The Safety of Small British Reservoirs

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SYNOPSIS. This paper discusses the risk posed by small, non-statutory reservoirs in Great Britain and the benefits that arise from carrying out simple risk assessments of such reservoirs. By drawing on two major studies carried out on behalf of the Environment Agency involving visits to, and assessment of, approximately 400 non-statutory reservoirs in England and Wales, the paper aims to describe and discuss:

- Appropriate methods of qualitative risk assessment for large portfolios of reservoirs;
- The risk posed to life and property by non-statutory reservoirs relative to statutory reservoirs;
- The use of reservoir condition assessments to improve flood risk management; and
- The implications for possible amendments to reservoir safety legislation in Great Britain.

INTRODUCTION

Since the introduction of reservoir safety legislation in 1930, no dam failures causing loss of life have occurred in Great Britain. The introduction of the Reservoirs Act 1975 in the 1980's introduced the role of the Supervising Engineer to provide continuous supervision of reservoir safety matters. This has been beneficial in identifying and resolving reservoir safety issues as well as providing a means of promoting safety legislation compliance by reservoir owners or users. However, two recent studies carried out by Halcrow Group for the Environment Agency suggest that there remains much scope for improvement in the current legislation with respect to small reservoirs that endanger lives or have the potential to cause significant damage. The purpose of this paper is to describe the scope and findings of these studies and to discuss the results in light of the current reservoir safety legislation.

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SOUTH WESSEX FLOOD RISK ASSESSMENTS OF RESERVOIRS

Project Aim

This study was carried out on 104 reservoirs in the South Wessex Area (mostly in Dorset and South Wiltshire) between 2005 and 2007. The breakdown of these reservoirs by type is shown below.

- 85 non-statutory reservoirs (less than 25,000m^3); 19 statutory reservoirs (more than 25,000m^3)
- 97 impounding reservoirs, 5 non-impounding reservoirs, 2 service reservoirs.

The main aim of the study was to evaluate and rank the reservoirs in terms of likelihood of failure. This information was then used to inform the Environment Agency's emergency and contingency planning provisions. In a small number of very poor condition non-statutory reservoirs, the Environment Agency wrote to the dam owners to inform them of the concerns. However the driver for the project was the need to understand the flood risk posed by reservoirs in order to inform flood risk management. The Environment Agency is a Category 1 responder under the Civil Contingencies Act 2004 and lead on flood risk issues for Local Resilience Forums (LRF's). The Act places a general duty on the Environment Agency to maintain arrangements to warn the public and provide advice and information about flooding. The Environment Agency's experience from dealing with the failure of a non-statutory reservoir in the New Forest in 2002 was a further driver for the project. Under the Water Act 2003, the Environment Agency became the enforcement authority for the Reservoirs Act 1975. However, to fulfill its wider functions and responsibilities, knowledge of the level of risk posed by all reservoirs, whether statutory or not, was deemed necessary to:

- Reduce flood risk where possible;
- Make informed decisions based on good data;
- Offer informed advice to others such as utilities, planners, local authorities, LRF's and the public.

It was recognized that there would be additional potential benefits, such as:

- Ensuring that any review of the current reservoir safety legislation is informed by reservoir flood risk studies;
- By identifying non-statutory reservoirs owners and making contact with them to discuss reservoir safety assessments, the owners are more likely to take interest and responsibility for the condition of their structures

- Where non-statutory reservoirs are believed to fall within the ambit of the Act, bathymetric surveys would be carried out and the national reservoir safety team notified where appropriate.

Methodology

An appropriate methodology was developed to assess the risk of dam failure and to enable the regional population of reservoirs to be ranked. This methodology was broadly based on a method previously used internationally for portfolio risk assessments (Hinks and Dedja, 2002). This method is a qualitative assessment whereby it is not necessary to estimate the annual probability of failure. Hydrological risk was assessed by estimating the ratio of desirable freeboard to actual freeboard. Geotechnical risk was assessed against a wide range of indicators covering both the intrinsic design condition and the current condition. Hydrological and geotechnical risk indices were then combined to allow the reservoirs to be ranked.

Results

Of the 104 reservoirs assessed, only 19 were statutory reservoirs and 95% were impounding reservoirs. The distribution of the 19 statutory reservoirs within the overall qualitative ranking by risk of failure is shown in table 1.

Table 1. South Wessex study: distribution of statutory reservoirs by rank

Reservoir Ranking (1 = highest risk of failure)	**Number of Non-Statutory Reservoirs by band**	**Number of Statutory Reservoirs by band**
1 – 15	15	0
16 - 30	14	1
31 – 45	14	1
46 – 60	14	1
61 – 75	13	2
76 – 90	9	6
91 – 104	6	8
Total	**85**	**19**

Table 1 demonstrates that in the South Wessex area there is a very clear indication that statutory reservoirs have a lower risk of failure than non-statutory reservoirs.

The highest risk rated reservoirs were commonly found to have inadequate spillway and freeboard provisions and some showed indications of having been overtopped. Other common problems were:

- well developed seepage problems;
- dense vegetation preventing any effective surveillance and poor tree management;
- uneven dam crest levels;
- wave erosion to upstream face;
- poor levels of maintenance to structures;
- lack of monitoring;
- lack of routine surveillance.

This might not be of great concern if non-statutory reservoirs did not pose a risk to life. Unfortunately, many of them do. An analysis of the 85 non-statutory reservoirs by dam category is provided in table 2 below.

Table 2. South Wessex non-statutory reservoirs by dam category (ICE, 1996)

Dam category	Percentage
A	11
B	24
C	35
D	31

INVESTIGATION OF POTENTIAL RESERVOIRS PROJECT

Project Aim

The 'Potentials' project commenced in 2006 and is being carried out by Halcrow Group Ltd on behalf of the Environment Agency. The aim of the project is to identify and assess small reservoirs in England and Wales that are currently not on the National Register of Large Raised Reservoirs but may fall within the ambit of the Reservoirs Act 1975. To date the project has assessed 319 reservoirs of which 141 are now considered not to fall within the ambit of the Act (i.e. hold less than 25,000m^3). The project is described in detail in this journal by Goff and Hope (2008). The project is of relevance to this paper as a large number of small reservoirs have been visited and assessed according not only to their capacity but also their condition and the apparent downstream hazard. Although detailed condition assessments, risk assessments and dambreak assessments were beyond the scope of the project, the condition score and flood category assigned to the reservoirs is of relevance when considering the question of the safety of small British reservoirs.

Methodology

A pilot study at the commencement of this project confirmed that site visits were essential to provide reasonable confidence in volume estimates: GIS techniques were insufficient in themselves to meet the aim of the project. Through visiting each of the 'candidate' reservoirs, it was then also possible

to assign a condition score to each dam. Scores were assigned according to the conditions described in Table 3.

Table 3. Guidance on dam condition score.

1	Excellent condition, no significant cause for concern.
2	Good condition, some minor maintenance issues.
3	Some cause for concern. Problems evident that may lead to a dam failure if not addressed.
4	Problems causing immediate concern for safety. Urgent works required.
5	Poor condition. Imminent dam failure possible.

Results

Summary tables of results from an analysis of the potential reservoirs are provided below. The results are given for all of the reservoirs assessed rather than just those with a volume less than 25,000m^3 as this provides better insight to the condition of dams not benefiting from current reservoir safety legislation.

Table 4 - Results by condition score

Condition Score	**No. Reservoirs**	**Proportion of total**
1	40	13%
2	117	37%
3	80	25%
4	17	5%
5	6	2%
-*	59	18%
Total	319	100%

Table 5 - Results by dam category

	Number of Reservoirs				
Estimated Volume (,000m^3)	**Dam Category A**	**Dam Category B**	**Dam Category C**	**Dam Category D**	**Total**
0	n/a	n/a	n/a	n/a	57
1-10	0	5	9	4	18
10-20	8	13	23	12	56
20-25	11	15	33	8	67
25-30	2	6	19	0	27
30-40	1	10	13	6	30
40-50	3	6	9	3	21
50+	10	13	14	6	43
Total	**35**	**68**	**120**	**39**	**319**

Table 6a - Condition and dam category by number (non-statutory)

Dam Category	No. of non-statutory reservoirs by dam condition score						Total
	1	2	3	4	5	-	
A	3	8	4	2	2	0	19
B	3	15	12	1	2	0	33
C	10	29	20	3	1	2	65
D	2	10	9	3	0	0	24
-*	0	0	0	0	0	0	0
Total	18	62	45	9	5	2	141

Table 6b - Condition and dam category by percentage (non-statutory)

Dam Category	% of non-statutory reservoirs by dam condition score						Total
	1	2	3	4	5	-	
A	2.1%	5.7%	2.8%	1.4%	1.4%	0.0%	13.5%
B	2.1%	10.6%	8.5%	0.7%	1.4%	0.0%	23.4%
C	7.1%	20.6%	14.2%	2.1%	0.7%	1.4%	46.1%
D	1.4%	7.1%	6.4%	2.1%	0.0%	0.0%	17.0%
-*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	12.8%	44.0%	31.9%	6.4%	3.6%	1.4%	100.0%

* In some cases a dam condition score and dam category was not assigned. This typically arose where the water body was found not to be a raised reservoir.

POST-INCIDENT REPORTING SYSTEM

The new Post-Incident Reporting System (PIR) is being administered by the Environment Agency. The system was trialed by Halcrow Group Ltd through 2006 and the finalized system has been in operation since January 2007 (Hamilton-King et al, 2008). Historically, reservoir incidents were recorded in a database administered by the Building Research Establishment. This data is now held in the new database administered by the Environment Agency. Prior to 2006, incidents were only added to the database if they became public knowledge through, for example, details being provided in technical papers or by word of mouth between reservoir safety specialists and the BRE. In many cases these were 'high profile' incidents. The breakdown of these incidents before and after the start of the new system is as follows:

Table 7. Reported incidents at non-statutory reservoirs

Period	Number of reportable incidents at non-statutory reservoirs
1985 - 2005	0
2006 - 2007	5

It is evident from Table 7 that although there has been an incident database available for many years to record reservoir incidents in the UK, the mechanism for reporting had been poor prior to the introduction of the new system. The percentage of incidents reported for non-statutory reservoirs is very small compared with those for statutory reservoirs. However, four out of the eleven reportable incidents arising in 2007 were for non-statutory reservoirs.

Incidents at statutory reservoirs are commonly reported by a panel engineer or an informed undertaker. Incidents at non-statutory reservoirs generally only come to light when there has been concern for the flooding effects of dambreak and the Environment Agency is well placed to identify such incidents.

The PIR cannot currently be used to assess the risk posed by non-statutory reservoirs. This is due to the means by which incidents have historically been identified. The new system has however improved the situation for non-statutory reservoirs in England and Wales with many incidents at non-statutory reservoirs now being identified and investigated where appropriate. As a group, the owners of non-statutory reservoirs are less well informed than owners of statutory reservoirs regarding both the mechanism and collective benefits of openly sharing information on incidents. As a result, incidents at non-statutory reservoirs generally only come to light in serious cases where the Environment Agency becomes involved to manage the flood risk, or where the owner contacts a Panel Engineer for urgent advice.

HISTORICAL FAILURES OF SMALL RESERVOIRS

There are numerous references on historical dam failures in the UK that led to loss of life (for example, Charles, 2002). It is interesting to note that the Skelmorlie disaster of 1925 in south-west Scotland that killed five people and contributed to the introduction of the Reservoirs (Safety Provisions) Act, 1930, was of 24,000m^3. In addition, the Darwen disaster of 1848 in Lancashire that killed twelve people arose from the failure of a 5m high embankment impounding about 20,000m^3. Both of these reservoirs would be regarded as non-statutory reservoirs today. Binnie (1987) reported that there was only 2m of water behind the subsidiary dam at Diggle Moss when it failed in 1810 causing five deaths in the Huddersfield area.

It is clear that even quite small reservoirs can pose a significant hazard, especially if they are not adequately inspected and supervised. Recent experience from investigating incidents at non-statutory reservoirs under the

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PIR suggests that the failure of non-statutory reservoirs might be common today with perhaps at least one small reservoir in the UK failing in most years. It is simply very fortunate that none of the failures in modern times have led to loss of life.

SUMMARY OF FINDINGS

The South Wessex project confirmed that within a population of statutory and non-statutory British reservoirs, one can expect that there is a very marked difference in terms of safety with statutory reservoirs generally being much safer than non-statutory reservoirs. In this particular population, 35% of the non-statutory reservoirs were considered to pose a significant threat to life in the event of a failure.

The investigation of potential reservoirs project assessed a large sample of 319 reservoirs that were not subject to reservoir safety legislation. 141 of these reservoirs were found to be too small to fall within the ambit of the Reservoirs Act 1975 and would therefore be termed 'non-statutory'. However, in nearly 42% of these non-statutory cases, maintenance works on the dam were considered either desirable or urgent, and some 37% had the potential to cause loss of life.

The post-incident reporting system cannot currently be used to assess the risk posed by small reservoirs based on the statistics of historical events. However, the new system is better able to capture incidents at small reservoirs and has served to underline the fact that many serious incidents at non-statutory reservoirs can be expected in a typical year. The other studies provide evidence that a small percentage of such reservoirs can be expected to pose a risk to life were they to fail.

There are no statistics on the number of small reservoirs in Britain but studies to date indicate that there is likely to be many that both pose a risk to life and are in need of urgent safety works.

POSSIBLE IMPLICATIONS FOR LEGISLATIVE CHANGE

There is evidence to suggest that each introduction of change to reservoir safety legislation to date has been progressively more effective in reducing the risk of reservoir failure. A summary of British reservoir safety legislation is provided by Charles (2002). It can be argued that the use of reservoir volume alone to define a statutory reservoir has many advantages: it is a simple criterion that in most cases is relatively easy to apply, but it does not always reflect the risk posed by reservoirs. In the view of the authors, future legislation should introduce sufficient flexibility to allow the application of effective safety provisions to any raised reservoir irrespective

of reservoir volume where it is judged that lives are clearly at risk. To any homeowner living immediately downstream of a small but very poorly maintained reservoir, such legislation would seem appropriate. One could equally argue that there are a small number of statutory reservoirs where the consequences of failure are not life threatening and where the statutory provisions could be reduced where certified by a panel engineer.

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