Environment Agency

enhancing... improving... cleaning... restoring...
changing... tackling... protecting... reducing...
creating a better place... influencing...
inspiring... advising... managing... adapting...

Learning from experience

Post-incident reporting for UK dams
2009 annual report

GEHO1010BSOO-E-P

ea/br/e/std/v1

We are the Environment Agency. It's our job to look after your environment and make it **a better place** - for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Rio House
Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

October 2010
ISBN 978-1-84911-193-5

Foreword

Dams and reservoirs are an important part of our national infrastructure, providing a vital service in storing the country's water. However, without effective management, ongoing monitoring and adequate maintenance these reservoirs have the potential to cause extensive damage and even loss of life. Although it is very rare for a dam to fail, we know that there are preventable incidents at UK reservoirs every year. We have produced this report to raise awareness of these incidents and share lessons learned with the reservoir industry.

The Flood and Water Management Act 2010 contains changes for the reservoir industry which include:

- moving to a risk based approach for regulation;
- lowering the volume threshold for reservoirs;
- and mandatory reporting of incidents.

The Government are considering the timing for implementation of these changes.

I would like to thank all of those within the reservoir industry who have contributed to and supported the post-incident reporting system. I hope that this report will encourage more reservoir operators to submit details of any incidents, so that we can improve the overall safety situation for the whole reservoir community. We've recently updated the reservoir safety section of our web site to be much clearer, so please visit http://www.environment-agency.gov.uk/business/sectors/118421.aspx to find the latest information.

Antony Deakin	FCRM Manager – Reservoir Safety

Contents

1 Introduction

The post-incident reporting system has been running for over three years with this being our third annual report. We administer the system and collect information on incidents at both large raised reservoirs (i.e. reservoirs under the Reservoirs Act 1975) and small raised reservoirs (reservoirs not currently covered by reservoir safety legislation). The aim of the system is to:

- gather information on reservoir incidents;
- investigate incidents where appropriate;
- learn lessons from incidents;
- inform the reservoir industry of trends and key lessons learned;
- provide information that can contribute to reservoir safety research and incident frequency data.

This annual report to the reservoir industry provides information on the nature of the lessons learned over the last year and trends in the number and type of incidents that have occurred.

Currently, post-incident reporting is a voluntary system. The Flood and Water Management Act was passed in April 2010 and will amend the Reservoirs Act 1975. When implemented, the amendments contained in the Act will introduce mandatory post-incident reporting.

The post-incident reporting system helps to prioritise subjects for reservoir safety research. An update on research projects is provided in Section 4.

Section 5 discusses the threats posed by small raised reservoirs. These are reservoirs with a volume between 10,000m^3 and 25,000m^3. We have recorded a number of incidents at these non-statutory reservoirs. When the provisions of the Flood and Water Management Act 2010 come into force, large reservoirs that pose little risk to life will be subject to less stringent regulation. Conversely, smaller reservoirs that pose a risk to life will be subject to greater regulatory control.

As well as recording and acting on incidents as and when they occur, we take a pro-active approach to reservoir risk management. For example, we have continued to manage the risk posed by reservoirs that have no owner . In 2009 work commenced to drain down such a reservoir in Lancashire that posed a considerable risk to the local community. You can read about the work at Hameldon Reservoir in Section 6.

We prepare bulletins, when appropriate, to provide an insight into an incident or group of incidents where there are particular points of learning that should be shared with the reservoir industry. We will prepare bulletins on the threats posed by animals and vegetation.

2 Analysis of the reported incidents

The following information is presented in this annual report:

- the number, type and severity of incidents that have occurred during 2009 and the previous five years;
- incident analysis in terms of threats to reservoirs and mechanisms of deterioration resulting from those threats;
- the main lessons that have been learned from the incidents;
- a brief summary of each incident and lessons learned where completed post-incident report forms have been received.

2.1 Severity and number of reported incidents 2004-2009

Incidents are entered on the database if they are considered reportable. Table 2.1 defines the three severity levels for reportable incidents.

Table 2.2 and Figure 2.1 show the number and severity of incidents that have been reported during 2004 to 2009. They only include incidents where we have been able to gather enough information to assign an incident level (generally where we have received a completed post-incident report form).

There were four incidents reported during 2009 to which we assigned an incident level. An additional incident that occurred in 2008 has also been added to the database.

Incident severity level	Definition of incident severity
One	Failure (uncontrolled sudden large release of retained water)
Two	Serious incident involving any of the following: o emergency drawdown o emergency works o serious operational failure in an emergency
Three	Any incident leading to: o an unscheduled visit by an inspecting engineer o a precautionary drawdown o unplanned physical works o human error leading to a major (adverse) change in operating procedures

Table 2.1. Reportable incidents

	2009	2004-2008
Total number of incidents	4	35
Incidents at large raised reservoirs	1	25
Incidents at small raised reservoirs	3	10
Level 1 incident	-	2
Level 2 incident	1	12
Level 3 incident	3	21

Table 2.2. Incidents reported in 2004-2009 showing severity level

The number of reported incidents decreased in 2009 and the total number of incidents was the lowest recorded since the start of the new system in January 2007.

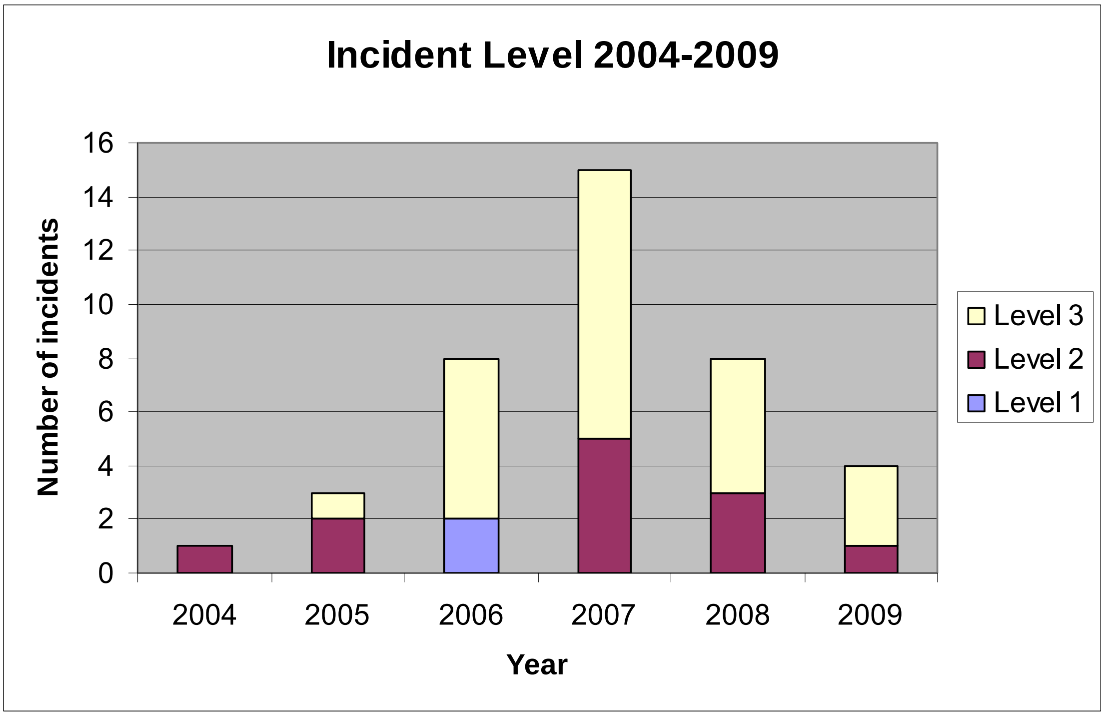


Figure 2.1. Incidents reported 2004-2009 showing severity level.

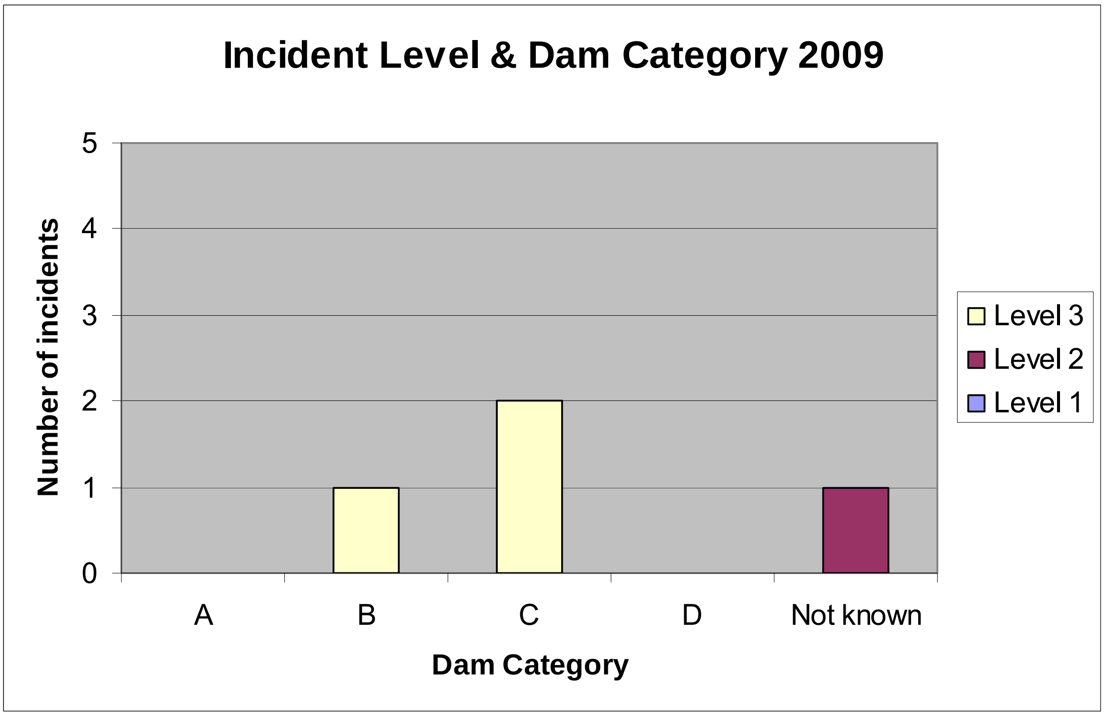


Figure 2.2. Incident level and dam category for 2009
Refer to appendix B for definition of dam categories

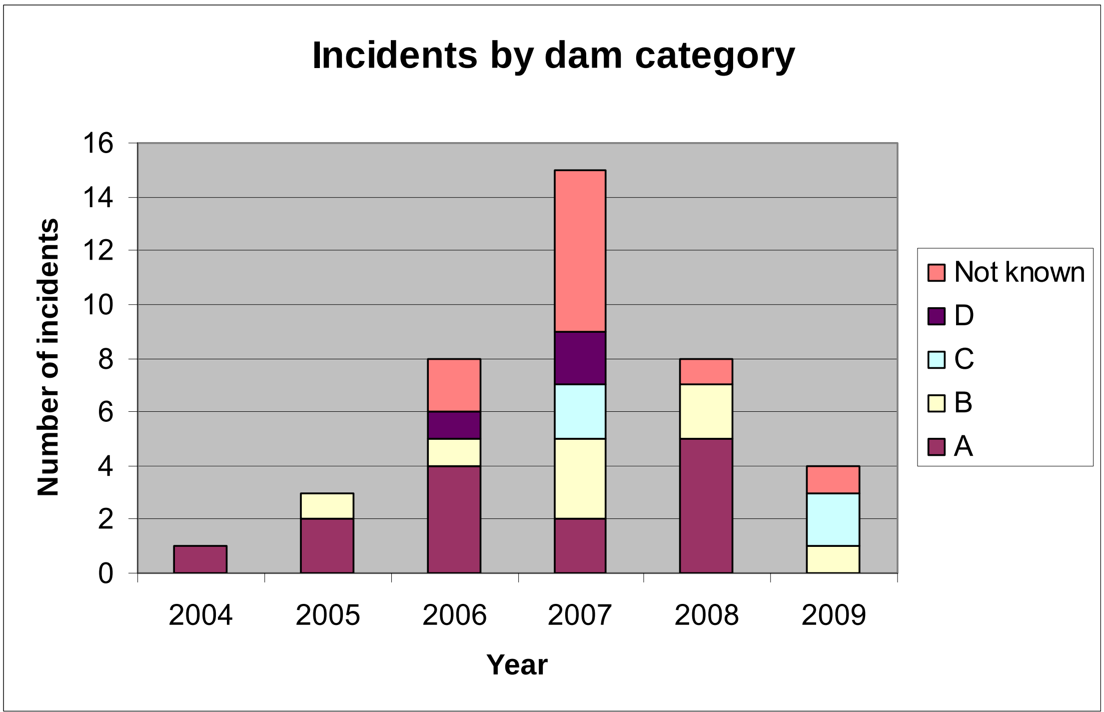


Figure 2.3. Distribution of incidents by year and dam category

2.2 Threats and mechanisms of deterioration

Tables 2.3 and 2.4 provide a summary of the reported incidents and include some characteristics of the dams, including dam category and height.

Incident No	Incident Date	Incident Severity	Year Built	Dam height (m)	Dam category	External threat	Internal threat	Mechanism of deterioration
35	Nov-04	2	1931	13	A	n/a	Embankment stability	Internal erosion through embankment
31	Jan-05	2	1911	27	A	n/a	Embankment stability	Internal erosion adjacent to appurtenant structure
29	Jun-05	3	1910	6	B	Inflow flood	n/a	Erosion by overtopping
30	Jun-05	2	1882	20	A	Inflow flood	n/a	Erosion by overtopping
317	Feb-06	3	1998	9	B	Mining	n/a	Settlement/deformation
311	Apr-06	3	1974	20	A	n/a	Appurtenant work stability	Pipework/culvert deterioration
304	Jun-06	3	1927	17	A	n/a	Embankment stability	Internal erosion through embankment
305	Jul-06	3	1750	4	D	n/a	Vegetation	Internal erosion adjacent to appurtenant structure
301	Oct-06	3	1956	15	A	n/a	Embankment stability	Settlement/deformation
306	Dec-06	1	Not known	2	Not known	Other	n/a	Other
303	Dec-06	3	1815	11	A	n/a	Embankment stability	Internal erosion adjacent to appurtenant structure
324	Feb-07	3	1820	3	D	n/a	Embankment stability	Internal erosion through embankment
330	Mar-07	3	1969	20	A	n/a	Embankment stability	n/a
323	May-07	3	1879	9	A	n/a	Embankment stability	Internal erosion adjacent to appurtenant structure
312	Jun-07	3	1800	3	D	n/a	Embankment	Internal erosion adjacent to appurtenant

Incident No	Incident Date	Incident Severity	Year Built	Dam height (m)	Dam category	External threat	Internal threat	Mechanism of deterioration
							stability	structure
308	Jun-07	2	1975	4	B	Inflow flood	n/a	Erosion by overtopping
307	Jun-07	2	1875	14	A	Inflow flood	Appurtenant work stability	Damage to safety critical structures
309	Jun-07	3	1963	5	B	Inflow flood	n/a	Erosion by overtopping
315	Jul-07	3	Not known	7	Not known	Inflow flood	Embankment stability	Increased internal water pressure causes instability
327	Aug-07	3	1760	6.5	B	n/a	Embankment stability	Internal erosion through embankment
326	Oct-07	3	1800	3	C	Wind, trees	Vegetation	Wind damage – trees
328	Jan-08	3	1950	3	A	Animals	n/a	Internal erosion through embankment
329	Jan-08	3	1808	9	B	n/a	Embankment stability	n/a
332	Aug-08	3	1815	11	A	n/a	Appurtenant work stability	Pipework/culvert deterioration
333	Sep-08	3	1815	6	A	n/a	n/a	n/a
337	Aug-08	3	1963	24	A	n/a	Embankment stability	Increased internal water pressure causes instability
341	Feb-09	3	1962	5	B	Other	Embankment stability	Internal erosion through embankment

Table 2.3 Summary of reported incidents at statutory reservoirs

Incident No	Incident Date	Incident Severity	Date Built	Dam height (m)	Dam category	External threat	Internal threat	Mechanism of deterioration
302	May-06	1	1800	3.5	Not known	Inflow flood	Embankment stability	Erosion by overtopping
316	Jun-07	2	1920	5	Not known	Other	n/a	Erosion by overtopping
322	Jun-07	2	1620	5	Not known	Inflow flood	n/a	Erosion by overtopping
310	Jul-07	3	Not known	1.5	Not known	Inflow flood	Abutment stability	Internal erosion through embankment
313	Jul-07	3	Not known	4	C	Inflow flood	n/a	Erosion by overtopping
321	Jul-07	2	1920	5	Not known	Inflow flood	n/a	n/a
325	Jan-08	2	Not known	13	A	Inflow flood	Embankment stability	Erosion by overtopping
335	Aug-08	2	1850	9	B	Inflow flood	n/a	Erosion by overtopping
334	Sep-08	2	Not known	5	Not known	Inflow flood	n/a	Erosion by overtopping
340	Jun-09	3	1994	2	C	n/a	Embankment stability	Internal erosion through embankment
338	Jul-09	3	Not known	4	C	n/a	Embankment stability	Internal erosion through embankment
344	Jul-09	2	Not known	2	Not known	Inflow flood	n/a	Erosion by overtopping

Table 2.4 Summary of reported incidents at non-statutory reservoirs

We have analysed reported incidents in terms of threats to dams and the mechanisms of deterioration resulting from those threats. Threats have been broadly divided into internal and external threats.

The internal threat categories used in the database include:

- instability associated with internal erosion of an embankment dam;
- slope instability associated with slip of an embankment dam;
- instability associated with appurtenant works;
- instability of the dam foundation;
- material deterioration (for example, corrosion);
- vegetation (for example, tree roots).

The external threat categories used in the database include:

- inflow - flood;
- inflow - direct rainfall;
- inflow - failure of upstream reservoir;
- seismic event;
- snow/ice;
- aircraft strike;
- vandalism;
- wind (wave generation);
- wind (tree damage);
- human error;
- animals;
- mining.

A summary of incidents for 2009 and for 2004-2008 in terms of threats and mechanisms of deterioration is given in Tables 2.5 and 2.6.

The main internal threat reported over the previous five years has been embankment stability. Internal erosion has been the mechanism of deterioration in fourteen of the incidents reported in the past six years.

Internal and external threats		**2009**	**2004-2008**
External	Inflow flood	1	14
	Mining	0	1
	Wind, trees	0	1
	Animals	0	1
	Other	1	2
Internal	Embankment stability	3	15
	Appurtenant works stability	0	3
	Abutment stability	0	1
	Vegetation	0	2

Table 2.5. Summary of threats

Mechanism of deterioration	2009	2004-2008
Erosion by overtopping	1	10
Internal erosion through embankment	3	6
Internal erosion adjacent to appurtenant works	0	5
Pipework/culvert deterioration	0	2
Damage to safety critical structures	0	1
Increased internal water pressure causes instability	0	2
Settlement	0	2
Wind damage – trees	0	1
Other	0	1

Table 2.6. Mechanisms of deterioration

2.3 Types of lessons learned

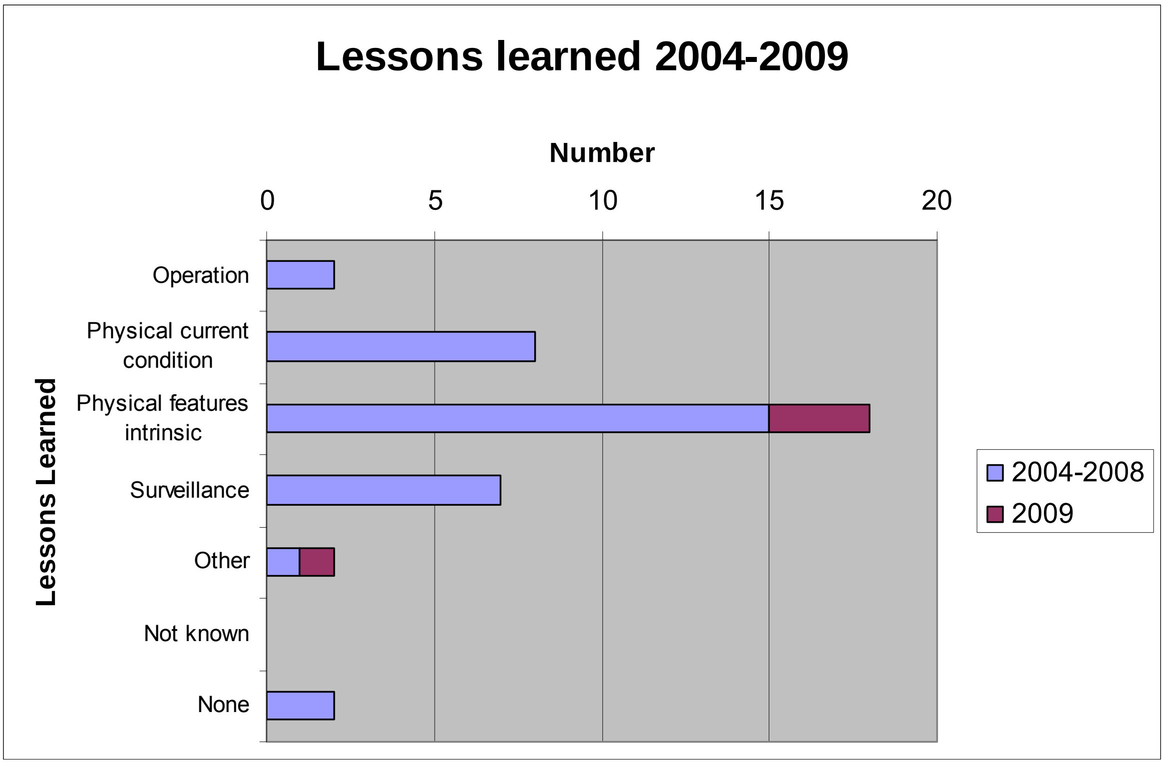
The following conclusions are based on a relatively small database of incidents:

- Despite extensive guidance on flood estimation and spillway design, flood events still account for many of the incidents, especially at non-statutory reservoirs.
- Emergency action was required during incidents 334 and 335 where earthfill embankments were overtopped and extensively damaged by flood events.
- Many of the incidents reported in 2007 were related to the summer storms.
- There were relatively few reported incidents in 2009.

Incidents recorded in the database are classified on the basis of the type of lessons learned. The lessons learned are split into five categories as explained in Table 2.7 below. Categorising the lessons learned in this way makes it easier to highlight trends in the sort of incident arising.

Type	Examples	Possible implications
Surveillance	Inadequate surveillance or processing of instrument observations.	Reservoirs require more, or better monitoring and surveillance.
Operation	Malfunction or mis-use of reservoir control facilities.	Reservoirs require more, or better trained staff or security against misuse.
Physical (current condition)	Inadequate performance due to deterioration of a design element by erosion, wear, weathering, corrosion, vandalism, poor maintenance, etc.	Reservoir components require better, more frequent maintenance.
Physical features (intrinsic)	Inadequate performance due to the original design and/or construction of a structure, or through changes in the loading (structural or hydraulic) experienced.	Reservoir components should be designed and built to meet current physical conditions
Emergency planning	Incidents relating to the application of emergency planning provisions (alarms, evacuations, etc).	There is a need for more effective use of emergency planning provisions at reservoirs.

Table 2.7. Types of lessons that can be learned



Incident category and ID	Lesson learned	PIR annual report year
Operation		
301 (Sutton Bingham)	This incident shows the value of settlement monitoring. It also highlighted that drawdown facilities need to be sufficient to reduce the water level in a reservoir even at times of high inflow.	2007
304	The frequency of surveillance should be reviewed under such conditions and increased if appropriate. The leakage point can be some distance off the toe of the dam. Surveillance should cover areas beyond the immediate area of the toe to check for leakage paths through the dam foundation.	2007
Current physical condition		
35	This incident highlights the need to carry out surveillance more often when a reservoir is filled above the normal operating level.	2007
305	The incident underlines the value of addressing leakage problems as they arise. If the initial problem of leakage into the drop shaft had been rectified, the subsequent more serious leakage path may not have developed.	2007
306	The incident underlines the need for good records of dam construction and the importance of regular surveillance, especially when the reservoir levels are unusually high.	2007
313	The incident underlines the need for proper surveillance and maintenance of dam embankments. There is a need for increased surveillance when embankments experience hydrostatic pressure greater than they have in recent times.	2007
324	Make sure that vegetation does not prevent thorough inspection of the dam.	2007
328	During high river levels the riverside embankment associated with a flood storage reservoir breached. The breach was found to be due to water seeping into animal burrows in the embankment. This incident highlights the importance of checking all reservoir embankments for damage from burrowing animals and repairing any damage found.	2008
329	This incident demonstrates that historical slips in embankments can be reactivated if water levels are not adequately controlled.	2008
Intrinsic condition		
29	If the reservoir had been registered previously, the safety provisions of the Act may have averted the incident.	2007

Incident category and ID	Lesson learned	PIR annual report year
30 (Boltby)	It is important to consider the risk of flows exceeding the capacity of spillway channels and, where appropriate, to consider erosion protection works. It would seem appropriate to carry out research into the performance of masonry spillway channels.	2007
31 (Lower Carno)	The incident shows how important regular, effective surveillance is.	2007
302	Embankments and spillways need to be designed and built to appropriate standards.	2007
307 (Ulley)	The incident highlights the need to more carefully observe and inspect masonry walls for vegetation and missing pointing. It also demonstrates that out-of-channel flow should not be allowed to occur where it could damage the structure of the dam.	2007
308 & 309	This highlights the need for careful detailing of dam crest raising works to consider the effects of extreme flood events. Using sheet piles to raise an embankment, which may be subject to overtopping, should be carefully considered and avoided if possible.	2007
311	All tunnels under dams should be regularly inspected and any information on the design and inspection of these tunnels should be kept with the reservoir records.	2007
315	Established vegetation prevented the slope from being inspected, which could have shown signs of failure before the incident arose. The incident underlines the need for good ground investigation and site management when developing reservoir works.	2007
316	Reservoirs in catchments of groundwater dominated hydrology must adequately cater for the significant groundwater response that might arise following severe rainfall.	2007
321	The incident highlights the need for panel engineers to only certify a reservoir as discontinued if its safety provisions meet current best practice.	2007
322	The incident shows the need for owners of small raised reservoirs to be aware of reservoir safety guidance.	2007
334	Adequate spillway capacity should be provided and maintained at all dams to a minimum standard appropriate for the downstream hazard. Spillway modifications should not be carried out without a proper flood safety assessment. Where overtopping occurs, trees and shrubs can greatly accentuate the depth of erosion	2008
325	The culvert through a road embankment blocked due to the lack of an effective debris screen. This shows the need for regular inspection and maintenance to ensure that blockage does not occur. This incident also highlights a problem with culverted road embankments which pose a risk to life but do not fall under the Reservoirs Act 1975.	2008
Surveillance		

Incident category and ID	Lesson learned	PIR annual report year
303	The incident highlights the need to carry out regular surveillance of any known points of seepage/leakage.	2007
310	The incident highlights that even small dams can pose a significant threat and need to be properly inspected and maintained.	2007
312	Keep points of seepage under regular surveillance so that changes are observed early.	2007
323	A proper seepage monitoring system would have helped to recognise the increase in seepage flow. Experience in visual surveillance is not always effectively passed on to new staff, so recording seepage flows is a better way of preserving the dam performance history. Seepage records would have helped in assessing this incident.	2007
335	This incident highlighted the importance of regular supervision and maintenance. It also highlights the value of emergency planning procedures.	2008
332	Discoloured water was seen discharging from the lower outlet pipe during a weekly visit. This incident shows the importance of routine surveillance in identifying any issues early enough to allow appropriate action to be taken.	2008
Other		
317	This highlights the importance of being vigilant if mining activity is taking place near a dam.	2007
None		
333	Seepage water thought to be sourced from the reservoir was subsequently found to have probably tracked through service ducts, possibly from the nearby river	2008

Table 2.8 Summary of lessons learned from 2007-2008 incidents (further details are provided in the annual reports referenced)

3. Incidents reported in 2008-2009

The three reportable incidents that occurred in 2009 are described below. An incident that occurred during 2008 but was too late to appear in the 2008 annual report is also included.

Incident 337 (2008)

Dam type	**Earthfill embankment**
Reservoir legal status	**Statutory reservoir**
Dam height (m)	**24**
Incident type	**Increased internal water pressure causes instability**
Incident severity	**3**

A long-standing wet area near the downstream toe of the dam was found to have deteriorated further, causing slumping. There were concerns that local instability would occur and an inspecting engineer was called to the site. The engineer recommended that slumped material was replaced and a french drain installed through the seepage horizon. The source of the seepage water was thought to be percolation of surface water through the downstream shoulder of the dam embankment.

Lessons learned

This incident demonstrates the value of regular surveillance. Areas of seepage which show no change over many years can worsen.

Incident 341

Dam type	**Earthfill embankment**
Reservoir legal status	**Statutory reservoir**
Dam height (m)	**5**
Incident type	**Internal erosion through embankment**
Incident severity	**3**

Leaks developed at a number of locations on the dam. The leaks appeared in the same place as the core had been raised 40 years before this incident. It is believed that the concrete slab joint sealant on the upstream face had deteriorated. This, along with the severe cold weather causing the contraction of the concrete, might have triggered the leaks. The incident is subject to on-going investigations.

Lessons learned

This incident is still being investigated. However, it is important to closely monitor the performance of dams that have been raised. Modifications can cause problems even decades after the time that they were made.

Incident 340

Dam type	**Gabion and clay embankment**
Reservoir legal status	**Non-Statutory reservoir**
Dam height (m)	**2**
Incident type	**Internal erosion through embankment**
Incident severity	**3**

Internal erosion was found at a secondary dam which also acted as the reservoir spillway. This embankment was replaced in 1994. It had been constructed using gabion-baskets, covered over with clay and surfaced with a concrete revetment system. Settlement of the crest and the appearance of a hole in the revetment indicated internal erosion. A channel was cut through adjacent ground to lower the reservoir water level in a controlled manner.

Lessons learned

This incident underlines the importance of seeking professional services in relation to the design of dam embankments as the embankment design was flawed.

The safety of the secondary dam (above) was preserved by cutting a channel (right) to draw down the reservoir.

Incident 338

Dam type	**Earthfill embankment**
Reservoir legal status	**Non-Statutory reservoir**
Dam height (m)	**4**
Incident type	**Internal erosion through embankment**
Incident severity	**3**

Repairs were carried out in 2005 to fill in voids caused by rotten tree roots in an ancient well-vegetated embankment. Sheet piling was installed along the upstream face to reduce the amount of water that might pass through the voids in the future. To limit costs, sheet piling was only used over two sections of the embankment length but not the entire length. In 2009, seepage was found emerging from the downstream face about 1m below the dam crest. The source of the seepage was at the edge of one of the sheet piled sections at the upstream face and the flow was passing through a soil pipe within the embankment. The reservoir level was lowered in response.

Lessons learned
Voids in embankments can lead to internal erosion incidents. In this case, piping developed between a void and the end of a length of sheet piles at the upstream face. Comprehensive grouting and sheet piling had not been carried out previously and this incident demonstrates that incidents can re-occur if preventative works are not comprehensive.

Incident 344

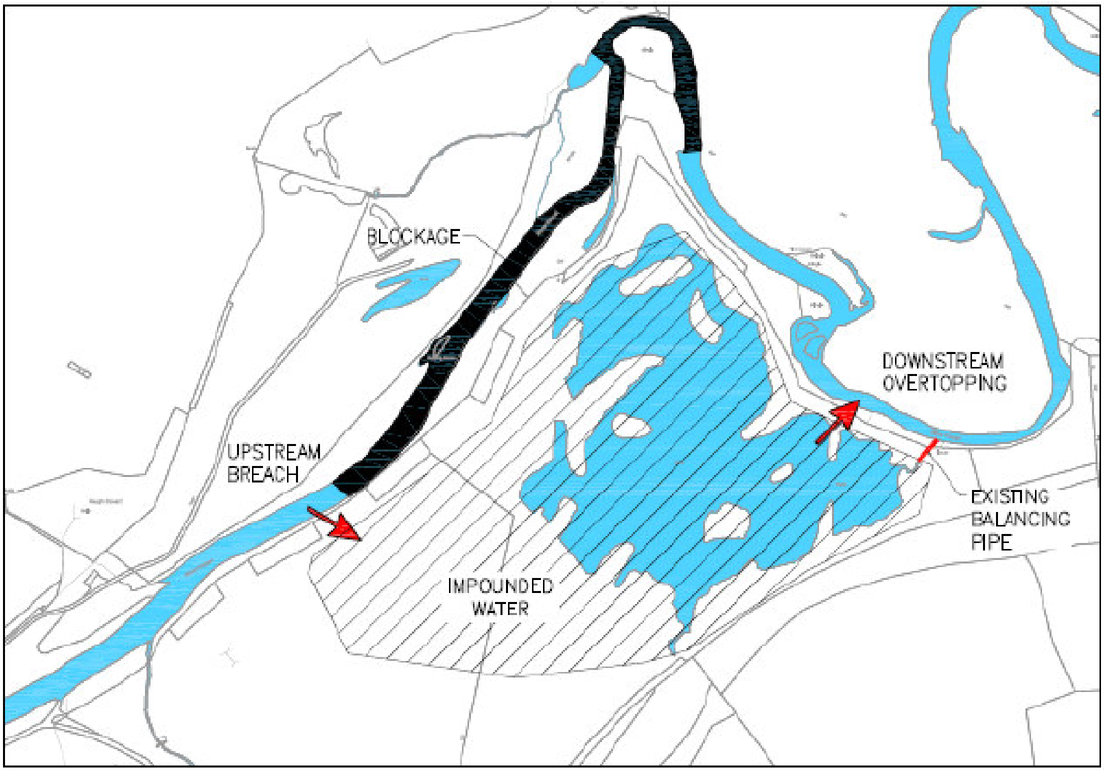
Dam type	**River bank**
Reservoir legal status	**Non-statutory impoundment adjacent to a river**
Dam height (m)	**2**
Incident type	**Inflow flood, erosion by overtopping**
Incident severity	**2**

Following heavy rainfall, a river channel, which had become choked with gravel, breached its bank and water discharged into an adjacent gravel pit. The pit filled with water and then started to spill back into the river channel further downstream. Erosion of the river bank threatened to release more than 100,000m^3 of water into the river channel. The blockage in the river channel was cleared, the upstream breach area into the gravel pit was sealed and the water impounded in the gravel pit was drained back into the river using an existing pipe outlet. Finally, an overflow section was constructed to allow water to pass safely through the gravel pit in the event that the pit filled again in the future.

Lessons learned

This incident shows how the threat of uncontrolled release of large volumes of water can arise at non-registered impoundments. It demonstrates the need for flood risk managers to be aware of the risk posed by low-lying areas adjacent to rivers where an impoundment could be created under flood conditions.

Photograph courtesy of J Falkingham.


BLOCKAGE
DOWNSTREAM
OVERTOPPING
UPSTREAM
BREACH
EXISTING
BALANCING
PIPE
IMPOUNDED
WATER

4. Research and Development Activities

4.1 Research on Statutory Safety Measures

All statutory reservoir inspection reports that contain safety recommendations are copied to the Reservoir Safety Team at the Environment Agency. The collection of these reports can provide insight into the common concerns raised by panel engineers. The research on statutory safety measures was introduced in the 2008 Annual Report

We have received reports since October 2004 so data sets are available for four complete years (2005 to 2008). The data for inspections carried out in 2009 is incomplete but is included in the table below. A Section 10(5) certificate is submitted in every case.

Year of reservoir inspection	Number of Section 10 reports received with safety recommendations	Total number of Section 10 reports received	Percentage
2005	113	254	44
2006	154	325	47
2007	116	299	39
2008	102	274	37
2009*	105	202	52

* Data for 2009 incomplete

Table 4.1 Breakdown of statutory safety recommendations and Section 10 reports by year

This table indicates that there is no clear trend over time in the percentage of reservoirs in England and Wales requiring statutory safety measures following an inspection under Section 10 of the Act.

1889 recommendations have been categorised from the 677 Section 10 reports received since October 2004. The findings are shown below.

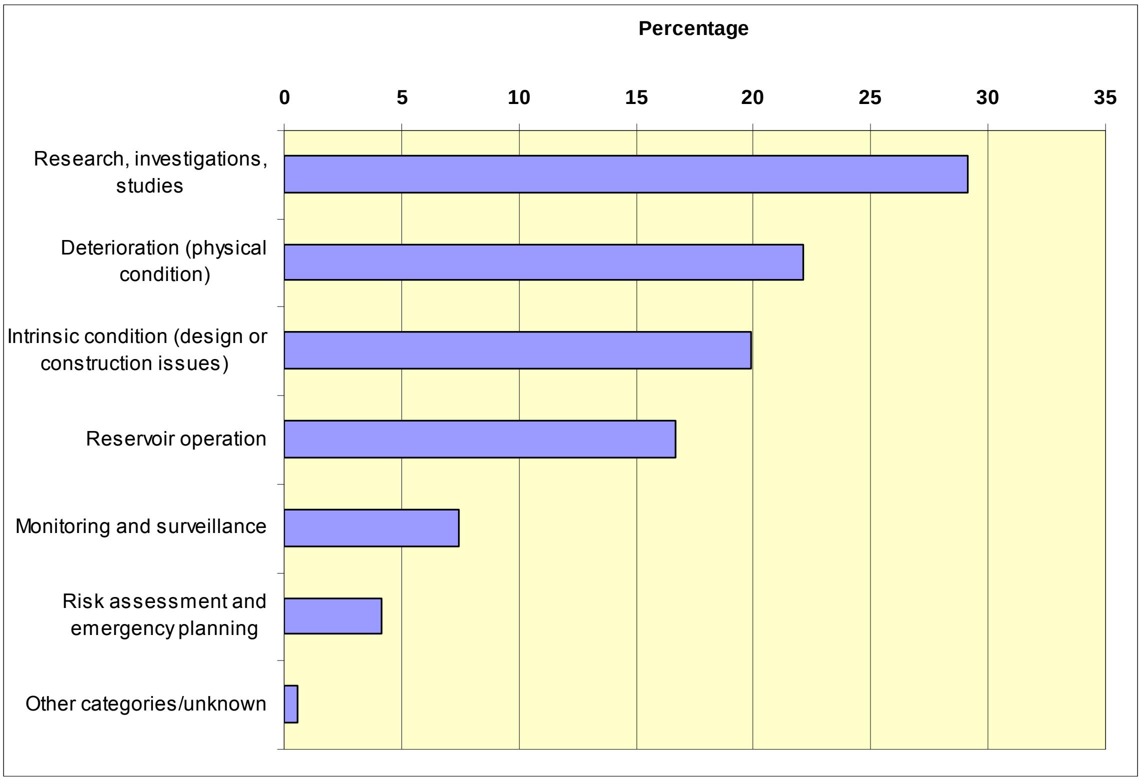


Figure 4.1. Breakdown of statutory safety recommendations by type

The data indicates that nearly thirty percent of all recommendations are in relation to investigations, studies or research to assess safety. By type, the most common recommendation is that a reservoir flood study be carried out.

4.2 Lessons from historical dam incidents

An Environment Agency Science Report will be published in 2010 on 'Lessons from historical dam incidents'. The document aims to:

- Promote the benefits of post-incident reporting and the use of the national database;
- Identify the most significant 100 incidents on the national database, in terms of impact and/or influence on the industry, from c.1800 to 2008;
- Classify these incidents by broad categories of incident type and lessons learnt;
- Prepare summaries for the 30 most significant British dam incidents, drawing on readily available published information. This will aim to provide basic information on the dam characteristics, design and construction aspects, how the incident arose, how the incident was managed, and a summary of the damage arising. Where appropriate, information will be added on the impact of the incident on the industry.

Detailed summaries are included for a small number of international incidents of a type not well represented in the British incident records. Brief summaries and points of learning for the 70 additional incidents have been included, together with some examples of how selected incidents have been managed.

Figure 4.2: Carsington Reservoir, 1984
The investigation of the failure by Professor Vaughan led to a better appreciation of the significance of progressive failure, and the overestimation of stability by limit equilibrium analysis.

4.3 Masonry stepped spillway research

We commissioned a research project to investigate the safety of stepped masonry spillways following the incidents at Boltby in 2005 and Ulley in 2007. The research was carried out between October 2008 and October 2009.

The research focused on shallow stepped spillways that are associated with UK embankment dams. Industry gave examples of their experience of operating these types of spillways, including their experience of distress and remedial measures. This was supplemented by a programme of hydraulic model testing to clarify how flow depths can be calculated and to improve understanding of the pressure fluctuations which spillway walls experience.

Moderate flows in stepped spillways tend to cascade from step to step whereas higher flows tend to skip from step to step, very high flows pass down the spillway barely touching the steps. This research focussed on the higher flows that skip from step to step.

Tests on models showed high pressure zones on the flat part of the steps and low pressures against the vertical faces of the steps. The research showed that, if the high pressure flows are able to get behind the masonry making up the spillway, blocks in the low pressure zones can be sucked out.

The areas of pressure will depend on the make-up of the spillway and the flow of water. Testing on models also showed that pressure was affected by both protruding and recessed blocks.

The report on the research highlights the need for regular inspection and includes advice on how to identify distress in spillways and appropriate means of repairing any damage. It encourages the use of photographs in inspection reports and investigating voids behind masonry walls. It also notes that regular inspection of the spillway is important to ensure the integrity of the mortar pointing.

The following images show the stages of the work.

5. The threat posed by small reservoirs

5.1 Introduction

The safety of large raised reservoirs in Great Britain is promoted through the provisions of the Reservoirs Act 1975. The Act is a public safety statute that aims to reduce the risk of catastrophic failure of a reservoir. It is structured to ensure the safe design, construction and operation of the reservoir by requiring inspection and supervision.

This legal requirement is enforced by the Environment Agency in England and Wales. Small raised reservoirs, i.e. those holding less than 25,000m^3 above the lowest point of the surrounding ground, fall outside the scope of this Act. The Government considered the danger posed by small raised reservoirs when debating the changes to the Reservoirs Act 1975 contained in the Flood and Water Management Act 2010.

5.2 Historical context

Since legislation was introduced to maintain reservoirs, there has been no loss of life from reservoir flooding. However, historically there are some well known incidents at small raised reservoirs that caused loss of life and/or damage to property. Examples of three of these incidents are shown in Table 5.1.

Reservoir Name	Year of failure	Reservoir Volume at time of failure (m^3)	Persons killed (no.)	Comment
Diggle Moss (Subsidiary dam)	1810	Unknown	5	Large reservoir with two dams. The reservoir was partially empty with only 2m depth of water behind the subsidiary dam when it failed due to "under seepage".
Darwen	1848	20,000	12	The dam was only 5m high. It failed by overtopping in a storm.
Skelmorlie	1925	24,000	5	This failure was attributed to grossly deficient overflow capacity.

Table 5.1 Selected historical incidents involving small raised reservoir dam failure

The above incidents are well known as life was lost. There may well have been many other serious 'near-miss' incidents that have gone unreported over the years. Some serious 'near-miss' incidents during the last two years are shown in Table 5.2 below.

Incident number	Year of incident	Volume at time of incident (m^3)	Comment
Incident 313	2007	~10,600	3.4m high earth embankment. Dam badly damaged by overtopping. Small risk to life.
Incident 334	2008	Unknown 10,000 approx.	5m high earth embankment. Dam badly damaged by overtopping. School downstream was closed.
Incident 335	2008	24,000	9m high earth embankment dam. Badly damaged by overtopping. In the event of a failure, 20 properties downstream would have been in danger.

Table 5.2 Recent 'near-miss' incidents at small raised reservoirs

It is unknown how many undocumented 'near-miss' incidents involving small reservoirs there are every year. However, the number of incidents recorded has increased since 2006 under the post-incident reporting system.

5.3 Common threats to the safety of small reservoirs

The available information indicates that the most common cause of near-miss or failure of small embankment dams is by overtopping of the dam and subsequent external erosion of the crest and downstream face. Overtopping of the dam crest during flood events can occur as a result of inadequate spillway capacity (whether due to design or blockage) and/or due to deterioration of the dam condition, for example by erosion or settlement of the embankment crest.

Experience suggests that the surveillance of the dam and associated structures of small raised reservoirs is usually much less frequent or effective than typically found at the large raised reservoirs covered by the Act and that many such dams are poorly maintained. For example, it is common to find the downstream face of the embankment so obscured by vegetation that the important warning signs of progressive seepage or instability are not noticed until it is too late.

Figure 5.1 This dam was nearly washed away when it was overtopped in 2008.

In many cases the importance of adequate spillway capacity, maintenance and surveillance is not well understood by the owners of many small raised reservoirs. This may in part be due to their lack of exposure to panel engineers and the wider reservoir safety community.

5.4 Research

In 2004 the Environment Agency became the Enforcement Authority for all 2,106 large raised reservoirs under the Reservoirs Act 1975 in England and Wales. It has commissioned various research projects that have highlighted the threat posed by small raised reservoirs. These include:

- The South Wessex Flood Risk Assessments of Reservoirs Project, 2005 - 2007
- The Investigation of Potential Reservoirs Project, 2006 - 2008

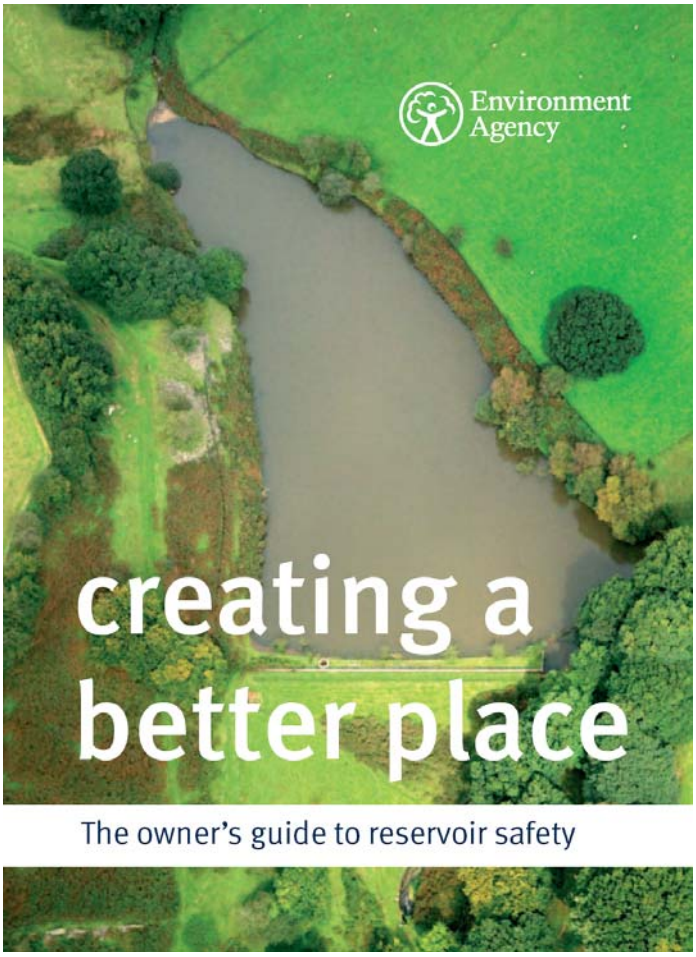
The following publications also include information on the history and risks posed by small raised reservoirs:

- Binnie 1987, *Early dam builders in Britain*, Thomas Telford, London.
- Charles 2002, *A historical perspective on reservoir safety legislation in the United Kingdom*, Reservoirs in a changing world, Thomas Telford, London.

- Goff & Warren 2008, *The Safety of Small British Reservoirs*, Ensuring reservoir safety into the future, Thomas Telford, London.

- Goff & Hope 2008, *Investigation of Potential Reservoirs*, Ensuring reservoir safety into the future, Thomas Telford, London

There has been little published information to provide reservoir owners with technical guidance on reservoir safety monitoring and surveillance. Of the 770 statutory reservoir owners, 75% have only one reservoir (typically, formed by a small embankment dam). Very few reservoir owners have access to in-house technical resources. In order to raise awareness of the need for effective surveillance and maintenance, we commissioned a simple guide to reservoir safety, aimed at the owners of small embankment dams, to raise awareness of safety issues thereby reducing risk. This was published and distributed in 2010 and is now available on our website.



6. Case study: Hameldon reservoir

Hameldon Reservoir is located on moorland near Accrington in Lancashire. It is thought that the reservoir was once used to supply a mill but serves no purpose now. When the company who owned the reservoir went into liquidation the reservoir was not claimed by any creditor and thus it transferred to the Crown as owner of last resort. In such instances, the Crown (the Duchy of Lancaster in this case) is legally entitled to choose not to exercise its right of ownership, and thus responsibility as owner under the Act.

The Environment Agency arranged for statutory inspections of the reservoir to be carried out in 2004, 2006 and 2008 using its reserve powers under Section 15 of the Reservoirs Act 1975. The 2008 inspection found the dam embankment to be in poor condition. The reservoir clearly posed a risk to life and this was later confirmed through dambreak modelling studies.

The condition of the dam appeared to be deteriorating and a study recommended discontinuance of the reservoir by excavating a notch through the full height of the embankment. Discontinuance was carried out using the Environment Agency's emergency powers under Section 16 of the Act.

Work to discontinue the reservoir was hampered by the need to provide alternative water supplies to nearby farms and by the need to pump out the reservoir before excavation could start. Pumping was necessary as there was no low level outlet pipe with which to empty the reservoir.

Hameldon: Key facts

- 135,000m^3 capacity
- 8m high earth embankment
- 841 properties at risk of inundation

Work commenced in 2009 and a discontinuance certificate was issued on 14 April 2010. The risk to the public has been removed and the site made safe.

Figure 6.1 The 'notching-through' of Hameldon Reservoir

7. Freedom of information

Some concern was expressed during the early stages of the post-incident reporting system that information provided to us about incidents would enter the public domain. This concern arose because, as a public body, we are subject to the Freedom of Information Act 2000 and the associated Environmental Information Regulations 2004 (EIR). As a public authority we have to apply a presumption in favour of disclosure. However, EIR regulation 12 allows us to refuse to disclose information if an exception to disclosure applies and the public interest in maintaining the exception outweighs the public interest in disclosing the information. Exceptions under regulation 12 include commercial confidentiality, volunteered information and national security.

8. Enforcement

Our aim through post-incident reporting is to improve reservoir safety. We have given a commitment to the reservoir industry that we will not use information acquired through post-incident reporting to retrospectively initiate enforcement action under the Reservoirs Act 1975.

9. Acknowledgements

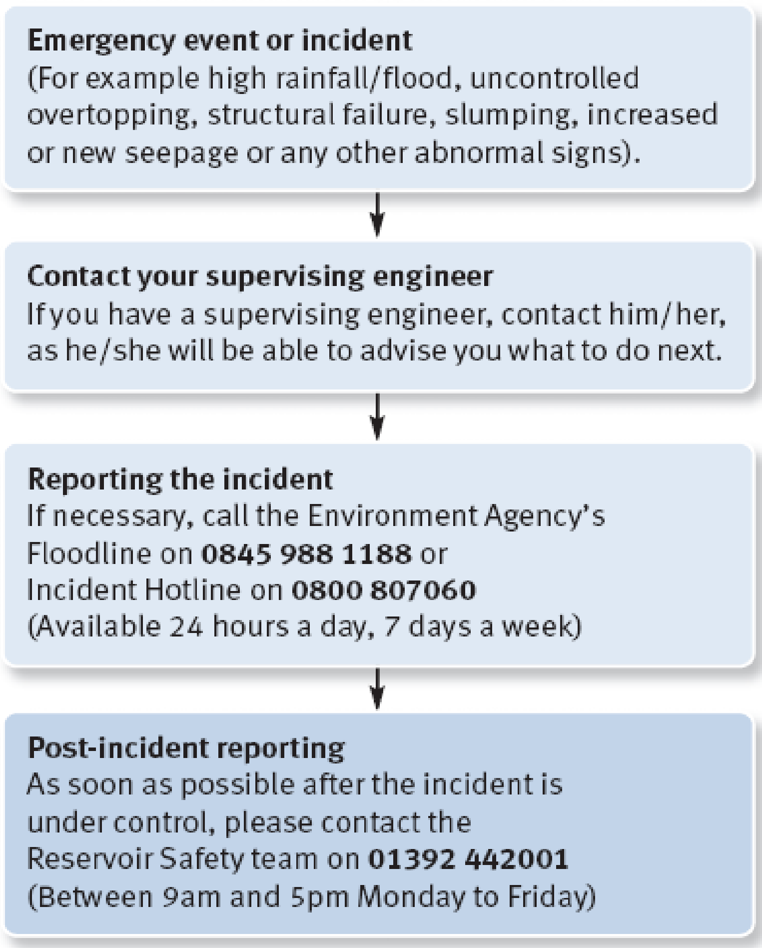
We would like to thank all those within the reservoir industry who have taken the time to contribute to the post-incident reporting system this year.

Appendix A: Reporting an incident

Details of how to report incidents, and an example of a post-incident report form are given in our publication 'Learning from Experience: Post-incident Reporting for UK Dams'. This also gives more information on the voluntary post-incident reporting system and answers some of the most common questions we have received.

We deliberately use the term 'post-incident reporting' so that it is clear that this system does not include incident management. If a problem arises at a reservoir you should follow the procedure outlined in the flow chart below.

We can receive post-incident information by phone, fax or email. Our contact details are at the back of this report. We suggest that you contact us as soon as possible after the incident is under control while the facts are still fresh in your mind. If the problem is likely to take some time to resolve, please let us know and we will call you back at a later date to find out more about the actions you have taken, and how effective they were.



Appendix B: Dam categories

Dam Category (from “Floods and Reservoir Safety”, Institution of Civil Engineers, 1996, 3rd edition)

Dam Category	Potential effect of a dam breach
A	Where a breach could endanger lives in a community*
B	Where a breach could (i) endanger lives not in a community or (ii) result in extensive damage
C	Where a breach would pose negligible risk to life and cause limited damage
D	Special cases where no loss of life can be foreseen as a result of a breach and very limited additional flood damage would be caused.

*A community in this context is considered to be 10 or more persons.

Appendix C: References

Charles J A (2005). Use of incident reporting and data collection in enhancing reservoir safety. Dams & Reservoirs, vol 15, no 3, November, pp 29-35

Environment Agency (2007) Learning from Experience: Post-incident reporting for UK Dams. Environment Agency, Bristol.

Environment Agency (2007) Improving safety, protecting lives: Biennial report on reservoir safety 1 April 2005 – 31 March 2007. Environment Agency, Bristol.

Environment Agency (2008) Learning from Experience: Post-incident reporting for UK dams 2007 Annual Report. Environment Agency, Bristol. http://publications.environment-agency.gov.uk/pdf/GEHO0408BNSH-e-e.pdf

Environment Agency (2009) Learning from experience: Post-incident reporting for UK dams 2008 Annual Report. Environment Agency, Bristol. http://publications.environment-agency.gov.uk/pdf/GEHO0409BPCX-e-e.pdf

Gosden J D and Brown A J (2004). An incident reporting and investigation system for UK dams. Dams & Reservoirs, vol 14, no 1, March, pp 21-28.

Hamilton-King L J, Hope I M and Warren A L (2008). Post-incident reporting: learning from experience to promote reservoir safety. Proceedings of the 15th British Dam Society Conference. Thomas Telford, London.

Skinner H D (2000). The use of historical data in assessing the risks posed by embankment dams. Dams & Reservoirs, vol 10, no 1, April, pp 9-12.

Tedd P, Skinner H D and Charles J A (2000). Developments in the British national dams database. Dams 2000. Proceedings of 11th British Dam Society Conference, pp 181-189. Thomas Telford, London.

Warren A L and Hope I M (2006). A new incident reporting system. Proceedings of 14th British Dam Society Conference, Durham, pp 27-36. Thomas Telford, London.

Post-incident reporting

Antony Deakin
Manager Reservoir Safety
Environment Agency
Manley House, Kestrel Way
Exeter
Devon EX2 7LQ

Tel: 01392 442001 Mobile: 07776 431871

email: tony.deakin@environment-agency.gov.uk
www.environment-agency.gov.uk/reservoirsafety

General information

Email: enquiries@environmentagency.gov.uk

or visit our website
www.environment-agency.gov.uk

incident hotline
0800 80 70 60 *(24hrs)*

floodline 0845 988 1188

Contact details

Incident reporting

Floodline 0845 988 1188 (24 hours)
Incident Hotline 0800 80 70 60 (24 hours)

Post-incident reporting

Please call us during normal office hours
(Monday-Friday 9am to 5pm) on 01392 442001.
Fax: 01392 444238

Or write to us at:
Reservoir Safety
Environment Agency
Manley House
Kestrel Way
Exeter
EX2 7LQ

Email: reservoirs@environment-agency.gov.uk
Website: www.environment-agency.gov.uk/reservoirsafety

Would you like to find out more about us, or about your environment?

Then call us on
08708 506 506* (Mon-Fri 8-6)

email
enquiries@environment-agency.gov.uk

or visit our website
www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

*** Approximate calls costs: 8p plus 6p per minute (standard landline). Please note charges will vary across telephone providers**

Environment first: This publication is printed on paper made from 100 per cent previously used waste. By-products from making the pulp and paper are used for composting and fertiliser, for making cement and for generating energy.