises from recommendations, in the interests of reservoir safety, by an Inspecting Engineer. The work at Lednock is unusual in that the owner has embarked on such extensive works before they became the subject of a reservoir safety recommendation.

The inspecting engineer, Mr. Alex Macdonald had recommended that the defects at the crest are dealt with as a maintenance matter and this meant that the decision to proceed and the timing were both matters solely for the owner. Does the author have any further information on the assessment process and any cost/benefit analysis, which justified the works proceeding when they did?

Neil Sandilands (Scottish and Southern Energy)
I will answer that question on Chris's behalf since I am the Supervising Engineer for the dam and the manager responsible for the strategic decision. First of all there was a safety issue. Lednock Dam has an overhanging crest and therefore falling debris from old repairs is a serious hazard. It is relatively easy to obtain funding where this sort of safety issue is involved. The second issue is asset management. Extensive concrete repairs were carried out in 1986 at a cost of around £100k. Because of the poor quality of the existing concrete we got no long-term value at all from this expenditure. On this occasion we have spent almost £400k and we have eliminated the problem. In the long term this represents much better value for money.

With regard to Geoff Sims' earlier question on concrete durability, our experience with concrete averaging 45 years old is that ordinary concrete with adequate cement content is sufficiently durable. In the Scottish Highlands there is little problem with chemical contamination. This point can be backed up by our very low expenditure on concrete repairs. Despite the massive quantities of concrete across our asset base we only spend around £150-200k per year on concrete repairs. The other thing that was key at Lednock was simple drainage measures to keep surface water off it. By contrast the road bridge in Perth, which is only around fifteen years old, has had more money spent on concrete repairs to it than the total on our structures over that period.

Alan Johnston

In presenting the paper on the future of Barcombe Reservoir David Tye pointed out "there is currently no consensus on what is an acceptable factor of safety against sliding for an existing dam". This is one of the topics included in the remit for the DETR research contract, which Jim Findlay of the Babtie Group described earlier in the conference in the 'Reservoir safety, upgrades to embankment dams' question. He has been trying to gather information from professionals such as ourselves as to what we do believe are acceptable factors of safety. It is a subject that merits discussion and the authors' contribution is helpful.

The paper describes measures designed to provide the dam with the same factor of safety as a new dam but it also advances reasons to use a lower factor of safety than on new construction. Can the authors please clarify, which approach is being adopted? I think that is one of the questions that has to be addressed. Do we need in fact to bring an existing dam, which has some defects, up to the same standard as a brand new one? I would have thought not.

In respect of the design value to be used in the strengthening, the criterion quoted, 1.35, is described as being used for the steady seepage stage for a new, untried structure. A more common figure for new construction is 1.5. However I agree that 1.35 can be acceptable in strengthening an existing dam. The authors' further comments would be welcome.

David Tye (Consultant)

I have approached this difficult subject from a fairly common sense and possibly more an owner's standpoint. I am sympathetic towards the view that new and existing dams should be looked at very differently. Certainly with old smallish structures with long established behaviour I find it difficult to see why a particular apparently subjective factor of safety should be provided. There is a question of credibility, when trying to argue something with an owner who believes the expert is just going arbitrarily to cause him to spend extra money. If the subjectivity is due to a lack of appreciation or a lack of knowledge, then I hope research will provide an answer.

At Barcombe Reservoir the Inspecting Engineer's recommendation was that the embankment should have an adequate factor of safety against failure by sliding. In the absence at the time of guidance as to what an acceptable value would be in these circumstances, we took the factor of safety for new construction. From experience a value of 1.35 was used. This value was consistent with Table 4 in the BRE Embankment Dams Guide, 1990, though this Table has since been revised in the 2nd Edition of the guide, (see Table 7) published in 1999.

The final section of our paper examines matters influencing the choice of an acceptable factor of safety in strengthening situations. Here a smaller proportional increase in value (20%, say) over the existing state of equilibrium, which is known to be above unity, could provide sufficient assurance. This is in contrast to the larger reserve of safety taken for new construction where allowance has to be made for differences between the performance of the prototype and that predicted from engineering properties determined from small-scale tests on samples of the constituent materials and other factors.

Rodney Bridle (Consultant)
Guidance on factors of safety commonly adopted for slope stability design of new embankment dams is given in Table 7 (p 26) of "An Engineering Guide to the Safety of Embankment Dams in the United Kingdom", Johnston, Millmore, Charles and Tedd, BRE, 2nd edition, 1999. In some instances the critical stability criterion is the seismic one. The methodology for assessing seismic stability is given in "An Engineering Guide to Seismic Risk to Dams in the United Kingdom" Charles, Abiss, Gosschalk and Hints, BRE, 1991, and in "An Application Note to the Engineering Guide to Seismic Risk to Dams in the United Kingdom", ICE, 1998.

In the future it may be possible to state stability in terms of the probability of failure. Probability is a part of the 'language' of risk, much used and understood by managers and non-engineers. Giving them advice using risk language would therefore help them to reach the right decisions about dams and dam safety. Use of this language would help us to consider how safe our dams are, which is important when it comes to the fundamental question of 'are they safe enough?'. It would also overcome the esotericism of our 'factor of safety' language, which means different things in different contexts (for example, a factor of safety in an embankment dam has a different meaning to one in a concrete dam).

Andrew Charles (Building Research Establishment)
In the design of a new embankment dam, the required minimum factor of safety against slope instability for the long-term steady-seepage case with the reservoir full would be at least 1.5. It might be argued that in the case of an old dam, where there have been many years of apparently satisfactory

performance, a slightly lower calculated factor of safety against slope instability is acceptable as the safety factor includes a factor of ignorance and the dam has successfully survived the critical periods of construction and reservoir filling. However, even if this line of reasoning is followed in assessing the stability of an old embankment dam, it is hard to believe that a geotechnical engineer would consider a factor of safety below, say, 1.3 to be acceptable.

There has been major expenditure on overflow works to meet improved flood standards, but there does not appear to have been any comparable effort to upgrade old embankments. The need for a major programme of works to upgrade old embankment dams to modern standards needs to be assessed in the light of the risks posed by internal erosion and slope instability.

Geoff Sims

I wonder if Arthur Penman could give us some information about the ease or difficulty with which the very extensive and expensive remedial works at Monkswood were justified and on what basis?

Arthur Penman

Thank you chairman for asking a question like that; it is a very relevant and pertinent one. At Monkswood I can only say that the owner became concerned about leakage on the argument that it might get worse and it might be something to do with stability. It was not really felt that that was too great a risk particularly since the measured amount of leakage did not increase with time, showing that it was non-erodible material. Now this was only what was measured by the reservoir keeper with his bucket from the end of this small pipe. How much this represented the true leak of course was not known. Clearly the leakage came from much further down in the puddle clay core than the level of this little instrument chamber and so there was concern that it could be getting greater without anyone knowing about it. It seemed to be a wise precaution to cut off the leak, although it is difficult to assess the value of water for the city of Bath in relation to the cost of it. But, I should hasten to say that the use of the reservoir had been completely changed. It's no longer a simple impounding reservoir. It's now, I think they call it, a bank reservoir as part of a stage of pumping, because the city of Bath now consumes so much more water that it did in the old days.

Derek Knight

I strongly support the remarks just made by Dr. Andrew Charles regarding factors of safety against sliding failure of embankment dams. It seems necessary to issue a warning not to reduce traditional factors of safety used in limit equilibrium analyses not only for new dams, but also for those where realistic stability analyses have been made for old dams. By realistic I mean those based on actual shear strength and allied data for a particular dam which has been geotechnically investigated by modern methods as a result of suspicions about its adequacy in sliding stability. Those suspicions may, of course, have arisen as the product of experience and judgement - something referred to by Professor Ralph B. Peck in his Laurits Bjerrum Memorial Lecture in the 1970s entitled "Where has all the judgement gone?".

Reference has already been rightly made in these current discussions to the changing attitude of public opinion on matters of risk and public safety. I think that any non-technical member of the public who happened to hear engineers discussing the possibility of accepting lower factors of sliding stability, where those factors were actually known, would be rightly very concerned, as a reflection of the raised safety expectations of today's society. One usually does not know the sliding factor of safety for a particular old dam but, where one does know it, then the same factor of safety should be applied as for a new dam, which will generally have been subject to more intense geotechnical investigation and analysis than an old dam. Accordingly, a factor of safety of not less than 1 .5 should apply to the limit equilibrium sliding stability case for deep-seated potential slip surfaces for downstream slope/profile stability in the full reservoir steady seepage case. Full reservoir would include the appropriate flood level.

In making these remarks I, of course, recognise that sliding stability adequacy accounts for only about a third of possible failure mechanisms, and therefore that a factor of safety as just discussed is not a measure of the factor of safety of a dam overall. Internal erosion potential is far more insidious and difficult to quantify. Stability and erosion are two main "failure mode causes". Attending to their mechanics should replace guessing numbers for the "probability" of their occurrence.

Cel Sutton (North West Water)

I am a bit concerned about the proposal to move to a probabilistic approach to assess safety. Risk probability statistics are a difficult concept for many engineers to understand. Convincing Boards of the need to ensure Dam Safety needs to be kept as simple as possible; it should not be hidden in what appears to be a rigorous mathematical analysis for which we have limited practical analysis, or feed back from, in the field of Dam Safety.

Jim Findlay (Babtie Group)
Alan Johnston has picked up on the statement in David Tye's presentation concerning FOS (that a consensus is needed on an acceptable value of F for an existing dam) and Derek Knight has stated his views on acceptable figures. This is directly relevant to the brief for the DETR research project on upgrades to embankment dams but is a topic on which the AR Panel community has mixed views. As Project Director for Babtie Group on the DETR research project, I wish to highlight some of the project thinking on the use of factors of safety as an indicator and the development of appropriate standards for older embankment dams when compared with more modern embankment dams.

There is a danger in depending on factors of safety as commonly used for embankment dams. These figures relate only to the limiting stability of the embankment slopes and are not an overall measure of the safety of the dam.

There are clear differences in the confidence that can be attached to factors of safety for modern and those for older dams and this has to be recognised in the acceptable figures appropriate in each case. There is a wide range of influences to factors of safety and I personally do not believe we can directly compare figures, whether they are 1.5 more or less, for new dams with equivalent figures for older ones.

Modern dams are designed and constructed such that there can be a high confidence in the internal geometry, material parameters of each zone and consistency of placing and compaction. They also include state at the art features designed to reduce risk of failure through recognized mechanisms. On the other hand, older dams (built say pre 1945) cannot always demonstrate this confidence and certainly do not have the same level of seepage and drainage protection.

Conversely, older dams have passed the critical phase of their lives (completion, first filling and first five years of service) when failure is most likely. They have experienced a range of operational conditions without undue consequences and thus have demonstrated an acceptable standard of performance. Modern dams, at the time when acceptable factors of safety are most likely to be set for them, have yet to demonstrate this performance.

The project will seek to resolve the question of appropriate standards for older embankment dam stability recognising the above influences.

Myles Andrews

I am concerned about setting the same criteria for new and older structures and am relieved to hear Jim Findlay's comments. This does not just apply to dams. The thought of a minimum factor of safety of 1.3 makes me very thankful that canals are exempt from the Reservoirs Act. It illustrates the need for great caution in applying modern soil mechanics analyses, without care, to old structures.

The other observation is that in the geotechnical community we are very rapidly moving away from lumped factors of safety to partial factored approaches and also to probabilistic methods of determining suitable parameter values for use in design. I wonder if anyone in the reservoir community has experience of similar moves that are now being enshrined in the more modern design codes for foundations and retaining walls and the recent Euro code draft.

John Sammons

I have sympathy with Myles Andrews' later comments. When discussing and comparing factors of safety against limiting stability we need to know how design parameters have been derived, how certain we are about them, and also what type of analysis has been carried out. For an embankment we might quote a factor of safety of 1.5 based on the average of a few strength tests but calculate a lower factor of safety, say 1.35, using conservative parameters, possibly based on back analysis of first time slides. Clarity and judgement is needed. We should be aware that most new structure failures are due to error, misunderstanding of behaviour or oversight rather than use of an inappropriate factor of safety. An example would be not recognising the presence of a pre-existing slip surface in a foundation.

As noted by Jim Findlay, old dams have passed the critical phase of their lives and survived a range of operational conditions. We need to consider what further problems might arise in the future. For example, material properties may deteriorate with time and pore-water pressure may rise due to increased seepage or infiltration. Where analysis suggests stability is uncertain, there is a strong case for carrying out works to provide an incremental improvement in the calculated factor of safety, possibly by 20 or 25 percent as suggested by David Tye. Care with details, such as drainage and seepage control, is important to ensure such improvement works do not have any adverse effect.

Neil Sandilands
I believe that the answer to making these difficulty decisions is through risk assessment. I do not share Rod Bridle's optimism about probabilistic analysis. The figures are only of value if they have credibility. With regard to Derek Knight's comments I do not believe that we, as engineers, have the right to make decisions on risk on behalf of society. We should make technical judgements based on the risk criteria handed down to us by society.

Alan Johnston in his excellent Binnie lecture referred to the suggestions made by Dr Le Guen of the HSE at the recent Dam Risk Seminar. I hesitate to correct the Binnie Lecturer. The criteria outlined by Dr Le Guen were not however suggestions. They form the basis on which the HSE will make judgements on our management of risk

Geoff Sims
I am going to bring this session to a close and I would like to congratulate most sincerely all of the speakers, those who have prepared presentations and those who have spoken from the floor. Thank you very much and well done.

Within the context of rehabilitation of dams we really have had three and a half hours of very useful discussion. I am looking forward eagerly to reading the written contributions where your more considered views containing specific data will contribute greatly to the debate about the way in which we, in the engineering community, relate to society at large and how we discharge our duty in maintaining for society the infrastructure it has come to depend upon. There is one observation I would like to make in relation to the quality of the discussion and the quality of the papers that have been revealed here. As the chairman of the ICOLD committee on rehabilitation of dams, I would like you to know that proceedings of the BDS conferences, of which this is the eleventh, have provided a very rich harvest in terms of case studies. I think this is very much to our credit. The session we have just had has confirmed that, at least, very much to my own satisfaction.

Keynote Lecture
Work of the World Commission on Dams

by Achim Steiner, Secretary General and Commissioner, WCD

It is with some trepidation that I stand before you today. Not only do I belong to this strange animal the World Commission on Dams, the WCD, which over the last two years has caused consternation, surprise and dismay in some circles and frustration amongst others, but also I am not even an engineer! Obviously, close to the worst thing one can do when it comes to the biennial conference of the British Dam Society! It gets worse; I am an economist and like all economists, well known for screwing up engineers' good ideas ! Not only that, I happen to be German, and bearing in mind what is about to happen tomorrow in the soccer (Germany v England), and knowing what English hooligans can do to us Germans, I will be taking great care to try and explain the WCD to you carefully, without getting caught in any battles !

May I begin by first of all expressing on behalf of the Commission our appreciation of the British Dam Society. It has been one of those members of the International Commission on Large Dams that recognised that the World Commission on Dams does not necessarily have to be anathema to dam building. On the contrary, it can provide an opportunity. This is really what I would like to share with you this morning. Despite everything you may have read, heard or assumed, the World Commission on Dams is not an attack on dams. It is an attempt to take the discussion of our dams further, to bring it back into a balanced discussion in society. Above all, quoting our Chairman, 'nothing should be taken as self-evident'. We should try to understand why dams have become such an issue of contention and try to discover what is fact, what is fiction, what is belief and what is unknown. All of these have been at the centre of our work.

The World Commission on Dams is really something quite unique. Unique in the sense that thirty-eight people met in a small village in Switzerland in 1997 and decided to set it up. These were thirty-eight people who at the time represented important voices in the debate about dams, from financiers, government, NGOs, affected communities, the engineering profession, ICOLD, and ICID. Unique too as they decided to go ahead without waiting for a United Nations mandate, or any official government buy-in.

And it is a little miracle that two and a half years later this Commission has not only been set up, but also captured the attention of many people, some well beyond the dams debate. International financing institutions, development organisations, environmental networks and other professions dealing with large scale infrastructure, are looking at the World Commission on Dams as an interesting example of how in today's world, where governments are not simply governing by decree anymore, planning is no longer just a matter of top down expertise driving development. The emergence of civilised society, of NGOs and community organisations, and the growing importance of the private sector means that in many countries any decision about a dam today is no longer only the prerogative of the state or the government but emerges from pressures by civil society and the private sector. Without access to capital and technology there is no dam. Without public support in more and more countries there will be no more dams.

Therefore trying to recognise this and bring it into the centre of our investigations has been a very important part of the Commission's work.

I shall introduce our Commissioners to you. They are not retired elder statesmen; they are not Lord Chancellors or ex-heads of court. They are the yous and I's, so to speak, of the dams debate. Perhaps not quite the BDS yous and I's, because they are in many ways the leaders of different constituencies within that dams debate. These people have now met seven times and will meet ten times in total over a two-year period, so you can see the commitment they have brought to the Commission. They include some surprising people. Medha Patkar is the leader of the movement against the Narmada Dam in India, not someone who has the respect of the Ministry of Water Resources in India, but she certainly commands the respect of thousands, if not tens of thousands, of people who live within the Narmada Valley. Another is Goran Lindahl, CEO of ABB (Asea Brown Boveri), one of the largest engineering concerns in the world. Also on the Commission is Jan Veltrop, former President of ICOLD, serving alongside Deborah Moore of the Environment Defence Fund and Joji Carino, an indigenous peoples' representative from the Philippines. The Chair is Kader Asmal, currently the Minister of Education, and previously the Minister of Water Affairs, in South Africa. The Vice Chair is Mr Lakshmi Chand Jain, from Industrial Development Services, India. There are two Australian Commissioners, Judy Henderson, former Chair of Oxfam, and Don Blackmore, CEO of the Murray Darling Commission. Professor Thayer Scudder, eminent anthropologist with an interest in those displaced by dams, and myself, Secretary General of WCD, complete the twelve.

I will focus largely on some of the findings of our work and use these to explain what the commission may be able to do for the dams debate in the years ahead. Our work program consisted largely of an attempt to understand experience with dams and not to pretend that we can conduct an empirical study. We estimate that currently 45,000 large dams have been constructed around the world. Even if you spent 5 or 10 years examining the matter, you would probably be unable to be sure if you had selected a statistically representative sample. What we have tried to do is to study intelligently the diversity of experience on the various key issues that drive the discussion about dams. And we have done so by doing 10 case studies, very detailed, looking at the whole history of one dam across all the different issues, and we have done that on four continents, on different dams. Obviously we also have to try to capture up-to-date knowledge and experience about dams and we defined 17 thematic reviews, as we call them, that touched on many of the major issues, including the economics, social implications, environment, options assessment and institutional and decision making process.

Even that, we felt, would not be sufficient to be sure that we had really captured not only the diversity of experience but also some of the broader trends. So we put in place a third precaution, the cross-check survey. This is probably the most comprehensive survey ever done systematically in terms of breadth of issues examined for 150 dams. The sample was constructed from the ICOLD World Register of Dams, to reflect broadly the characteristics of the global population of large dams in age, type, purpose and so on. The cross check survey is now virtually completed.

If you take those three blocks of work together, you can begin to see that the Commission can reasonably claim that it has a very good understanding of what is going on in dams. It is not trying to come to an answer about whether 60% or 80% of the world's dams have been good or bad. It is trying to understand how we can learn lessons from the past to make sure that future dam decision making is not variable, nor likely to lead to conflict or confrontation. Not a matter of who has the greater voice, or access to the media, or access to capital power and influence, but really that good dams are built and bad dams are not built. Both exist, of course, and I expect all of you have come across both types in the course of your work.

The other thing that we have done, and this really distinguishes the Commission, is that from the beginning, we have made our work a multi-stake holder process. This is very important, and this is a key message to you as members of the British Dam Society, that one of the reasons why we have such a desperate state of affairs when it comes to discussing dams in public, is that we have not talked to one another. If you do not talk to one another, you are isolated from one another and in the end conflict and confrontation occurs. Trying to prove the other side is wrong is basically the only avenue open, and your frustration with NGOs, with the media, trying to represent fairly the benefits and impacts of dams is shared by many of them on the other side, who feel that for years they have pointed out things that have not been listened to. Today we all know what has happened, and that there are problems, but if only we had spoken to each other earlier, perhaps they would not have arisen in such magnitude.

So much for the background to the Commission. I would like to report to you just some of the highlights from our work, 17 thematic reviews, case studies, cross-check surveys. We invited submissions and received over 800 from around the world, voluntarily sent, covering broad topics such as national master planning on water management in India and the German government's experience with development aid on dam construction, to local communities in Brazil who wrote to share their experiences with us about what happened after resettlement. Eight hundred and five testimonies that have added to the Commission' s understanding of why, sometimes, the debate is not a matter of only rational or neutral and objective assessment, but really needs to be looked at from many different points of view.

If you are a resettled person living downstream and you relied for 90% of your livelihood on fisheries and those fisheries have gone, any kind of benefit that the dam generates, and usually it does not even generate it for you as it is built for a larger national purpose, is a fairly absolute infringement on your life. Whatever you do for that fisherman or his family, it does not compensate for their loss. And this has been one of the extraordinary things that we have found, that often it is not so much the dam itself that has been controversial but the way the decisions were taken. Not about how, and in what form, the dam was constructed, and with what inputs, but above all how equity considerations were taken into account. Very simply, what you do when you build a dam is that you take a resource and you transform it, you take the benefits that used to accrue to one group of people and transform them into another resource and benefit that accrues to another group of people. Most simple logic in life would mean that you compensate those who you take something away from, in order to make it more bearable. In societies where democracy and where planning processes and regulations are mature, where you have a strong citizenry, those things work fairly well. England has a whole system of public inquiries, that are checks and balances in the negotiation process. But over the last 25 years, most dams that have been constructed in the world have been constructed in countries where regulatory frameworks are not in place, technical capacity was not available and certainly there was no mature public debate that allowed any balancing of the various impacts of the project to take place equitably. We have found that this lack of balance is at the heart of the whole debate about dams.

Resettlement was the first major group of issues that we dealt with. Let me begin with social issues: we have studied the questions of equity and distribution, social impacts and cultural heritage, and indigenous communities. Many contributors clearly stated that, as many of you already know from your own experience, resettlement has been one of the sorest points associated with dams. And the extraordinary thing is that one can't really argue that many of the 'mistakes', so called 'mistakes', took place because of ignorance. This is one thing that clearly comes out from the work we have done. Let me give you two examples. In 1905, Norway became independent from Sweden. At that time, by any definition, it was a developing country. The poorest country in Europe, in fact. A population of 2.5 million people, colonised by their neighbours, with a rural agrarian based economy. Today Norway is a country with 99.6% of its power coming from hydropower; it is probably the richest per capita nation in Europe. The wealth has not come from hydropower alone, of course; the discovery of offshore oil has had a big impact! Many other nations are not so fortunate! The reason why I cite Norway is that in 1906 when it began the development of its energy policy, it put in place a benefit sharing scheme that still exceeds much of what has been done in many other countries. At that time it could not build dams itself and had no money, and had to bring foreign investors in. The law required foreign investors to build dams in such a way that they had a beneficial mechanism and that 10% of the power would go to the local municipality for rural electrification (Today those municipalities can choose whether they use the electricity themselves or sell it into the grid, obviously that was not an option in 1906). Right from the beginning, in 1906, there was development involving dams that was development for Norwegians generally that also had to also have a clear benefit sharing mechanism built into it for those living near the development.

Let me take you 40 years on to Kariba Dam, in Zambia/Zimbabwe. A large dam built with major resettlement programmes. You might remember Operation Noah, elephants being lifted by helicopters. Do you realise that most of the communities that were resettled at the time, even today, 40 years later, do not have access to electricity? Only last year, on the initiation of a World Bank supported loan, the Zambian Electricity Authority actually went back and started a rehabilitation programme for those very communities who at the time were re-settled. Is that really necessary? Clearly not, but those were the kinds of judgements and decisions taken at that time that are haunting the dams debate to this day.

I would like to make an important point about resettlement. In itself, it is a physical process. As a basic minimum, you try to compensate people, but that is not enough. But if you think of your own family situation, if after generations of living in a family home, you were displaced, compensation for the value of the house by market value would not be enough. This is one of the things that the Commission will very strongly advocate, that in future, resettlement should really be development, not just compensation. That is *the first guarantee. Those that pay the highest price for building a dam should* be the ones who benefit first from it, immediately and substantially. The costs of this type of resettlement as part of the development would, in 99.5% of the cases, not adversely affect the economics of the dam. That it was not done like this was simply the arrogance perhaps, and I say this all humility now, perhaps the blindness and reflected the reality of how power and politics worked at the time. Those people, those illiterate, poor, rural peasants were not politically important. They were in the way of development and the price paid to move them out was very small. However, it has been a very expensive price for dams, for societies and for many economies, because many countries are today having to go back to resettlement programmes where continuing legacies of lack of compensation, social problems, lack of development and so on persist.

Let me also mention cultural heritage. It is another good example of how dams, could have been and in some cases have been, a major opportunity, not a threat, to cultural heritage. You may have seen the recent reports about the dam in Turkey where major archaeological finds were discovered in the reservoir only during construction. This is a classic example of not using the dam as an opportunity because nobody thought of investing in cultural heritage and some archaeology. Only about two years ago did some Turkish archaeologist receive funding to start digging and they found the most extraordinary things.

There are cases where dams properly planned and well thought through put a major archaeological research programme in place to help society to preserve cultural heritage. It is not an issue that you can't build dams to take care of cultural heritage, you usually can. Depending on when you think of it and how you think of it, much can be done. It is not always an engineers' prerogative, you are not archaeologists, you are not social scientists, but you are part of a team that is working around such a project.

Let me run through other examples of the kind of lessons that we have drawn from our work.

In hydropower, the issue of carbon trading and greenhouse gas emissions is a major issue on the international agenda. Some of you may have seen what I call the botched job of New Scientist magazine a couple of weeks ago about some of the work that we have done on this issue. It baffles me that a so called respectable science magazine wantonly misrepresented much of the evidence that we put on the table. However, in principle, what has become clear is that hydropower cannot simply be called green in terms of greenhouse gas emissions. We assembled scientists both from within utilities such as Hydro Quebec and Electricity de France and other researchers from Universities and asked them to discuss and agree on what science tells us at the moment, and to tell us what we do not know and what we need to do to find out. What we can say a priori is, in terms of the climate change convention and the so-called Kyoto protocol whereby countries could trade their carbon credits, that hydropower is not necessarily clean because methane emissions are associated with hydropower dams and reservoirs in particular in tropical forested regions. Methane is a very lethal gas in terms of our ozone layer, 20 times more lethal than $C0_2$ emissions. The significance of this is important. What we are trying to do in the Commission is not to say because of it hydropower should not be considered, or it is so small lets go ahead. What we are saying is that this is an important issue for the future of hydro power economically, and you must get the science right. We have laid out a few of the steps that we believe will assist governments to determine whether hydropower is a cleaner option or, in fact, not the cleanest option compared to other energy generating opportunities. This is an example of how, in the Commission's work, we have examined some of the environmental issues. Looking at the polarity of the debate and trying to find out what is assumption and what is ideology, because a lot of these feature in the debate.

Another example on the environmental agenda is mitigation. Many of you are familiar with the ingenious ways of trying to mitigate the impact of dam construction, and quite rightly are proud of the measures that have been developed and put in place. The difference that we have found is that you can start mitigation from the point of view of mitigating the worst case scenario of the impact. The more you reduce the impact on the worst case, the greater your success in mitigation. However, if you take the original state of affairs before the dam was present and look at the mitigation from that point of view, it puts a different perspective on it. An untouched river system is a 'wild' river, so to speak. If it is dammed and then has mitigation measures put on it; they do not recreate the ecology that was there before. What we have found, unfortunately, is many instances where mitigation was first of all developed in theory, but quite often not put into practice. And as those who are familiar with the parallel processes of technical planning and environmental impact assessment of mitigation will know, mitigation measures do not always work or they do not work sufficiently. Therefore we have to go back to first principles when we build a dam. Avoidance must be the first principle; if avoidance is not possible, mitigation is the second option, but it should not be simply posed as a convenient hypothesis. It must be tested, it must be prudent, to work. Once you have dammed a river, it is too late to find out your fish ladder doesn't work, and there are many examples of that having occurred. Again, I should say that we are not trying to condemn anyone but trying to understand where things go right and where things go wrong and how do we might deal with them in the planning and construction of future dams.

Some other examples, options and alternatives I would like to present to you as, in essence, a professional community that explains to society why dams are its best option. It may be risky for me to stand before you and say that in many cases there is no longer an imperative to build a dam. But that is not really the question. The question is, compared to what other options, is a dam the best idea? Also, under what criteria of development is it the best option? Two brief examples: Power - in terms of power generation we no longer have to build dams today. We may want to build them because they may be the best option, but we don't need them anymore because we have other alternatives. It gets more complicated when you go to countries like India and China. They have monsoon climates, with a need to capture water, and also, the particular issue of food security and irrigation. There we have found a far more complicated picture where dams clearly will, in some cases, be the only option. Therefore the question is not - dams, whether or not? - but how? In flood control and flood management, again the evidence becomes far less imperative. Yes, dams have provided flood control but, in fact, the more we have studied the issue of flood management we have also found that dams can compound over time the issue of floods. Therefore it is not only a matter of damming the flood; it is managing water and managing its critical function.

China is an excellent example; China has been damming itself so to speak for the last 80- 100 years with dykes. In many cases, this results in rivers that are now high above the flood plain. This means that any breach of those dykes and dams immediately has the terrible consequences that you read about in the papers. Deep down the Three Gorges Project is a desperate measure to deal with a compound situation that has emerged over the last 80 -100 years. More and more people are crammed into a very endangered space, at the same time as various stop-gap measures have been put in place to control floods. In the end, this creates a potentially very lethal situation where if one of those goes wrong, hundreds and thousands of people are affected. That is why the Chinese Government (and this is not a Commission finding) is looking far more today at investing money in flood management upstream rather than simply building more dykes and dams. But that has come after 60 - 70 years of an almost blind notion of damming the water in order to control floods. Again this story is not that simple, it s not that straight-forward and certainly it is not self evident that the dam is always the best option. And I think this is where the engineering profession is challenged to explain to society why and how it can be, and also to engage in discussion with the public where they may not understand or agree with it.

Let me perhaps focus on some of the key issues that we believe will also drive the final report of the Commission. Obviously I am not at this stage either able nor at liberty to really share with you what's in it, but I can be quite honest. We are still working very hard to grasp what exactly is going to be in it, because we have so much information and we obviously need to concentrate on what matters can really influence decision making.

One of the big themes of the report will be that the debate about dams cannot be one of benefits versus impacts. We are all culpable in conducting that debate because you cannot quote a figure of so many hectares irrigated or so much food produced or so many megawatts generated, as self evident justifications for a dam, just as you cannot argue that because you are losing one or two fish species as a result of damming the river, you should not dam. It is the benefit and impact equations that should actually determine whether to build a dam. And it is there that we have not been very good at combining the economic, the ecological and the social variables and actually balancing them. So the first issue that the Commission will focus on is to create a more intelligent debate and public discourse about dams, that doesn't get hung up on issues such as we produce 20% of the worlds electricity, how can we be wrong; or, how terrible so many rivers have been dammed and there are only five wild rivers left in our country. So what? It does not tell you anything about whether that was the best option you had as a society at that point in time.

The second question is who decides? It is fundamental in understanding the dams controversy to appreciate that much of what we argue about is who decided for whom, what was the best option and at what costs to whom. I gave you two examples earlier. Therefore the Commission will focus a great deal on the decision making process that has to involve the public, both the immediately affected public and the broader public, by this I mean the environmental public, so to speak, who want to have wilderness. In Norway, a country that has obviously been very successful in building dams, has resettled less than 50 people over the last century. Unbelievable, it has built all those dams while resettling less than 50 people, yet is still not willing to build more dams. Are they stupid? No, they are making value choices; they are comparing their options. Ironically the Government fell a few weeks ago over the question of whether they can construct a gas-fired power station, which really makes an interesting scenario in the energy debate.

Thirdly, we need to look at dams in the context of the river basin, and you might all say; well that's obvious. So why haven't we done it? We have not even done it in many of our so called technically sophisticated and mature economies in Europe. To this day many of the existing dams have not been revisited in terms of their operating regime, how they could be run differently in terms of the river basin. We are managing some of our dams the same way as when we built them over a hundred years ago. Is that really the most intelligent option we have, with all the technology, all the knowledge and all the science that is available today? Clearly not, and clearly this is a major opportunity for revisiting (and this is one of the other major points the commission will make) the existing 45,000 large dams in the world. The dam is cast in concrete perhaps but its operational regime is not. You can do many different things with a dam and you can adjust its operation to reflect what society may value as a more important asset at the time. Thus you can avoid the debate over whether you either have the dam or you have to decommission it. Which is where the debate currently ends up as a dead end most of the time.

Then we need to ensure best practice in compliance. This is where we are having a very interesting discussion within the Commission, reflecting discussion of the engineers and the social and environmental constituencies. The engineers argue that they design a dam and that is their function, as they are not a political entity, they can't decide over resettlement, they can't decide over the environment, that is not their role. However, ICOLD published a number of years back a second edition of its Environmental Guidelines. The Commission has had that guideline on the table ever since its first meeting because Jan Veltrop, your Honorary President, brought his copy there. At every meeting we keep asking ourselves why people are not following those guidelines? ICOLD has already spelt out much of what I have just spoken about, but it is not being implemented. Then we get into this complicated argument; it is the Government, well in fact it is the private contractors, it is the fly-by-night operators, it is this, that and the other. This is what is killing dams, that it is the rejection of responsibility that you are acting in a consortium, whether you are an engineer, whether you are an environmental scientist, whether you are a contractor or consultant. What does an affected community do once the dam is built? And this is really where we have found some very tragic stories. Everybody leaves, the dam is there, and who do you turn to. Refer to the Government? They say no, and they give you a major procedure but you are a poor rural farmer. You can't reach the contractor - long time gone, we have built our dam, we have nothing to do with it. You go to the World Bank who funded the dam? No, we only provide the loan, so therefore we are not liable for mitigation not having been implemented, or resettlement programme not having being completed. You would be ashamed if you saw how many instances we have found where people have never been compensated. Social resettlement plans were there, compensation measures were agreed, yet 10, 15 years later they have not been paid, they have not received even some of the fundamental things that were promised to them. But there is nobody they can turn to, who can they go to? This is one of the things that we need to come back and ask ourselves. How can we ensure that we do what is already known to be best practice and how do we create both the regulatory framework and the incentive for it to be done? Because you can't legislate alone for sensible action, you have to create incentives; it has to become economically convincing for a company to be known to be adhering to best practice, even when national laws may not prescribe it. Because that is what makes the difference. So the next time an ABB, Siemens or a General Electric goes to the World Bank to tender, maybe they would get bonus points because their record has been so good and has exceeded regulations, it has actually become worthwhile for them to invest in best practice.

Some comments on the relationship between WCD and ICOLD. I do not know to what extent you are interested in this. Since you are engineers I presume that you don't waste a lot of time on institutional politics, but it is well known that the relationship between the World Commission on Dams and the International Commission on Large Dams has been a troubled one in some respects, and a very good one in other respects. I would like to make it very clear from our point of view that although there have been elements within the ICOLD community who have had a very negative attitude towards the Commission, there are many others from the President downwards who have been extraordinarily supportive. Kaare Hoeg has been an extraordinary partner to work with in this process, playing a very different and difficult role in bridging the understanding between the many ICOLD committees and the WCD. The greatest regret that I see in this is that much of the energy in some parts of ICOLD was wasted at the beginning in trying to attack a Commission on a process of this kind. ICOLD needs to ask itself why on earth did the world put this Commission in place in the first place, why are we wasting all this money having to do all these studies and being engaged in all these consultations? A lot of it has to do with the fact that ICOLD have failed to deliver a platform for that dialogue to take place, that is the simple truth.

The World Commission on Dams will say goodbye on the 31st August this year when their work is completed and the mandate accomplished. The Commissioners are quite clear of that in their own mind. The actors are out there, the arenas are out there and the negotiation platforms between consultants and NGOs are all there.

That is not what was needed. What was needed was an independent input that had some kind of authority to hopefully bring the debate back to a more sensible and integrated approach. In that sense the World Commission on Dams, far more than being a threat, is really an opportunity for ICOLD, and I have discussed this with a number of the national committees of ICOLD. Our great hope is that in Beijing later this year, the ICOLD community will not take the WCD report or its findings in terms of "we disagree with this portion, how could you possibly say that, you haven't done enough statistical work". Our answer to the last, by the way, is that if you found what we found, which is the lack of data available, we would hand the argument back to you and say "How could you spend so much money and not even monitor or provide some of the data?" It is stunning in our cross check survey how many columns came back with no information available after spending three or four or five hundred million pounds on the project. It is stunning and we would show you this because I think you would be surprised yourselves in how little monitoring has taken place. However, I expect you will be able to pick many holes in our WCD report on that level, but that would again be a wasted opportunity.

What we are handing back to ICOLD, to the NGOs, and to governments is a foundation on which to conduct a future dialogue around dams, taking all perspectives into account. You can either take this opportunity or you can continue to be the International Commission on Large Dams that focuses on dam safety and the technical side of the argument. Meanwhile society is moving on with this debate and ICOLD is not being given the hearing it deserves, as the most authoritative and most competent source of information on dams in the world. Who knows about that? Very few people.

Finally let me say also that ICOLD needs help within its own ranks in order for the north-south dialogue to be a more creative one. In the reaction to our work we have found this great divide. Between, on the one hand, the northern membership of ICOLD which has lived through many of these debates already, and is used to conducting a dialogue with the public, public consultations, public enquiries and the like. Then you have countries like China, like India and others, that still regard the notion of engaging the public as essentially a threat to dam building. That is something that clearly, through your experience you need to try to explain, convey and help many of the other national committees to understand that it is the best chance you may have to be able to build a dam in 25 years from now. And that is our hope, that we can open some eyes in that respect. Sadly, we lost China from the World Commission on Dams. We had a Chinese Commissioner but about a year and half ago, the decision (after political changes in the ministry) was made to withdraw her. In effect this has meant that China has not really collaborated with the Commission at all. This is a great regret for us because China is a country with many, many dams; it has also one of the most dynamic reform policies underway as far as dam construction goes. In the end though, ours is not a commission about China, nor a commission about Chinese dams. In some ways China may have lost a great opportunity to explain to the international community what exactly is happening in their country, and will always face difficulties in finding that it is on its own in a PR response to some of the criticisms that will come. The Congress in Beijing is an enormous opportunity to show to the Chinese community of professionals, many of whom are in fact not trying to hold back, (they are trying to engage), that the best chance for future dam construction is to have an intelligent and fair dialogue on whether at the end of the day a dam is the best option or not. Dams will always be a technical option, but it is really in the hands of those who know how to build dams to make sure that the option of dams is not lost in the broader political discussion.

THE GEOFFREY BINNIE LECTURE 2000

Introduction
by Mr. R. C. Bridle, Chairman of the British Dam Society

It is my pleasure and privilage to introduce the Year 2000 Geoffrey Binnie lecture. The Geoffrey Binnie lecture was initiated in 1980 as the BNCOLD Lecture. In 1990, following an endowment from Binnie & Partners in memory of Geoffrey Binnie, the lecture was entitled the Geoffrey Binnie Lecture. It is the prestige lecture of the British Dam Society, given every two years. Alan Johnston will be the ninth Geoffrey Binnie lecturer. He is the second lecturer from the Babtie Group. David Coates gave the BNCOLD lecture in 1988. Alan needs little introduction and we all know him as a distinguished engineer. I have been looking at his CV and other documents given to me by Alan's collegues in Babtie to find the background on the route Alan has followed through his distinguished career.

It is easy to commence by saying that Alan is a Fellow of the Royal Academy of Engineering. He took a degree in the civil engineering at Glasgow University where Rankine, after whom the prestige geotechnical lecture is named, had been professor in the late 1880s. He also very worthily completed a diploma in public administration five years after graduating. Alan has served the profession with distinction as an engineer, as a manager and director, and as a professional. I have found that Alan's contributions are well illustrated by lists. Here's one, relating to Alan's contribution to the business of consulting engineering through Babtie's:

Banks, Geddes, Paton, Coates, Johnston, Perfect.

It may not be complete, but you may recognise that it is a list of senior partners and CEO' of the Babtie Group.

Here is a list relating to Alan's professional distinction:

Panel I, Panel AR, ICE Reservoirs Committee, ICOLD Committee on Dam Safety, ICE Seismic Stability Working Party, Norwegian Water Resources and Energy Administration - appointed Engineer for dam construction and inspection.

Here is another list you will recognise:

Haws, Carlisle, Sims Johnston, Martin.

They are, of course, BDS Chairman. Alan was our Chairman from 1995 to 1997. He was very distinguished in that role. In fact, James Martin and I asked if he would stay on the committee for an extra year because we so much valued his expertise in the business and affairs of ICOLD and BDS.

He has also contributed much to the profession through research jobs. Alan is one of the team working on the DETR project that will give us guidance on what to do about the conflict between the Flood Studies Report and the new Flood Estimation Handbook and here is another list:

Johnston, Millmore, Charles and Tedd.

You will know they are the authors of the 'Guide to the Safety of Embankment Dams', another job that Alan executed so successfully.

Looking at Alan's (in the CV's phrase) 'technical and project related work', here is a list of the dam types Alan has engineered:

Earthfill, rockfill, buttress and pre-stressed.

Interesting that he worked on Alt-na Lairghe, the only pre-stressed dam in the UK, one of few in the world. Now a final list. This one is of new dams on which Alan has had an important role; it could be said that they are Alan's dams, they include:

Bradan, Colliford, Roadford and Carsington

I suspect that these are the dams that will provide the core of his Binnie lecture "Taken for Granted". I'd like to thank Alan for the inspiration he has given us in the past, and to thank him in anticipation of the inspiration that his lecture will give us, and now invite our Year 2000 Geoffrey Binnie Lecturer, Alan Johnston to deliver his lecture.

TAKEN FOR GRANTED

by T.A. Johnston.

It is an honour to present the Geoffrey Binnie lecture and I am grateful to the British Dam Society for inviting me to do so in the year 2000.

Geoffrey Binnie

After retiring as Senior Partner of Binnie and Partners in 1972 Geoffrey Binnie was the author of two books known to most of this audience "Early Dam Builders in Britain" and "Early Victorian Water Engineers".

His achievements as a consulting engineer are less well-known now. To quote from Alan Twort's history of Binnie & Partners,[1] Geoffrey Binnie was one of the most successful dam engineers of the 20th century. Gorge Dam, Hong Kong; Kalatuwara, Sri Lanka; Dokan and Dibbis in Iraq and Mangla, Jari and Sukian Dyke in Pakistan all stand today as a testimony to his abilities".

It was Society's lack of recognition of our predecessors that spurred Binnie to authorship. He wrote "As the third generation in a family of waterworks engineers, I was prompted to try to see justice done to Bateman, Hawksley and other pioneers of my profession"[2]. If some day an author sets out to record the achievements of 20th century dam engineers we can expect Geoffrey Binnie to feature prominently.

Introduction

The start of a new century is an appropriate time to look back over the developments in dam engineering in the 20th century and to look forward to the challenges we face as dam engineers as we enter the 21st century. With this in mind I comment on technical matters and also present some views on the role of dam engineers in Society.

The title of the lecture, "Taken for Granted", is a phrase with different shades of meaning. I use it to cover two main themes - the need for dam engineers to question the rules and customs by which we operate and Society's continuing lack of recognition of the value of reservoirs and the engineers who devise them. There are gaps in our knowledge and understanding and we do not always organise ourselves in the best fashion. After a review of dam engineering in the 20th century I will illustrate these themes using a number of topic headings:

- Public Recognition
- Legislation
- Procurement
- Privatisation
- Stability of Embankments
- Factor of Safety
- Risk Assessment

Dams of the 20th century

In choosing nine examples to represent features of 20th century dams and also to introduce my later topics I have not tried to identify the century's most important dams. Instead I use projects with which I have had some connection. Shakespeare wrote of the seven ages of man. My examples come from seven ages as an engineer: student, assistant-under-agreement, graduate, project engineer, associate, partner/director, consultant. The dams are ones where information is readily available to me from Babtie Group's records or from my involvement as a Panel AR engineer. These are shown on Figure 1.

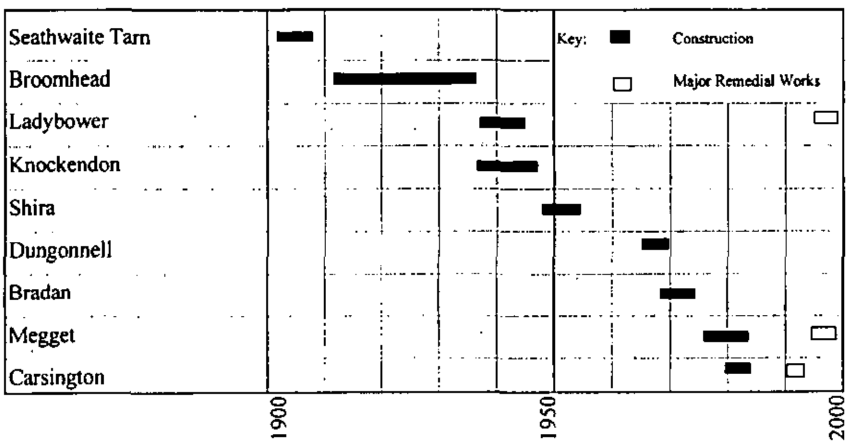

Figure 1. Nine Dams Spanning the 20th Century

It is my hope that this review of continuing evolution will encourage us to ask questions such as - "What changes in design and construction lie ahead? What defects have we overlooked in our existing dams? How will changes in the world around us change the way we work?"

Seathwaite Tarn Dam

Seathwaite Tarn was completed in 1907 for Furness in Cumbria and it had shortcomings in flood provision, stability and construction methods. The original overflow has been replaced and the dam has been strengthened a number of times, most recently by post-tensioned cables from the crest to the foundation and a rock buttress has been added on the downstream toe.

Earlier gravity dams such as Vyrnwy and Thirlmere had masonry facings, most of which look as well today as when they were built. The mass concrete in the hearting incorporated 'plums' ie large stones which reduced the shrinkage of the concrete. At Seathwaite joiners rather than masons formed the faces and the concrete was placed in 150mm thick layers without vertical construction joints. Not surprisingly the dam leaks and as far as appearance is concerned, the changes were not for the better. However, Seathwaite was one of the dams which demonstrated that expensive masonry facings were not essential. The problems of concrete shrinkage and leakage on gravity dams have been overcome on later dams by the use of monolith construction and more recently by roller-compacted concrete.

Broomhead Dam

The hinterland of Sheffield has posed many problems to dam builders. The tragedies in the 19th century in which nearly 250 people were killed in the Dale Dyke disaster and the collapse at Bilberry dam with the loss of over eighty lives are well-known. The 20th century has its own lessons learned through experience. Sheffield Corporation's Broomhead Dam had an unusually long construction period. Started in 1913, it was brought into use in 1936. Delays were caused by the 1914-18 War and the subsequent Depression but construction problems were the main contributor. With hindsight the basic problem appears to have been insufficient knowledge of what we now call the hydro-geology of the valley. Site investigation techniques were in their infancy and the existence and significance of artesian water under the dam and in the valley sides only became clear as work progressed on site. We have much more effective site exploration plant and techniques available now and Broomhead reminds us to use them to the full.

The spillway channel is built into the hillside at the left end of the dam and it was the location of probably the most dramatic event, a slip in the valley side which destroyed the overflow basin. The solution involved massive strengthening works and a set of drainage tunnels which are buried from view on the valley side.[3] Major inflows of water to the cut-off trench during construction and loss of water under the dam on impounding were overcome using a control system which has remained in use. The bed-rock is under an uplift pressure generated from the reservoir basin and a system of pressure relief wells and pipework is used to reconcile two conflicting aims i.e. the reduction of water pressure under the dam and the reduction of leakage from the reservoir. The system is shown on Figure 2.

We tend to think of review panels as comparatively new but second opinions have been sought for many years. At Broomhead, Sheffield Corporation called in three eminent engineers as advisers, Messrs W S Nicholson, W J E Binnie and H K Lapworth. They signed the certificates under the 1930 Reservoirs (Safety Provisions) Act along with the Construction Engineer, Mr J K Swales. One of the conditions for impounding still applies; the maximum permitted water pressure at the relief holes. The allowable pressure is indicated on Figure 2.

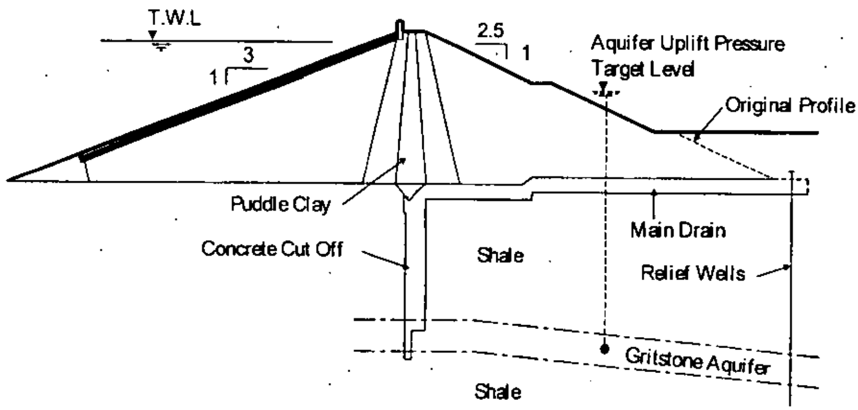

Figure 2. Broomhead Dam, Cross-section

Soil mechanics was one of the 20th century's major advances. The new science was being introduced as Broomhead was completed. At the first Congress of the International Commission on Large Dams (ICOLD) in 1933, the fathers of soil mechanics were seeking to apply their new science and ICOLD countries were asked to describe their methods of selecting embankment slopes. Dr Karl Terzaghi reported that only five countries considered it essential to investigate stability and calculate what came to be called the factor of safety.[4] Of particular interest to us, Mr Binnie stated that coefficients of friction and cohesion were not taken into account in Britain.

Terzaghi recognised the limitations of laboratory testing and he used another term, the instability factor, to describe the ratio between laboratory and insitu values. He hoped that improvements in laboratory testing would, in time, eliminate the need for an instability factor. Seventy years on, laboratory techniques have been refined but judgement is still needed to translate laboratory results for friction and cohesion into design parameters.

Knockendon Dam

Knockendon was one of the first dams to benefit from soil mechanics. Built between 1938 and 1947 it was at half-height when Muirhead dam, which was under construction for the same owner, Irvine and District Water Board, suffered a major slip. The investigations established the importance of construction pore pressures in reducing stability and provided a blueprint for a re-assessment of Knockendon which revealed that it was being built with a factor of safety close to unity. A design value of 1.33 was adopted. To achieve this the upstream slope was flattened, granular fill was introduced in the downstream shoulder and the construction methods changed. The lower half of the dam had been built as Bateman preferred, with the construction layers sloping inwards to the core. In the upper part the layers slope outwards and boulder clay fill was placed over the full width using dump trucks and bulldozers. In a paper on Knockendon Mr James Banks highlighted the interdependence of design and construction and advised engineers to take advantage of the latest type of plant - for example, by designing with a more conservative assumption of the pore-water pressure than if a slower programme construction was contemplated'[5] These were prophetic words. Construction periods have reduced dramatically and the geotechnical engineer monitoring pore pressure plays a key role in an earth dam's safety during construction.

Glen Shira Main Dam

During the heyday of 'the Hydro,' from World War II to the early 1960's a new large dam (using the ICOLD definition) was completed every 3 months on average for 13 years for the North of Scotland Hydro-Electric Board.[6] In addition many smaller dams were built. The Glen Shira project[7] had three dams each of a different type while in an adjacent valley the Allt-na-Lairige[8] dam was being built.

Here again the need to link design with construction methods was recognised. Many building materials were in short supply and much effort went into devising ways of saving cement and minimising formwork. At Shira round-head rather than diamond-head buttresses were chosen for the main dam to maximise the re-use of the formwork. Minimising the volume of concrete led to Allt-na-Lairige being the United Kingdom's first prestressed concrete dam.

Dungonnell Dam
Dungonnell Dam in Northern Ireland is another trailblazer. Completed in 1970 to supply water for Ballymena it is the first dam in the United Kingdom with an asphaltic concrete upstream facing.[9]

There are now six asphaltic upstream membranes in the UK. They have required little maintenance apart from Winscar which has required remedial work from time to time,[10] and the use of asphaltic concrete is now well-established as a practical way of combining wave resistance with impermeability. The only maintenance work on the Dungonnell face has been re-sealing of the joint at the base of the parapet. This is a common location for re-sealing due to the joint opening as the membrane creeps slowly down the face.

Bradan Dam
Bradan Dam built for Ayrshire & Bute Water Board in the early 1970's highlighted the value of a thorough site investigation. The initial investigations indicated that bed-rock was near the surface. However, a trial excavation revealed that, instead of being 2 metres deep, bedrock was at a maximum depth of 9 metres. Highly compressed boulder clay till overlay bedrock. The till had a bulk density of 2.4 Mg/m^3, the same as concrete. It is not surprising that the drillers were confused.

Bradan is a conventional gravity dam built in monoliths but it came close to being the first roller-compacted concrete dam in the United Kingdom. As site work got underway the designers gained experience of RCC on a major mass concrete retaining wall on a motorway project and realised that the technique could be used on a dam. The pros and cons were discussed with the contractor but there was no financial advantage in changing at that time and work went ahead with conventional monoliths. Since then a few small RCC dams have been built in this country and many major ones overseas. However, the UK's first major RCC dam is a task for the 21st Century.

Carsington Dam
The major slip in Severn Trent Water's original Carsington Dam as it neared completion in 1984 was a salutary lesson to dam engineers. The failure was caused by the cumulative effect of several unsuspected circumstances, i.e. soil solifluction shear planes in the foundation, progressive failure reducing shear strength and load transfer laterally. This can be put another way. The factor of safety contained insufficient allowance for the unknown. [11, 12, 13] Finite element analysis is one of the most powerful tools now available and

it played a valuable role in the analysis of the mechanism of failure.

The new Carsington Dam was completed in 1991, the main differences being that the foundation clay was removed so that the dam is founded on weathered bed-rock, it has flatter side-slopes, the core is symmetrical rather than having an upstream boot and it now has an upstream blanket. [14,15,16]

The completed Carsington scheme is not just an engineering achievement. It has been a major environmental gain for the Midlands. The Visitors Centre has more than 1 million visitors a year, a clear indication that Carsington has overcome the adverse publicity surrounding the failure.

Megget Dam

It should be no surprise that my last two examples, Megget and Ladybower, relate to remedial works. For the past 20 years there has been a reluctance to build new reservoirs. Consequently there is often insufficient capacity in the network to allow for emptying a reservoir during remedial works. At both dams the design, the construction methods and the capital costs were greatly influenced by the need to maintain the reservoirs in operation.

Megget, owned by East of Scotland Water, is an embankment dam with gravel shoulders and an asphaltic concrete central core. The upstream face is steep, 1 (vertical) to $1^1/2$ (horizontal), protected by riprap. Since completion in 1983 the upstream face has suffered regular damage due to wave action.

Windspeed and fetch are the key design parameters for upstream protection and the expert guidance has changed radically on both topics in recent years.

Records of windspeeds are now much more extensive and the Meteorological Office has uprated its forecasts in the light of the new information. The consequence of the under-estimation of wind-speeds was considerable. Mr W P McLeish was the Construction Engineer when he wrote "Had the Met Office 1989 data been available at the time of original design, the geometry of the upstream face of the dam may well have been different, probably incorporating a flatter upstream slope with a berm to give access for maintenance".[17] The changes have significant implications for many exposed structures and for dams the effect of the revisions to the forecast windspeeds has been compounded by a change in the recommended method of calculating the effective over-water fetch to the dam.

The change in the method of estimating the effective fetch was introduced in 1996 in the third edition of 'Floods and Reservoir Safety'.[18] The use of the maximum straight over-water distance to measure the fetch is now recommended rather than an arc radiating from the dam and for narrow reservoirs such as Megget the change has been significant.

As shown on Figure 3, an innovative solution, bituminous pattern grouting, has been adopted to strengthen the face. The technique is well-established in marine works on shores which are flatter than the faces of dams.[19] Megget broke new ground in using the technique on a reservoir and on such a steep face.[20]

Ladybower Dam

Ladybower, owned by Severn Trent Water, is another dam with a long construction period affected by wartime. The highest puddle clay core dam in the UK, it was started in 1936 and completed in 1945.[21] The fill is principally rockfill placed in 1.5m deep layers with no formal compaction. Settlement has totalled about 1.6m since completion and the owner's settlement records have been used in a finite element analysis which has shown that the dam is subject to settlement related to draw-down.[22]

In 1999, BDS visited the site to see improvement works in progress.[23] The works have three main objectives - increased freeboard, increased stability and replacement of the draw-off valves, and have now been completed. Increasingly, remedial works have to surmount environmental and operational constraints. The Peak Park Planning Authority introduced an unusual restriction at Ladybower - dump trucks were not allowed to pass up or down the dam face in the early stages due to concerns about noise, and a conveyor belt system was installed from the crest of the dam to the toe to transport the rockfill used to buttress the downstream shoulder.

For operational reasons the reservoir was close to full and before replacing the valves in the draw-off towers, underwater technology from the North Sea oil industry was used to inspect the draw-off tunnels and seal the inlets. This was carried out working from a barge shown on Figure 4 using an ROV (remote operating vehicle), working from upstream.

The new, higher crest has been set downstream of the original crest and the water-barrier provided by the puddle clay core is extended upwards, firstly by a bentonite trench and then by a high density polyethylene membrane on the sloping face.

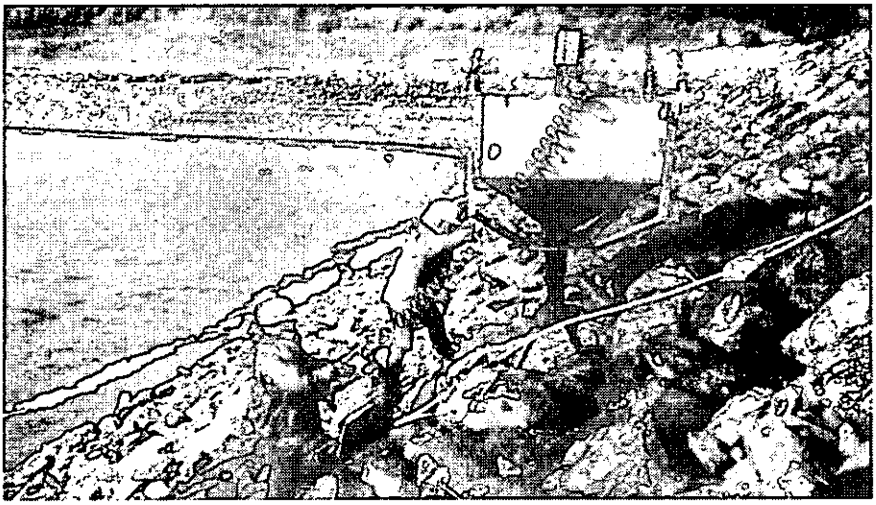

Figure 3. Bituminous Grouting to Rip-Rap, Megget Dam

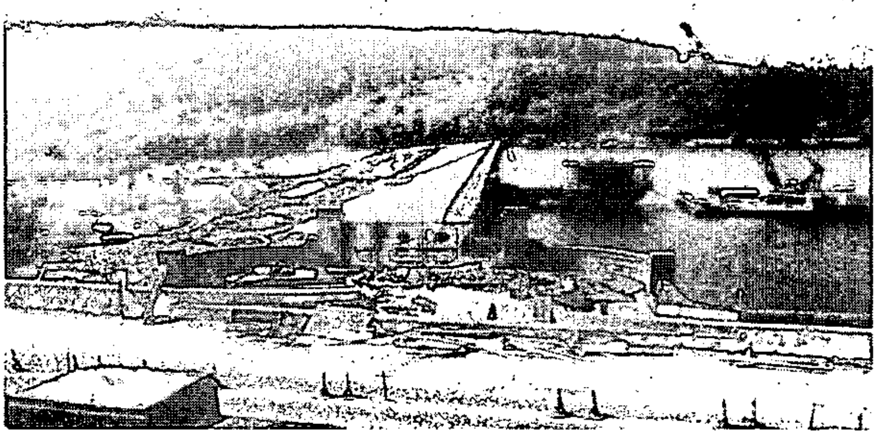

Figure 4. Barge used for Underwater Installation Work at Ladybower Dam

Looking Forward

My selection of nine out of the 329 large dams built in the UK since 1900 (according to ICOLD statistics) has been subjective but it does provide us with pointers for the next century. The past may not repeat itself but it is the best guide we have and it is reasonable to assume that

- design standards and construction methods will change
- our understanding of dam behaviour will improve
- new materials will come into use
- operational and environmental constraints will increase

Public Recognition

The 20th century saw the UK's stock of large dams almost treble. Most required skill and ingenuity similar to my arbitrary selection. Why then are dam engineers and their works not more widely recognised? And does it matter? One explanation is that a job well done attracts little attention in the press and elsewhere. Perhaps the lack of recent disasters is one reason for the public's apparent disinterest in reservoirs.

We would need the help of a public relations expert and perhaps a psychologist to understand fully why dam engineers are not more widely acclaimed. However there are clues close to home. Last year the 'New Civil Engineer' presented a series on Civil Engineering achievements of the 20th century covering each branch of civil engineering - bridges, marine works, dams, etc. In most sectors they named outstanding projects and individuals. One exception was Dams. The journalist who wrote the feature entitled 'The Dam Builders' mentioned no engineer by name and only two firms of designers, Sir Alexander Gibb & Partners for Kariba and Babtie Shaw & Morton for Kielder. Though Mangla was pictured there was no mention of Binnie & Partners or Geoffrey Binnie.[24] However the readers, the civil engineers, acknowledged some major contributors to dam engineering. In the magazine's poll to find the 'Civil Engineer of the Century' Ove Arup was awarded the title. The next four places included three engineers with dam connections, Professor (now Sir) Alec Skempton, Professor Karl Terzaghi and Sir Angus Paton. When individual dam engineers are not highlighted by technical journalists the general public can be forgiven for not knowing their names in the way that they know the names of leading architects.

Dam engineers work in teams, exchanging experience and ideas. Designs and construction methods evolve from calculations and assessments, and from formal and informal exchanges of views and it is often difficult to recall which member of the team had which particular bright idea.

Does the lack of recognition of engineers matter? The answer is "Yes" if it leads to Society being deprived of the benefits of well-built and well-managed reservoirs. This suggestion may seem alarmist but the recent involvement of BDS in providing information to the World Commission on Dams suggests otherwise. The Commission was set up in response to opposition to proposed reservoirs in developing and under-developed countries. To enable it to form a considered view the Commission has been gathering views for and against dams. The submissions from opponents have vastly out-numbered those by supporters. We may believe that the value of reservoirs is self-evident. This is not the case.

Perceptions change with time.

In the UK in the second half of the 19th century, disease diminished and industrial prosperity grew and it was recognised that this was due in large measure to harnessing water in reservoirs. Each locality was proud of its reservoir. Now reservoirs are taken for granted by the community and it falls to reservoir professionals to advocate their value following the example of Rod Bridle and Geoff Sims whose submission to the Commission on the benefits of United Kingdom dams was published in "Dams and Reservoirs" last year.[25]

Once reservoirs are created it is vital that they are maintained properly and there is a need for dam engineers to accept a role as advocates for adequate expenditure on existing reservoirs. The alternative to proper management and maintenance may be as dramatic as it is unacceptable - the collapse of a major dam. In other industries major disasters involving loss of life have concentrated minds on the need to ensure that the best practices are being adopted at all times. One of our tasks is to ensure that the UK reservoir industry does not need the spur of a disaster to ensure that the best practices are adopted. The expertise in the UK in the maintenance of reservoirs is acknowledged widely and dam engineers must take an active role in ensuring that this expertise is used wisely. Dam engineers must do more than complain, they must explain. They must explain how increased expenditure can improve the flexibility of the reservoir system, prolong the life of our reservoirs and improve public safety.

Reservoir Safety Legislation

Despite our concerns over lack of recognition, reservoir engineers are in a special position compared with other civil engineers. The panels of engineers under the Reservoirs Act have no parallels in other branches of civil engineering in the UK and it is useful to remind ourselves how this situation has come about.

The collapse of Bilberry dam in 1852 led to an Act of 1863 which entitled any person concerned about the safety of a reservoir to submit a complaint to a magistrate. Dale Dyke reservoir failed the following year and this time the inquest jury recommended 'governmental inspection of all work of this character; and such inspection should be frequent, sufficient and regular.'

Sixty-six years passed and more lives were lost before the 1930 Act introduced inspection. Forty-five years later the current Reservoirs Act introduced supervision. So 136 years after Dale Dyke do we have wholly satisfactory reservoir legislation? If not, it is time now to lay the groundwork for the next Reservoirs Act. In February 2000 at the launch of the new Guide to the 1995 Act [26] Richard Vincent of the Department of the Environment, Transport and the Regions encouraged dam engineers to identify possible straightforward improvements to the existing legislation with a view to their incorporation in a Water Bill in the near future.

However we need to ask also "What should be covered in the next Reservoirs Act, the Reservoirs Act 2000 and X, to reflect the world in which we live and work?" My list of topics would include the role of Panel Engineers; acceptable standards of safety; the contents of reservoir reports and records; the consequences of changes in procurement methods and of privatisation; the role of review panels and transparency.

Panel Engineers

In some respects present practice is at odds with the assumptions underlying the Act. The system is built on the broad shoulders of individual Panel Engineers. For example one 'Construction Engineer' is responsible for the design and supervision of construction of a new reservoir. In this we are out of step with most countries and when challenged, our response is that there have been no deaths due to an escape of water since the 1930 Act. There is justification for linking the satisfactory safety record to the Panel Engineer system but developments in soil mechanics and flood forecasting should also take credit. The present system assumes a Panel AR Engineer who designs all aspects of a reservoir. This may have been true of Bateman and his Victorian colleagues. It is not true now. The modern Construction Engineer is a team leader, a spokesman. When a client requires a new dam or remedial works, he normally appoints a firm of Consulting Engineers. The individual Panel Engineer will be an important factor but not the only factor in the appointment.

Certificates and Reports

Once employed the Panel Engineer is required to put his name to unrealistic statements. For example, his Final Certificate states 'the reservoir may safely be filled with water'. This reassures the client and the public. But what does it really mean? I suspect that Panel Engineers read 'safely' to mean something like 'as safely as is reasonably practicable'. If this is what is meant, then perhaps the next Reservoirs Act will allow the Construction Engineer to say something like 'Having considered the need for the reservoir to be as safe as is reasonably practicable I am satisfied that the reservoir may be used for the storage of water'.

The initial impetus for the Reservoirs Acts was concern over the ability of dams to discharge extreme floods safely. Hence the requirement that Inspecting Engineers' reports include findings on the adequacy of the overflows and related matters. There is no similar requirement to include findings on other major causes of dam failures such as the structural adequacy of the dam or its susceptibility to internal erosion. It is difficult to justify the continuation of these omissions.

Procurement

Current legislation has no specific requirements regarding the contractual arrangements for reservoir work and this is another aspect worthy of scrutiny. To find evidence of how critical the method of procurement can be to the safety of construction works we need look no further than the collapse of the Heathrow Express Tunnel.

Reservoir work is now procured by a range of methods and reservoir safety legislation needs to take account of current procurement methods and deal with any problems while they are potential rather than actual. In essence it is essential to be satisfied that the individuals or bodies charged with the safety of a new reservoir do have the authority and the resources to fulfil their duties.

When the Reservoirs Act was drafted there were three key roles in construction contracts - the owner, the construction engineer and the contractor - and one set of Conditions of Contract, the I.C.E. Conditions. Cases of in-house design by owners' staff were rare exceptions. The Engineer was generally involved from the start of feasibility to the issue of a Final Certificate.

In recent years there have been various innovations in procurement. On the one hand there have been contracts for engineering services in discrete packages e.g. planning and outline design; detailed design; supervision of construction and, conversely, design and construction have been amalgamated in design and build contracts. Assigning outline design, detailed design and supervision to water-tight compartments compounds the task of communication and increases the chances of overlooking some vital factor.

While I have not heard of design and construct contracts for impounding reservoirs, they have been used for service reservoirs and it is important to learn from the problems which have emerged. When an owner procures the work on a design and construct basis, the designer can be relegated to a secondary role as a design sub-contractor. In extreme cases there can be friction between the *de facto* designer of the works and the Construction Engineer under the Act who can be side-lined and regarded with the same irritation as building control engineers who approve plans for building works.

Privatisation

Using 'the reservoir industry' as a convenient term to include storage reservoirs for water supply and power generation, the industry passed from the private sector to the public in the 19th and first half of the 20th century. Now with privatisation it is back in the private sector. This is unlikely to be the end of the swing of the pendulum from private ownership to public and back again. At present some water companies are investigating alternative ways of organising their businesses. These suggestions include returning the water infrastructure, including the reservoirs, to bodies owned by the customers. With these discussions taking place it is appropriate to consider the impact of privatisation on our reservoirs.

We have all read that railway safety is alleged to have suffered following privatisation. I have not seen similar allegations in respect of reservoir safety. But then we have not had the equivalent of the Southall and Paddington rail disasters. To ensure that safety is not hampered we need to take account of the changes brought by privatisation.

Privatisation has introduced a requirement to justify expenditure on reservoirs in a more structured fashion and financial discipline is a sensible part of managing our reservoirs. However, difficulties arise when engineers attempt to provide cost/benefit justifications for expenditure on reservoir safety. It is usually straightforward to estimate the costs in money terms but this is not the case with the benefits. It is difficult to estimate the number of lives which may be saved or the damage which may be avoided by a particular measure and there is no clear guidance on the value to place on each life. In appraising road safety measures DETR places a value of over £900,000 on a statistical life but different values are used in other industries. In the UK, I have not heard of financial appraisals of reservoir safety measures related to the potential value of lives saved but I suspect that their time will come. At present most remedial works take place in response to recommendations in the interests of safety in Inspecting Engineers' reports. However, this need not and should not be the only trigger. Continuing developments in asset management and risk assessment techniques enable us to take a longer-term view of the benefits of upgrading reservoirs, ensure that the optimum rather than the minimum measures are adopted and enable work to be prioritised on a rational basis. The recent reconstruction of the crest of Lednock Dam, a concrete gravity dam, exemplifies this approach[27]. The Inspecting Engineer who reported on defects in the crest did not consider that the situation required the reconstruction of the crest as 'a measure recommended in the interests of safety'. However the owner, Scottish & Southern Energy Ltd, took a wider view and proceeded to rebuild the crest.

The financial pressures of privatisation have led to a reduction in the number of staff employed on reservoir maintenance and safety. The reservoir keeper working and often living on site has been replaced by an operative responsible for a group of reservoirs. And no matter how conscientious he is, he cannot be checking on the upstream pitching on Reservoir A when he is in his van between Reservoirs B and C. There is reliance on instruments but the need for systematic checking and re-calibration of such instruments can be overlooked. Instrumentation is a valuable supplement to regular visual examinations, it is not a substitute.

The reductions in engineering staff apply at all levels. The amount of time which senior managers devote to reservoir safety has diminished. Not many years ago, the Head of Engineering or the Divisional Manager would attend every Statutory Inspection and get a first hand report of the condition of each reservoir. Not now. I suspect that he is alerted only when major expenditure is imminent.

Review Panels

I have already mentioned the Panel of Experts at Broomhead Dam. Review Panels are now used more frequently and in a more proactive role, as a method of avoiding difficulties rather than reacting to them. The next review of the Reservoirs Act may formalise the position of Review Panels. If public safety is part of their role, perhaps the appointments should be made by the Secretary of State or subject to his approval.

Transparency

'Transparency' is part of current jargon. In respect of reservoirs this means that information on the risks attached to reservoirs should be available to the public, which is not the case at present. The 1975 Act took a backward step in that it removed the need for Inspecting Engineers' reports to be open to public scrutiny. It will be no surprise if this requirement is reinstated and in a way which requires comprehensive risk assessments to be included in reservoir records.

Technical Challenges

Coming full circle I return to technical topics, particularly some of the subjects likely to occupy the profession in the next few years. Most are continuations of familiar themes but there are new subjects also.

Remedial works due to ageing or higher standards are likely to increase and the ICOLD Bulletin on Rehabilitation of Dams will be valuable to us. Picking just one topic, masonry pitching deserves special mention. On many embankment dams the stones have been breaking up due to ice and wave action over the decades and have slipped for this reason or because the face has settled. The durability and effectiveness of these faces now merits closer attention.

Just when most of us thought that projected floods could not get bigger, the Flood Estimation Handbook has re-opened the debate on design floods.[28] The controversy is likely to continue for some time and it may well lead to the revision of 'Floods and Reservoir Safety'.

Two years ago Andrew Charles brought us up to date with developments regarding internal erosion. This continues to be studied world-wide and Canadian, US and Swedish engineers have recently embarked on an ambitious programme aimed at identifying internal erosion before it reaches a critical stage. DETR have also included this in a research contract.

Embankment stability has not been a high profile topic in recent years and so I will spend a little more time on it and link it to my concluding topic, risk analysis.

Assessment of Embankment Stability

We take for granted that dams should be designed with an adequate factor of safety. In the words of David Coats, one of my mentors in Babtie, Shaw & Morton and a previous Binnie lecturer, the Factor of Safety is also a Factor of Ignorance. We need an allowance for what we do not know as well as what we do know.

We have inherited dams which were not designed or built to current standards. In particular they were not designed to provide a calculated factor of safety and often the factor of safety has not been investigated at all. If dams look stable it has been assumed that they have adequate factors of safety. I doubt if this approach will survive long into the 21st century.

The publication of the Seismic Guide and the Application Note to the Guide.[29,30] led to stability checks of a number of dams. The first stage in the checks in the checks has been an analysis under normal in-service conditions and the factors of safety revealed have often been lower than expected. There is no indication that a major dam stabilisation programme is required but there are grounds for including a stability analysis in the records for all large raised reservoirs. If so, how will the stability be assessed?

For the past half century the factor of safety calculated by a limit equilibrium analysis has been the accepted method of assessing stability. Now limit equilibrium's role as the sole or even the best method of analysis is being questioned. The factor of safety faces two challenges. Firstly, from finite element analysis which provides the ability to calculate how a dam will settle (or rise) and move upstream /downstream and how the stresses will change as it responds to changing loads. The other challenge comes from advocates of probabilistic risk assessment who suggest that the factor of safety approach disguises the fact that even well-built dams are a hazard. The probabilistic approach argues that, since failure cannot be completely ruled out, engineers should define and aim for a target probability of failure as part of the design process.

Risk Analysis

Risk analysis has always been implicit in building and owning dams but in recent years it has become a subject in its own right. It is twelve years since the Department of the Environment funded a feasibility study into "Probabilistic Risk Assessment for Reservoirs" and Professor David Bowles addressed a BDS meeting on "Risk Assessment for Dam Safety Evaluation". The present situation is similar to limit equilibrium analysis in the 1930's - the terminology is not agreed and only a small number of countries are investigating its use. The CIRIA report, "The hazard and risk posed by UK reservoirs"[31], is a useful step forward and it has its parallels in other countries e.g. Australia, Canada and the United States. At present the ICOLD Committee on Dam Safety is preparing a Bulletin on risk assessment as an aid to dam safety management and I hope it will help to standardise both the terminology and the technology and be a useful guide for engineers on appropriate risk analysis techniques. Risk Analysis is already accepted as a useful tool in prioritising expenditure to ensure that safety and other benefits are maximised and the years ahead will clarify further roles.

The reservoir industry's position under the Reservoirs Act has led us to assess reservoir safety in the UK with little reference to other industries. This situation should not be taken for granted. It has not been necessary to consider whether reservoirs are built and maintained to equivalent safety standards to, for example, the petrochemical and nuclear industries but questions of this type are beginning to be asked. The use of risk analysis techniques may be a by-product of the drive for transparency. One of the roles of risk analysis may be to provide a framework and methodology to enable the reservoir community to demonstrate formally that its overall standards of safety match other 'high hazard' industries. Last year the Health and Safety Executive published a discussion document "Reducing Risks, Protecting People".[32] At the BDS seminar on "Risk Management in Dam Safety Practice" in May 2000, the document's author, Dr Jean Le Guen, suggested that a standard applicable to all industries could be that the risk of an event causing more than 50 deaths should not exceed 1 in 5000 years. At present we do not know how our reservoirs would fare in cross-industry comparisons and against such a standard and it would be prudent to prepare for comparisons of this type.

At present we do not have values for the acceptable risk of dam failure for each category of dam in the UK. While the public and politicians have a role in such discussions, I believe it is a topic on which dam engineers should take the lead.

If, say, 1 in 5000 years is the acceptable risk of failure for high hazard dams in respect of any cause how does this relate to the acceptable risk from specific causes such as over-topping, internal erosion, instability and settlement not to mention unforeseen events? We are familiar with the use of probabilities in selecting design floods and seismic events. We need now to combine this information with work on instability and internal erosion to arrive at a total picture of the risk posed by a dam. This is what the public needs. To tell them that a dam has been designed for a Probable Maximum Flood and that the embankment has a factor of safety of 1.5 is of limited value. What they should be told is the risk of the dam collapsing from any cause.

Attempts have been made to establish the link between the probability of failure and the factor of safety in stability analyses. One example is the design of the embankment dams on the James Bay project in Canada[33]. The dams vary in height and, the designers found the relationship between the factor of safety and probability of failure varies with the height of dam. They adopted 1 in 1000 years as the target probability of slope stability failure and for the 12m high dam used on Figure 5, this equated to a factor

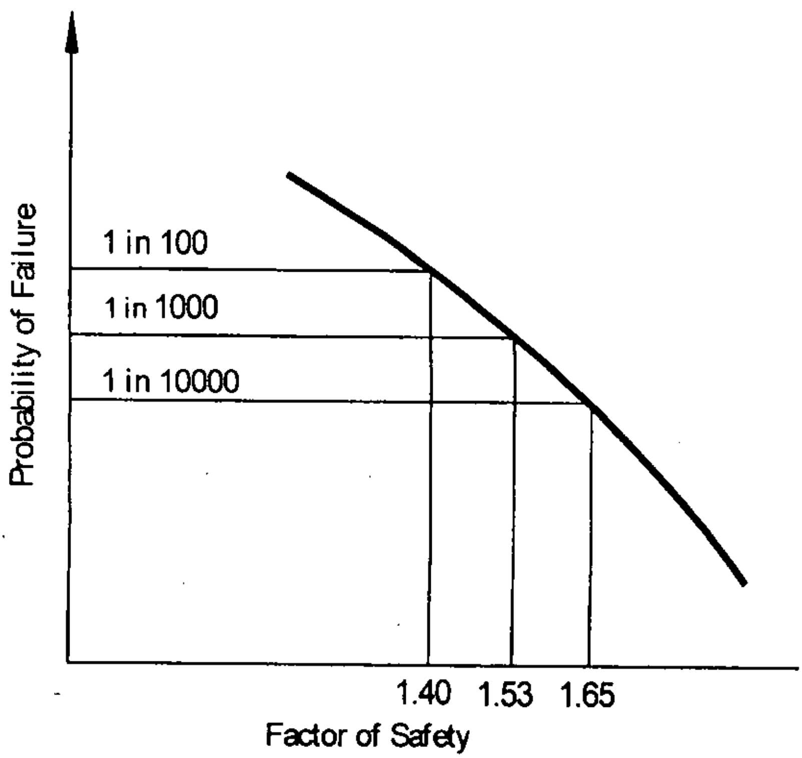

Figure 5. Relationship between Probability of Failure and Factor of Safety on Embankment at James Bay Project, Canada

of safety 1.53. However for a 23m high dam with a large berm the same target probability, 1 in 1000, was achieved with a factor of safety of only 1.26. In the United Kingdom we have not yet investigated this relationship - perhaps it will feature in a DETR Research Programme in the near future.

Failure due to seepage i.e. internal erosion and piping is probably the most difficult element to quantify. However Professor Robin Fell of Australia has made a start and he has quoted probabilities of failure due to seepage such as 1 in 5000 years for a homogeneous dam and 1 in 50,000 years for an earthfill dam with vertical and horizontal drains[34].

There is a long way to go but the building blocks are being assembled for a comprehensive assessment of probability of dam failure.

Summary

In conclusion, the main points I have tried to make are:

- Dam engineering is a developing science
- Dam engineers have key roles as advocates for reservoirs
- Lack of recognition can lead to lack of investment
- Reservoir legislation should reflect changes in Society's expectations and in the industry
- Formal risk analysis is gaining acceptance
- Reservoir safety assessments should be comprehensive, transparent and comparable with other industries

Acknowledgements

I am grateful for the encouragement and suggestions I have received in preparing this lecture. As always the Babtie Group have been immensely supportive and to all the individuals involved from Babtie and elsewhere, I would like to assure them that I do not take their help for granted.

Conclusion

In this lecture, rather than presenting answers I have posed questions. In doing so I am confident that the dam engineers of the 21st century, with the British Dam Society in the lead, will find the answers.

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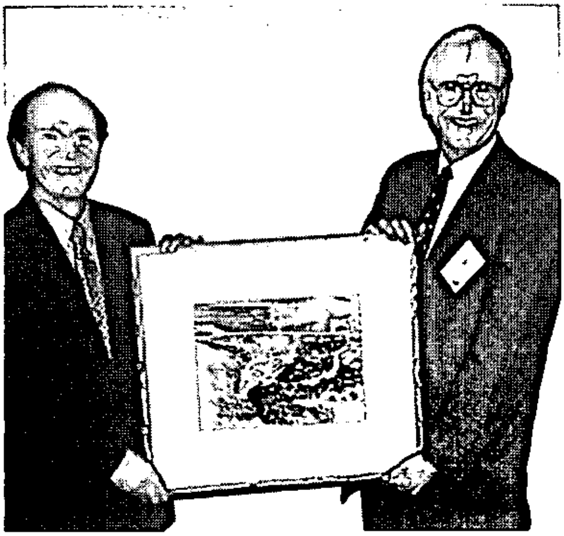
VOTE OF THANKS
by Dr. G. P. Sims



Alan Johnston being presented with a painting of Roadford dam by Rod Bridle, Chairman of the British Dam Society.

Ladies and Gentlemen, I am particularly pleased to have been asked to speak on your behalf to offer Alan our sincere thanks for what has been a fascinating lecture. I also want to include Anne in my thanks. I know how many hours it takes to prepare a one hour lecture, and I know too the value of the support she will have given him during his work.

I know that it is conventional to say, in a vote of thanks, that the lecture was fascinating. But consider the case. The lecture has fulfilled the fundamental requirement of a Binnie Lecture. It has both informed us and provoked us. Alan has encouraged us to ponder, to find the patterns in the development of dam engineering during the last century. He also provokes us to think hard about how we, as civil engineers and as the British Dam Society, should behave in future to raise our profile. He encourages us to believe that to do so is in the interests of the community at large. He wishes us to do this, not only because we deserve it, but because otherwise the important aspects of the safety of engineered structures will not receive the attention it deserves. His observations are particularly timely in view of the review of strategy that BDS has recently started under the chairmanship of the Vice Chairman Andy Hughes.

The first half of the lecture was an overview of the development of British dam engineering in the 20th century from the perspective of one of the most gifted of dam engineers alive today. You can distinguish engineers of quality by their ability to write well and by their ability to sift a mass of evidence and to identify the important trends. Alan has done this for us through his brief accounts of seven dams: Seathwaite, Glen Shira, Dungonnell, Braden, Carsington, Megget and Ladybower. By a few deftly executed sketches he has revealed to us the development through the century of:

- Economic use of materials after war. Why else would one go to such lengths to reduce concrete volume as they did when designing Glen Shira as a buttress? Why else would James Banks have designed Allt-na-Llairige as a prestressed dam ?
- The increasing realisation that SI is key to success in the design and maintenance of a dam.
- The developing understanding of soil mechanics in design and of heavy plant in construction. Without systematic compaction Ladybower has already settled 1600mm. Indeed this is one of the problems with Hume dam on the Murray River in Australia, where the compaction was described in terms of the number of passes of a Clydesdale horse.
- The gradual acceptance of the use of pfa and other additives to concrete, introducing the concept of RCC, of which there is still no major example here in the UK.
- The improving analysis including Finite Element. It will be important to make sure that we train our engineers so that they can make full use of the power of the computers they will have. How many of us, in searching for a location of low cost engineering analysis abroad, have been struck by the ease with which these tools are used, and the real difficulty in finding people who understand the results to make good use of them.

Alan's last point was the developing importance of rehabilitation. This is an area of particular interest of mine, and I am still limp from the production of the ICOLD Bulletin on the subject. I share Alan's view that the future in rehabilitation lies in developing methods that can be carried out while the reservoir is still full. I will take note of, and report to ICOLD for the successor committee Alan's observations on the protection of upstream faces. I am glad that our bulletin at least covers his remarks in part.

Alan is one of the best placed to encourage us to start thinking about the next generation of reservoir safety legislation. It is particularly appropriate that he should make this suggestion to the BDS. It is a good opportunity for

BDS to raise our profile nationally. This must surely be one of the elements of our strategy as it develops during the year. It is surely right to move on from the polymathic Panel Engineer towards the recognition that much human activity these days is carried out by teams. The UK is unusual in not requiring the safety inspection to contain any specific reference to stability or internal erosion for example. We must come to terms with the increasing and, on the whole welcome, involvement of private finance into the development of infrastructure projects. After all it provides a source of delight and income for us engineers.

This is another area where Alan suggests that BDS can take an initiative. Owners who are involved with modern procurement have a great need for guidance on how to preserve the safety of their property through out all the stages of the process. BDS Guidelines for them would, I am sure be welcomed.

The final item on Alan's formidable agenda is that of risk analysis. This is an area of burgeoning activity. ICOLD is studying it in the Dam Safety Committee, and even the Rehabilitation Committee has a section on it, in connection with the prioritising of maintenance. CIRIA will soon give birth. The next big prize will be for a quantifiable approach to internal erosion.

So, ladies and gentlemen, I believe we have been given a most thoughtful and provoking Geoffrey Binnie Lecture. This is exactly what the founding fathers had in mind. Knowing something of writing speeches and papers, I know how many hours thought has gone into the preparation of the lecture, and how much accommodation has been offered to Alan by Anne. We are grateful for the result. Please join with me in expressing our appreciation to Alan and to Anne.

CONFERENCE CLOSING REMARKS AND VOTE OF THANKS

by Mr. R. C. Bridle, Chairman of the British Dam Society

Now it's my duty to sum up the Conference. I think we can say that the BDS is a vibrant Society. I've been impressed by how conscientiously everyone has attended and participated in our sessions. When I see now, at mid-day on a sunny Saturday, that the hall is full and everyone is paying attention, I wonder if there is a secret ingredient in dams to keep us so absorbed? They certainly have an attraction and there is always something new to learn about them. They also pose heavy responsibilities on those charged with keeping them safe and we are all aware of the consequences if they go wrong.

Although the average age of those in the hall is high, I am pleased to note that old or should I say middle age is not the reason why we are absorbed. There are young members here, and more women members than before, though too few. Emma Baker, research student from Bristol University, is our youngest delegate. I would like to emphasise that the BDS is not exclusively for engineers, it is for all professionals with an interest in dams and reservoirs, and it is pleasing that our non-engineer members are growing. Another category of membership that I would like to grow is those from the enforcement authorities. There are some pioneers from authorities with us today. I hope they have found the conference useful and will encourage others in similar positions to join BDS and come to future conferences. I would also very much like to welcome our senior members. It is very nice to have Derek Knight, Ted Gosschalk and Dr Arthur Penman with us.

We've been fortunate to have heard such an excellent Binnie lecture. We now know what it was that was "taken for granted". Alan Johnston has given us insights into so much experience and introduced us to many issues. His point that we should try to make sure that the usefulness of reservoirs is no longer taken for granted by giving them a higher profile, challenges us in communication. We might take a lead from the WCD's outreach programme and try to be more positive and pro-active in communicating.

Achim Steiner's address on the World Commission on Dams made me feel optimistic about the likely outcome of the WCD. I very much hope that ICOLD can take up an effective post-WCD role. We should all note that the first launch of the WCD documents is going to be in London at a venue not yet selected on the 16th November 2000. Also, BDS and ICE Water Board are in the process of organising a symposium to look at how the dam community based in UK should respond and develop from the WCD guidelines. A date has not yet been fixed, but will probably be early February 2001.

The Conference has had an emphasis on change and innovation using technologies and techniques used elsewhere and applying them to dams. We are very fortunate in UK that we have a responsive research programme largely funded by the Department of Environment, Transport and Regions and our thanks to Richard Vincent for being vigilant and responsive to our needs in that direction.

Risk Assessment and Probabilities of Failure

Risk management is one of the management technologies that will be increasingly applied to dams. The CIRIA report will shortly be published, thank you to Henry Hewlett for giving us an insight into it during the Conference. Look out also for Neil Sandilands' reports on the Risk Day held at ICE on the 18th May 2000. Des Hertford and Ray Stewart from BC Hydro in Canada addressed us, as did Dr Le Guen of the Health and Safety Executive and Henry Hewlett from RKL-Arup reporting on the CIRIA Risk Management Guide. It was very interesting to hear the Canadians praising various HSE publications as providing the philosophical and intellectual framework for our thinking in dealing with our safety responsibilities. They particularly referred to Dr Le Guen's "Reducing Risks, Protecting People" (commonly referred to as R2P2). You will be very interested to know that the BC Hydro's work is no longer following the Quantitative Risk Assessment route. This is because they have found that this is not fruitful. They are now following the Failure Modes Effects (and Criticality) Analysis, FMECA. This is recommended in the CIRIA Risk Management Guide following on from its initial application by Scottish and Southern Energy.

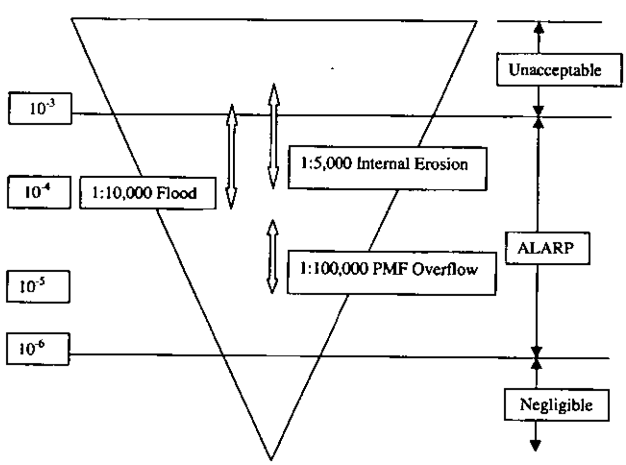
Coming out of the discussions on the 18th May and various things that have been said at this Conference, I would like to share some thoughts with you, trying to quantify how safe or unsafe our dams are. I fear the conclusion is that they are not as safe as we'd like to think, they may even be unacceptably unsafe. I'd like you to take careful note of this because we spend much time discussing rare events such as 1 in 10,000 year floods and I fear that this may give the impression that the odds against a dam failing are around 1 in 10,000.

I have prepared an ALARP diagram to illustrate my concerns. Very crudely it can be said that the boundary between the unacceptable region and the least safe ALARP risk equates to a probability of 1:1,000, and the boundary between the lowest ALARP risk and the negligible risk region is taken to be a probability of 1:1,000,000. These limits and the intermediate 1:10,000 and 1:100,000 lines of probability have been shown on the ALARP diagram. I have also shown the position of the probability of dam failure from two families of failure modes (the FM in the FMECA acronym).

If we consider the family of failure modes that relate to the design spillway flood at a dam we know, for instance, that the PMF flood might be equivalent to a 1 in 100,000 event. However, our estimate of PMF may be too low, in which case our probability of failure will increase, and penetrate deeper into the ALARP region. Or we may find that we have designed a spillway for a PMF but the dam itself would withstand some over-topping and consequently the probability of failure may be a little better than 1 in 100,000. This gives a range of probabilities of failure from the family of failure modes related to dealing with floods. Note that it does not penetrate the negligible area at the bottom of the ALARP diagram (although one would have to say that philosophically the PMF is intended to be the biggest flood ever, and is perhaps in the negligible region by definition).

Since the conference I have learnt that the 1 in 10,000 year rainfall estimated by the Flood Studies Report may be very much smaller than that estimated using the new Flood Estimation Handbook. In an extreme case, the 1:10,000 FSR rainfall was shown to be only 1:1,500 using FEH. Any comfort we may have felt in an apparently very remote possibility of failure has been

Figure showing range of probabilities of various failure modes



greatly undermined in this case. If the spillway in this case was not entirely sufficient for the design flood, the probability of failure of the dam through overtopping may have fallen from 1:1,500 to less than 1:1,000 - and into the "unacceptable zone".

If we consider internal erosion, Alan Johnston cited in his Binnie lecture Robin Fells' estimate of a 1:5,000 probability of failure by internal erosion of a dam without modern filters. Now 1:5,000 is an estimate. Dams outside Australia may be more or less vulnerable to internal erosion than Fells' sample. Our stock of dams in UK will probably be shown by the new risk assessment process in the CIRIA Guide to be vulnerable to internal erosion. Applying a range to the 1:5,000 estimate, we can see on the ALARP diagram that some dams may fall into the unacceptable zone when considering the family of failures associated with internal erosion and piping.

These are sobering thoughts. They are made more so when we reflect that I have spoken in terms of the probability of dam failure, when the probabilities are actually intended to be probabilities of lives at risk. Therefore if the failure of a dam would put more than one life at risk, measures must be taken to reduce the probability of failure by a factor equivalent to the number of lives at risk. This relationship is shown on F:N plots (where F = probability of failure and N = lives at risk). We must try to evaluate, however crudely, the probability of failure arising through the various modes. We should then carry out safety measures to reduce the probabilities at least to ALARP levels, preferably to levels proposed by various authorities on F:N plots.

We should take care not to be led into complacency about how safe our dams are by thinking only of failure modes associated with phenomena, such as floods and earthquakes, where rare event statistics are commonly used. Other failure modes are less easily placed in a statistical context, and seem to have a greater likelihood of occurrence. Our challenge over the coming years is to develop methods of identification, investigation and analysis of those modes, to identify the risk they pose and develop the means to retrofit protective measures if they prove necessary.

Environmental Analysis
Our Conference has had an excellent session on environmental assessment and mitigation. I am so pleased that we are now integrating these aspects of science into the routines of dam development, maintenance, rehabilitation and re-development. I encourage environmental members to continue to

develop assessment methodologies, they are very necessary to assist environmental scientists to deal with the demands we now make of them as applied scientists. It is interesting to reflect on the rapid changes achieved in this direction when we remember that ecology was a purely observation science only a few years ago. I would like to see more numerate sustainability criteria being applied in our environmental assessments, for example, comparisons of greenhouse gas generation when looking at sourcing of fill materials locally or from distant sources.

Improving the Effectiveness of Dams and Reservoirs
As our stock of dams ages we have to do more maintenance and rehabilitation. Achim Steiner highlighted the potential for improving the efficiency of our dams and reservoirs. The parallel in UK water supply is leakage reduction. Making better use of existing dams reduces the need for new ones, of course, but presents many challenges for us in developing methods to improve their performance.

It's good to see that we are using modern analytical methods, as at Ladybower, and new methods of investigation, as at Rotton Park and Guide Reservoirs, to help us to maintain and renew our dams. We have heard about slurry walls, membranes installed under water and other methods of repair.

Continuous Professional Development
Although it seems the world of dams is an old-fashioned one, we must apply innovation and new technologies to them and this means that we really have to keep up to date. We need to come to conferences, buy computer programs, read 'Dams and Reservoirs', serve on steering groups and come to meetings. In short, you must devote time to CPD, continuous professional development. Remember that CPD does take up time and make sure that your rates provide some extra funds for it. Future re-appointment to the reservoir safety panels will require that you demonstrate that you do CPD and are up to date. Even without all these sticks, we owe it to dam owners and the public to be doing a modern professional job on our dams.

Next Conference - Dublin, September 2002
I am very pleased to be able to tell you that we have had a very kind invitation from our Irish members, Jack O'Keefe of the Electricity Supply Board and the Dublin Corporation water people in particular. They have invited us and we're very pleased to accept their invitation, to go to Dublin from the 3rd to 6th September 2002 for our next Conference. There has been a series of happy coincidences which have made 2002 an extremely suitable date

for Dublin. There are several dams near Dublin and at some of them new spillways are being constructed. We should be able to see those in progress. Also, it happens that Andy Rowland, one of our committee members, is the project manager for that work and he has volunteered to be chairman of the organising committee. Of course he will be going to Dublin frequently and be able to co-ordinate the arrangements in Ireland and GB. Our Irish members have managed to find the money to visit us every two years, but we have some concerns about numbers of GB people who will go to Dublin because of the extra travel cost (although air fares as low as £29 return are available!). Please start saving up now! We will try to keep travel costs down and we will be looking at arranging group fares, for example. We will perhaps re-arrange things slightly to include a Saturday night because that makes the fares lower. We hope that more accompanying persons will come and perhaps have a few days holiday afterwards and, of course, we are hoping that more people than usual from the island of Ireland will come. There are a number of mine dams in Ireland and we hope that some of the mine dam community will be encouraged to come to our Conference. Many members have been very enthusiastic about going to Dublin and its not just the Guinness, my wife wants to go to the Abbey Theatre.

ICOLD Beijing, September 2000

At ICOLD in Beijing, we will be proposing Geoff Sims for President. He has two opponents, Mr Varma from India and Mr Mochabelele from Lesotho. ICOLD will be facing, whatever response they make to WCD, a period of change. During such a period, the President will need to be strong and well supported. Geoff will have our support, he will have the support of his employer, Brown and Root, and we can call on support from our government. ICOLD will need these resources and we think Geoff can offer just that little bit more of them than his rivals. So good luck to Geoff in the elections. They are on the 17th September.

I wanted to say something about the UK's role in ICOLD. ICOLD is really the vehicle for the dissemination of good practice in dams. ICOLD Bulletins are like CIRIA or DETR publications, they present good practice. Dams bring large scale benefits to the needy. In UK we have much to offer on good practice. BDS encourages people from UK with expertise to participate in ICOLD. The most recent new recruit is Rodney White from HR Wallingford who will take up the new UK place on the ICOLD Technical Committee on Sedimentation, another example of how UK serves the world through ICOLD.

Final Thanks

Cardiff Bay Barrage

Thanks to our friends at the Cardiff Barrage for showing us round. Many of us work on dam safety under the Reservoirs Act 1975 and the Cardiff Barrage, like others, seems to be a reservoir that somehow escapes being within the Act. I know that legal opinion supports this and from a practical dam safety point of view the downstream risks are limited. I don't know that a rush of water through the Barrage into the sea would pose a great risk and there is no substantial reason to protect the public from the hazard in the way that the Reservoirs Act does for the hazard posed by 'proper' dams. However, the Barrage encompasses every aspect of dam engineering, some with a vengeance, for example, the wave protection on the sea side. There are few reservoirs that would be subject to the scale of waves that occur there. The gates and the flood flow release mechanisms are also massive and more challenging than we normally meet on reservoirs. The enlightened approach to environmental mitigation and accommodation work is also impressive; it will be nice when the critics stop carping about what has been lost and appreciating what has been gained. It is fitting that the new Welsh Parliamentary Assembly Building will overlook the barrage, the sea and the lake. Congratulations on a very impressive project, good luck with the finishing touches and future operations and very many thanks for showing the barrage to us in such detail.

Organisers

And now our final thank you's.

To the technicians, the ICE Conference office, Barbara O'Donohue and Anita Ashley, Lisa Stafford, our Secretary at ICE, sadly leaving us soon, and especially to the Organising Committee of Jim Millmore, Peter Kite, Andrew Robertshaw, Keith Gardiner, Barry Straughton, Colin Hunt and Paul Tedd for giving us such an excellent and friendly conference.

DEVELOPMENTS IN RESERVOIR HYDROLOGY

INNOVATION IN HYDRAULIC STRUCTURES

DETR RESERVOIR RESEARCH PROGRAMME

RISK AND RESERVOIR SAFETY

ENVIRONMENTAL IMPLICATIONS - BENEFITS AND DISBENEFITS

LESSONS LEARNT FROM OVERSEAS EXPERIENCE

INVESTIGATIONS AND REMEDIAL WORKS TO EXTEND ASSET LIFE

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GEOFFREY BINNIE LECTURE 2000 "TAKEN FOR GRANTED"

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