HR Wallingford
Working with water

Leigh Flood Storage Area Review

Independent audit of operation in the December 2013 flood

MCR5376-RT001-R04-00 July 2015

Document information

Document permissions	Confidential - client
Project number	MCR5376
Project name	Leigh Flood Storage Area Review
Report title	Independent audit of operation in the December 2013 flood
Report number	RT001
Release number	R04-00
Report date	July 2015
Client	Environment Agency
Client representative	Neil Gunn
Project manager	Andrew Tagg
Project director	Andrew Brown

Document authorisation

Prepared	Approved	Authorised
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Document history

Date	Release	Prepared	Approved	Authorised	Notes
24 Jul 2015	04-00	PGS	AFT	AFT	Appendix C added at client's request
23 Jul 2015	03-00	PGS	AFT	AFT	Revised based on invited third-party comments
14 May 2015	02-00	PGS	AFT	AFT	Minor corrections included
30 Apr 2015	01-00	PGS	AFT	AFT	Released to client for comment

Executive summary of the independent audit

In December 2014 the Environment Agency requested that HR Wallingford should undertake an independent audit of the Agency's operation of the Leigh flood storage area. The Environment Agency requested that the main issues to consider in the review should be:

- Did the Environment Agency follow the procedures?
- Did the operations worsen or cause flooding elsewhere in the catchment?
- Could the Environment Agency have done better?

Did the Environment Agency follow the procedures?

- The procedures for operating the Leigh FSA are well documented with clear lines of authority for effective decision making. The procedures identify routes of consultation between operational staff in specified roles so that the basis and consequences of decisions on the operation of the sluices are considered.
- The Control Room log and the logs provided for other Environment Agency functions have been examined and compared with the Environment Agency Operational Procedures for the Leigh FSA dated September 2013; the procedures were followed for all key decisions during the event.
- In December 2013 there were seven trained Leigh Barrier Operators available for duty. Between 23rd and 27th December 2013 five Operators undertook shifts in the control room to operate the structure during the flood; their individual length of experience as Operators varied from 5 to over 7 years.
- The Lead Operator took the decision to double-up on operators in the control room since the flood was clearly an unusual event. Although not covered in the procedures this decision was entirely appropriate and contributed to the effective operation of the structure.

Did the operations worsen or cause flooding elsewhere in the catchment?

- Given the rainfall over the Medway catchment, it was inevitable that Tonbridge, Yalding, Maidstone and other locations along the Medway would have flooded on 24th and 25th December 2013. The storage capacity available at the Leigh FSA was insufficient to prevent all flooding from occurring.
- Without the Leigh FSA there can be no doubt whatsoever that the flooding in communities adjacent to the River Medway from Tonbridge to Maidstone would have been significantly greater. Its operation did not cause or worsen flooding downstream. The only area in which flood levels were raised above those which would have occurred in the absence of the structure is in the storage reservoir itself.
- The operation of the Leigh FSA reduced peak flood levels in Tonbridge by approximately 0.6 m, in line with the rationale for the construction of the structure in accordance with the original Medway Flood Relief Act. The operation of the Leigh FSA reduced the initial rate of rise of flood level in Tonbridge from that which would otherwise have been experienced during the event with unrestricted flows.
- The benefits of the operation of the Leigh FSA for communities further downstream to Yalding and beyond are likely to have been similar, but without detailed hydraulic modelling it is not possible to quantify the effects precisely.

Could the Environment Agency have done better?

- A reconstruction of the inflow during the event is presented in this report and a hypothetical operational scenario has been identified which could have offered additional risk reduction at Tonbridge and for communities downstream. **However, without perfect foreknowledge of the inflows, this hypothetical optimal scenario could not have been found with sufficient confidence to enable its implementation**.
- The Operators' debrief and subsequent Action tracker documents 59 specific actions based on their experience in the event. Although many are already listed as complete, the Environment Agency should ensure that a plan is in place to implement the remaining actions.
- The Environment Agency should commission a revision of the Reservoir Balance Sheet tools as a matter of urgency to include the actual time of all observations made in deviation mode (rather than the assumption of a fixed 15 minutes schedule) and to ensure that the underlying volume relationship does not imply surface area decreases as level increases at any point.
- The description of the modes of operation, although clear for trained staff might cause unnecessary public concern and in particular the use of the word "*deviation*" is open to widespread misinterpretation.

The report contains other recommendations that the Environment Agency should consider which may improve the data available for decision making and may improve the resilience of the operation of the Leigh FSA.

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1. Introduction

1.1. Background to the Leigh FSA

Throughout this report, the Environment Agency preferred description of *Leigh FSA* (or Leigh Flood Storage Area) is used (note Appendix A contains a full list of abbreviations and acronyms). In many documents and staff positions the earlier name "Leigh Barrier" occurs. The change in name to Leigh FSA gives a better description of the function of the structure as providing temporary storage of flood waters rather than being a "barrier" that prevents all flood flows from passing downstream. The use of the name Leigh FSA should assist in the public understanding of the purpose of the structure.

1.1.1. Origin and description

Following a sequence of floods through the 1960s and especially the September 1968 event, Parliament passed the River Medway (Flood Relief) Act (1976) – termed "**the Act**" in this report, which authorised the then Southern Water Authority as the responsible Authority to acquire land and construct works for the relief of flooding in part of the River Medway catchment. The preamble to the Act makes specific reference to the propensity for extensive flooding in Tonbridge and Hildenborough parishes and the substantial alleviation possible through "*controlling the flow of the river and by storing temporarily part of such flow*". Part II of the Act describes the works to be constructed in some detail, including an embankment and sluice gates. Sub-section 17(1) of the Act gives the Authority power to operate sluice gates to control the flow in "*such a manner and for such periods as they think necessary and desirable*" and then lists four circumstances of operation – to control floods, in any other emergency, for testing the gates and finally for any other purpose. Sub-section 17(3) of the Act states that the power to operate the sluice gates in case of floods or emergencies shall be in accordance with a "scheme" made by the Authority and approved by the Minister, which may be replaced by another scheme at some subsequent time.

Subsequently the Leigh flood storage area (FSA) was constructed to reduce the risk of flooding in Tonbridge. The main structure comprises an earthen embankment approximately 1.3 km in length across the River Medway flood plain at Leigh approximately 2 km upstream of Tonbridge at Ordnance Survey grid reference TQ 562 457. At its highest point, the embankment crest is 5.7 m above local ground level. The embankment crest level is generally set at 29.15 m ODN which provides a freeboard of 1.10 m above the maximum permitted operational water level of 28.05 m ODN. Freeboard is incorporated into the design as a safety factor to accommodate factors such as wind effects on the water surface, extreme inflows above the design event, settlement of the embankment crest etc.

There is an in-line set of sluices on the River Medway having three gates, the outer two have similar dimensions and the centre gate which is normally open is wider and has a higher sill level. There is a separate gate on the Powder Mill Stream on the left flood plain of the Medway. The structure is operated from a control room on land adjacent to the Leigh FSA but lying beyond the limit of inundation of extreme floods. It is of prime importance that the Leigh FSA can be operated locally to the site under all conditions.

The original design of the sluice capacity at structure was for 300 m^3/s (the estimated peak flow rate of the once in 150 year flood) to pass through the sluices, with the upstream water level maintained at 28.05 m ODN, on the assumption that one of the three gates is not operational. With all three gates operating, their combined maximum capacity is 450 m^3/s . The gates are driven by electric motors. Should these motors fail to operate on demand, back-up procedures are put into effect. These include availability of mobile power

supplies and the ability for manual rather than powered operation of the gates in extremis. Thus there is a degree of redundancy in the operation of the structure which should ensure resilience to loss of primary power during an emergency.

The Environment Agency now owns and operates the Leigh FSA as the legal successor to the former Southern Water Authority. The operation of the structure is set out as a series of procedures covering automatic control in quiescent periods and under direct control by staff in the control room when river flows are expected to be raised above a certain threshold. I have taken these operational procedures to be the "scheme" required by Sub-section 17(3) of the Act.

1.1.2. Purpose

From the wording of the preamble to the Act the primary purpose of the Leigh FSA can be identified as to alleviate flooding in Tonbridge and Hildenborough.

Under Sub-section 17(1a) the Authority has in fact a more generally drawn power to operate the sluices to "*prevent or alleviate or otherwise control floods or inundations caused by overflow of the river [Medway] downstream of the control structure*". Moreover, the Act recognises that in exercising its powers the Authority may cause flooding of land upstream as a consequence of operation to reduce flow downstream or in an emergency.

Sub-section 20(1) of the Act also gives the Authority the power to control the passage of vehicles on Ensfield Road. This road becomes flooded and impassable when the Leigh FSA fills.

1.1.3. Over-riding requirements

The Leigh FSA is an impoundment that is governed by the provisions of the Reservoirs Act (1975). The purpose of the Reservoirs Act is to regulate all impounding reservoirs with capacity that exceeds 25,000 m^3 to ensure public safety; the Leigh FSA can impound over 20 times this amount. When fully brought into force, the Flood and Water Act (2010) may reduce this limit to 10,000 m^3.

The Reservoirs Act requires a regime of regular inspection and maintenance of the structure. The latest reservoir inspection report under the 1975 Reservoirs Act records that the normal maximum operating water level is 28.05 m ODN; this is 1.1 m below the general embankment crest level for safety purposes. When the structure is under stress (i.e. when the Leigh FSA fills), the relevant supervising engineer should be informed and their advice followed.

The River Medway Act in its Sub-section 18(5) constrains the operation of weirs and penstock gate on the Powder Mill Stream to ensure that the water level downstream of the structure is no less than 23.95 m ODN. This will set a condition for operation under low flow conditions in the catchment and not in a flood; hence it is not considered further in this review.

In addition to these specific requirements, the Environment Agency may assume a general "duty of care" to the public in its exercise of the powers that it was granted under the Act to construct and operate the Leigh FSA.

1.2. Overview of the event 23-27 Dec 2013

1.2.1. Severity in context

The Environment Agency has commissioned JBA Consulting to produce a separate report on the flood severity throughout the Medway catchment. The JBA report discusses several factors that describe the flood severity in terms of quantity of rain that fell, the river flow rates experienced and water levels achieved. As with all floods these factors differ at any location and across the catchment and are specific to this event. Thus when comparing against a historic flood – for example the major flood of September 1968 – the December 2013 flood appears to have different relative severity at different locations in the catchment (JBA, 2015). The Executive Summary of the JBA severity report is included in Appendix B below; it states that in the December 2013 event flows in the Medway rivers were amongst the highest ever recorded, in several places exceeding those of the September 1968 event. The rainfall was particularly severe on the Upper Medway catchment that drains into the Leigh FSA, both for the month of December as a whole and for the storm on 23rd December that led to the flooding on 24th to 26th December 2013.

1.2.2. Impacts in the Medway catchment

In line with good professional practice, the Environment Agency is currently preparing a factual post-event report on the December 2013 flood, which documents the extent of the event and the effects on the communities that experienced inundation during the event. The Environment Agency made available a draft copy of this report (Environment Agency, 2015) for the purposes of this review to illustrate the factual evidence available on the effect of the flood.

The communities affected in the December 2013 flood were: Edenbridge, Forest Row, Tonbridge, Hildenborough, Five Oak Green, East Peckham, Lamberhurst, Little Mill, Smarden, Laddingford, Collier Street, Yalding, Wateringbury and Maidstone with the sources of flood water being the Rivers Medway, Eden, Beult, Teise and Bourne and their smaller tributaries. In the December 2013 flood over 900 homes and businesses were flooded, but there are no records of any fatalities being attributed to the flooding.

1.3. Terms of reference for investigation

1.3.1. Three key Questions

The specification for this audit issued by Environment Agency requested that the audit should cover the following three questions as related to management of the structure for the flood event which occurred between 23/12/13 and 27/12/13:

1. *Did we follow the procedures?*
2. *Did our operations worsen or cause flooding elsewhere in the catchment?*
3. *Could we have done better?*

The specification also stated "*As operators we have a desire to improve our performance in future events. However, another driver for our investigation is the persistence of rumours that flooding in several different communities was caused or exacerbated by the operation of the structure*".

The Symonds Lane and Hampsted Lane Flood Action Group of Yalding requested an additional review question should be considered:

"*Are the existing procedures the best procedures to manage the catchment, including vulnerable communities downstream of Tonbridge?*"

The report addresses the essence of this question implicitly in answering the second and third questions posed by the Environment Agency in the original specification.

1.3.2. Issues excluded

During the consultation with third parties requested by the Environment Agency, some additional areas for investigation of interest to these parties were suggested. Following discussions with the Agency, the specification was not broadened to cover the planned investment in flood risk management measures in the catchment over coming years nor the procedures for issuing public flood warnings.

The Audit has focussed on the operation of the Leigh FSA in the period requested. In terms of flood warnings, the Audit has considered the interaction between the staff in the Leigh FSA control room and the Agency staff involved in flood forecasting, flood warning, and incident management. The operational procedures for the Leigh FSA cover such interaction so that appropriate decisions can be made on issuing public warnings by staff other than those operating the Leigh FSA.

1.4. Data available

The Environment Agency has provided the following information:

- Met Office weather forecasts available to the Leigh FSA operators;
- Contemporary river gauge information (the feeds available to the operators);
- Contemporary rainfall information;
- Forecast inflow data from the Environment Agency national flood forecasting system;
- The Leigh Barrier Operator Procedures that are used at the Leigh FSA (redacted of sensitive security information), dated 13 September 2013;
- A consultancy report prepared by Mott MacDonald for the Environment Agency, entitled "Leigh Barrier Operating Procedures Revision C", dated July 2013[1];
- Control room log for 23/12/13 to 27/12/13;
- Operators' logs;
- Other duty logs;
- The reservoir balance sheet and other operator tools;
- A catalogue of flood models of the catchment either completed or in progress;
- A return period analysis completed by JBA Consulting following the event;
- The draft report for the Kent and South London Winter 2013/14 Floods;
- The most recent reservoir safety inspection reports;
- A topographic survey of the Leigh FSA undertaken in mid-2014 to confirm the storage volumes available;

[1] It is important to note that although the document produced by Mott MacDonald has "procedures" in its title it does not determine the procedures in place, the document was commissioned by the Environment Agency to inform their review of operator procedures is 2013.

- Flood levels and flow rates from hydraulic modelling at selected locations as requested during the review.

1.5. Approach taken to the Audit

1.5.1. Review documents

The Environment Agency provided over 130 documents for the Audit in the general categories described in Section 1.4 by upload to the secure electronic data transfer portal at HR Wallingford in several tranches in December 2014 and January 2015. Some documents were found to be duplicated, based on the recorded file name and creation date. Such duplicates were assumed to be identical.

All files were opened and the content inspected and prioritised for detailed consideration. Some documents were not considered further in the Audit as they were judged not to have bearing on the operational decision process or the consequences of operation of the Leigh FSA.

1.5.2. Interview EA staff and third parties

Dr Paul Samuels visited the Leigh FSA control room buildings on 8th and 9th January 2015. This provided an opportunity to hear first-hand from operators who were on duty throughout the event in December 2013 and also to meet two representative members of the public by invitation of the Environment Agency. Subsequently Dr Samuels spoke by phone to other Agency staff who were unavailable on 8-9 January and to staff at the Agency consultants JBA Consulting and Mott MacDonald. The Environment Agency sought comments from interested third parties on Release R02 of this Audit report and these comments and responses to each one are tabulated in Appendix C.

1.5.3. Technical assessments

An important part of the Audit was to establish whether an alternative operation of the Leigh FSA could have had benefits to downstream communities. To support this it was necessary to reconstruct the probable inflow into the FSA from the River Medway catchment upstream based upon the records available. The reconstructed inflow was then used to identify the effects of alternative strategies for operating the sluice gates.

In addition the information on the Leigh FSA as incorporated in the reservoir balance model spreadsheet tools has been examined.

1.6. Outline of the report

The remainder of this report is laid out as follows:

- Section 2 describes the operational policy for the Leigh FSA;
- Section 3 reviews the actual operation of the Leigh FSA during the event;
- Section 4 considers the impact of the actual flooding in comparison with alternative operational scenarios;
- Section 5 provides recommendations for future operation of the Leigh FSA;
- Section 6 contains a restatement of conclusions and recommendations drawn in Sections 2 to 5.

The report also includes some references and three appendices"

- Appendix A is a Glossary of Abbreviations and Acronyms
- Appendix B is the Executive Summary of the JBA report on the flood severity
- Appendix C is a tabulation of comments and responses on release R02 of the current report .

Metric units of measurement are used throughout the report.

Quantity	Units
Water and ground levels	m ODN: metres above Ordnance Datum Newlyn
River discharge	m^3/s or cumec: cubic metres per second,
Volume	m^3 or cu m: cubic metres, sometimes millions of m^3
Area	Ha: hectare which is 10000 m^2
Rainfall depth	mm: millimetres

2. The operational procedures for the Leigh FSA

The information in this Section has been summarised from the relevant chapters of the Environment Agency, South East Region, Kent and South London, Leigh Barrier Operator Procedures, and the manuals and tools available to make decisions on the operation of the sluice gates. These documents were made available for the Audit. Section 3 below considers the actual operation of the Leigh FSA in December 2013 in the context of the procedures summarised below.

2.1. Staffing

The Environment Agency designates specific members of staff to be trained and available as a Leigh Barrier Officer (LBO). During normal quiescent flow conditions at the Leigh FSA these members of staff fulfil other responsibilities and duties within the Agency including potentially as flood incident duty officers (FIDO) working across their home area.

The Leigh Barrier Operator Procedures made available for the purposes of this Audit includes a list of seven staff designated as an LBO.

If the sluices are likely to run other than in Automatic Mode (see 2.4.1 below), then a rota is prepared for a LBO to be on standby or on duty in the control room for the duration of non-automatic operation.

The LBOs are assisted by Leigh Barrier Support Officers (LBSOs) but the LBSOs are not empowered to make operational decisions on the control of the sluice gates.

2.2. Decision hierarchy

The need to put the LBO team on standby is determined by the North Kent Flood Incident Duty Officer, (NK FIDO); it is understood that a FIDO is always in post. The decision is based upon the conditions in the upper Medway catchment, weather and flow forecasts. If one of a number of triggers is met then the NK FIDO contacts the LBO team to assign one of them as the Leigh Barrier Duty Officer (LBDO). If for some reason this is not possible the NK FIDO informs the Area Base Control (ABC).

Once a LBDO is in place they take primary responsibility for monitoring the situation at the Leigh FSA and any necessary operation of the structure. Initially, monitoring may be done at the Control Room or remotely from another place.

The LBDO prepares or updates a rota to ensure that a LBO is available for duty if the need is likely to extend beyond 8 hours or over a weekend or holiday period. The Agency Flood Resilience Team (FRT) is responsible for ensuring that an LBO rostered for duty as a LBDO does not have conflicting responsibilities on any other rota.

The sluices are changed from automatic to manual control by the time the flow through the sluices reaches 40 m^3/s. Once the flow reaches 50 m^3/s and is rising the LBDO must attend the Control Room and liaise with other duty officers with different roles for managing the event that is in progress.

The LBDO has a series of trigger points to liaise with the other duty officers for them to issue flood alerts or warnings, direct field operational teams etc. The LBDO will issue an impounding warning when appropriate in consultation with other duty functions and also will initiate the closure of Ensfield Road.

On the commencement of impounding, the LBDO informs certain staff who have key responsibilities and also the independent Supervising Engineer responsible for the structure under the Reservoirs Act.

Once the reservoir is impounding the LBDO takes decisions in consultation with the Kent Flood Warning Duty Officer (K FWDO) and the Monitoring and Forecasting Duty Officer (MFDO) to explore the implications of the operations under differing forecast scenarios. The structure may be operated in either "default" mode or "deviation" mode for large floods. The ABC is kept informed during the impoundment.

2.3. Tools, data and documentation

The operation of the Leigh Barrier is via a computer interface within a stand-alone copy of the South East Telemetry system (SETEL) that operates independently of SETEL. The LBDO can receive information from the Environment Agency telemetry through SETEL and also can take in information on future flow scenarios from the national flood forecasting system (NFFS). This interface operates in real time and enables the LBDO to monitor the current situation at the structure and elsewhere in the catchment, with information on the recent past and future forecast scenarios.

Each LBO also has access to two additional software tools developed specifically for the structure by the consultancy Mott-MacDonald (MM); these are the Gate Opening Calculator (GOC) and the Reservoir Balance Sheet (RBS). The GOC and RBS are used independently of the main computer interface with relevant data copied by the LBO from the real-time operational tools to these off-line support tools.

The GOC will give the sluice gate positions to achieve a desired outflow through the structure, taking account of the water levels on either side of the embankment. The calculations are based on the theoretical performance of the sluice gate design, and it is our understanding from discussions with the MM staff responsible that no in-situ calibration has been undertaken for the gates (see also the discussion in Section 5.3 below).

The RBS is a more complex tool than the GOC; it allows the LBDO to explore the impacts of different operational decisions for the sluice gate openings in the context of a range of future flow forecasts. The RBS is an EXCEL application and this allows the LBDO to modify forecast inflows and gate positions to develop decisions on how much water to impound or allow through the structure and the consequent maximum level achieved in the reservoir. The output from the RBS is colour-coded according to set thresholds to highlight critical issues to the operator. These trigger points include moving from default to deviation mode of operation, outflow exceeding the threshold for flooding at key downstream locations and the maximum predicted water level in the Leigh FSA exceeding the operational maximum of 28.05 m ODN. Since the RBS is used offline it is also suitable for use in post-event analysis and for staff development and training.

2.4. Modes of operation

2.4.1. Automatic mode

Automatic mode is the normal, day-to-day mode for the sluice gates at the Leigh FSA when the river flow in the River Medway is less than 35 m^3/s and so lies well within the capacity of the river channel downstream. The central gate is fully open. The water level on the upstream side to the structure is monitored via an automatic gauge and the side gates may be opened and closed automatically by equal amounts to maintain the water level within a target range. The side gates can be opened by up to 1m in Automatic mode.

2.4.2. Manual mode

Once the required discharge to maintain normal water level upstream of the sluices exceeds 40 m^3/s the LBDO changes operation from automatic to manual if this change has not been triggered within SETEL from the limit set for openings of the side gates under automatic control. The smaller central gate is closed and the water levels are controlled by the LBDO operating the two, higher capacity, side gates.

In manual operation, the LBDO monitors the water levels and sets the required side gate openings from the real-time operational system, using values from the GOC as required. Manual mode of operation continues whilst the level does not exceed 24.70 m ODN and so the reservoir has not started to impound. For outflows above 50 m^3/s the LBDO must operate the structure from the control room. Section 4.4. of the Leigh Barrier Operator Procedures sets out a series of actions that need to be taken at specified trigger points in manual mode which lasts until impoundment commences. The ABC must be informed of any decision to deviate[2] from the course of actions set down in Section 4.4 of the procedures.

2.4.3. Default mode

In default mode the reservoir is filled progressively as required with the outflow increased as necessary to a target flow of 75 ± 5 m^3/s. The LBDO prepares an operational plan for discharges downstream to keep water level below the maximum permitted impounded level. This is achieved by adjustment of the gate openings as in manual mode with the GOC being used to advise on gate openings as the water level in the reservoir changes. As the upstream water level rises, the required gate opening will reduce according to the performance characteristics of the gates. The procedures require the outflow to be recorded every 15 minutes. The procedures contain trigger points, related to the volume of flood storage used, at which deviation from default mode of operation should be considered.

2.4.4. Deviation mode

If the default mode cannot reliably control the maximum water level within the storage area to 28.05 m ODN or less with the maximum default outflow of 75 m^3/s, the procedures move to “deviation” mode, but this is a well-planned mode of operation and not a “deviation” in the common usage of this word. In “deviation” mode some degree of inundation in communities downstream is inevitable. A strategy for gate openings is prepared, agreed, implemented and reviewed to ensure the maximum water level does not exceed 28.05 m.

It is self-evident that in the most exceptional conditions this might not be achievable since the design of the structure was to discharge the 1 in 150 year flood peak and higher flows may occur. The procedures do not provide any additional instructions for such exceptional circumstances, apart from the need to ensure the Supervising Engineer has contacted the Inspecting Engineer if overtopping is projected or occurs.

2.5. Record keeping

The Environment Agency Leigh Barrier Operator Procedures dated 13 September 2013 set out certain records that should be kept in a Monitoring Log in an EXCEL spreadsheet for each event when an LBO is assigned to operational duty. The Monitoring Log spreadsheet records:

- Flow at Colliers Land Bridge (River Medway) and Flow at Vexour (River Eden);

[2] Here the common English usage of “deviate” is understood as a decision not to follow the normal course of action. This is distinct from the specialist use in “Deviation Mode” of operation as described in Section 2.4.4

- Predicted Inflow to the Leigh FSA;
- Gate Openings;
- Upstream water level;
- Outflow through the sluices.

In addition the LBDO can include in the monitoring log a description of issues in the event and review of the event. When the FSA is impounding, additional records of flows are kept in a copy of the RBS spreadsheet. The Procedures require these spreadsheets to be archived in a named location on the Environment Agency's computer file storage.

The LBOs each keep a personal record of incidents and their actions and communication when not in the Leigh FSA control room. When the control room is in use, the duty officer keeps a written account of discussions, actions, incidents etc. in a log book.

In July 2013, the Environment Agency's consultants, Mott MacDonald, produced a report titled "*Leigh Barrier Operating Procedures Revision C*" . This report was commissioned to assist the Environment Agency in revising the formal **Leigh Barrier Operator Procedures** that were issued on 13 September 2013. It is unfortunate that the title of the Mott MacDonald document implies it has the status as operating procedures, since this is not the case and can lead to misunderstanding outside the Environment Agency on the status of the document. For example, the Mott MacDonald report suggested in Section 1.4.1 the contents of a record keeping procedure in terms of Log Book comprising five Tables labelled A to E. This type of record book has not been used, since the Environment Agency did not incorporate this into the final **Leigh Barrier Operator Procedures**. The records set out in the later Environment Agency procedures have been adopted.

2.6. Summary of findings

The procedures for operating the Leigh FSA are well documented with clear lines of authority for effective decision making. The procedures identify routes of consultation between operational staff in specified roles so that the basis and consequences of decisions on the operation of the sluices are considered.

The consequences of the NK FIDO informing the ABC that they are unable to appoint a LBDO when needed are not described in the procedures. It is understood that the ABC will take action to rectify any conflicting responsibilities the LBOs have so that sufficient operators are available for being assigned in turn as LBDO. The procedures could be updated to make it clear that this is in fact the case.

The description of the modes of operation, although clear for trained staff might cause unnecessary public concern and in particular the use of the word "deviation" is open to widespread misinterpretation. The use of the descriptors "default" and "deviation" should be reconsidered in the context of any public communications regarding an event. Alternatives could be "Active" or "Manage" for "default" and "Defend" or "Flood" or "High Flood" for "deviation".

The operating procedures do not provide specific guidance for the exceptional case where the deviation mode of operation of the sluices cannot keep the water level from exceeding the maximum operating level. The Environment Agency should consider whether some additional guidance on exceptional conditions should be prepared for Chapter 5.

3. Assessment of operation in the event

3.1. Staffing of the control room

In December 2013 there were seven fully trained LBOs working within the Agency, but for personal reasons two were not allocated for duty during the event. The remaining five trained LBOs undertook shifts to operate the structure during the flood. The log book from the control room shows when they attended during the event. They are numbered below in the order found of their attendance in the Control Room during the event, the additional comments have been derived from the personal log books and interview with the operators concerned. See table 3.1 and Figure 3.1 below.

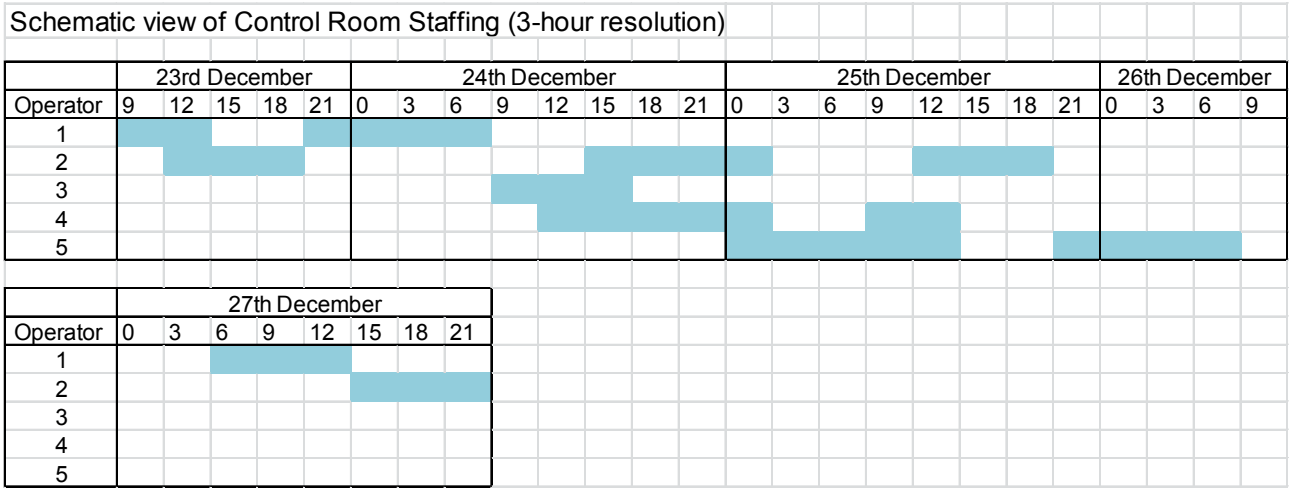
Early on 24/12 Operator 5 as the lead operator took the decision to double-up on licenced operators in the control room since the flood was clearly an unusual event, more severe than in recent years. Although not covered in the procedures this decision was entirely appropriate and contributed to the effective operation of the structure.

During the flood, particularly on the 24th December, vehicular access to the Control Room was difficult, due to substantial depths of flood water on both directions of the approach roads. It is known that Powder Mill Lane floods even in more frequent events, however, the December 2013 flood was unusual in that the road approaching from Leigh village was also deeply flooded close to the control room due to blocked surface water drains, requiring specialist vehicles to gain access. This delayed LBOs arriving for duty.

Table 3.1: Staffing of the Control Room during the event

	Duty or assisting	Additional comments
Operator 1	23/12 09:45 – 15:15 23/12 22:00 - 24/12 08:30 27/12 06:20 – 14:25	Monitored Leigh FSA 23/12 06:00 – 06:30 Over 6 years' experience at the Leigh FSA
Operator 2	23/12 13:50 - 22:00 24/12 15:50 – 25/12 02:10 25/12 13:00 – 22:00 27/12 14:00 - >21:30	Remotely monitored and operated LFSA on 21/12 and 22/12 5 years' experience at the Leigh FSA
Operator 3	24/12 08:30- 16:20	Over 6 years' experience at the Leigh FSA
Operator 4	24/12 11:20 – 25/12 01:20 25/12 <10:30? – 13:45	Over 7 years' experience, previously the lead operator.
Operator 5	25/12 02:00 – 25/12 13:15 25/12 22:00 – 26/12 08:30	Over 7 years' experience at the Leigh FSA, designated as lead operator for the Leigh FSA earlier in 2013. Acted as North Kent (NK) FIDO on 23/12. Active in advice to the LBDO team on a designated rest day on 24/12 (09:00 – 13:00)

Figure 3.1 Schematic view of staffing



During interviews with the LBO team, the issue of training and continuing staff development was discussed. The Agency undertakes staff development for the LBO team, including contingency exercises for major incidents either based on actual events or on hypothetical extreme events. Thus the training covers a wide range of events that might occur, to augment the direct experience of the Operators. The Mott MacDonald report "Leigh Barrier Operational Procedures, Revision C" (July 2011) contains an appendix of historic events that have led to impounding. Clearly, the December 2013 flood should be incorporated as a key event for future training scenarios.

3.2. Records available for assessment

Scanned copies of the following record logs were supplied for the purposes of this Audit:

- The Leigh FSA control room;
- Personal log book of Operator 1;
- Personal log book of Operator 2;
- Personal log book of Operator 5;
- The Area Base Controller (ABC);
- The Flood Incident Duty Officer (FIDO);
- The Flood Warning Duty Officer (FWDO).

The extracts of these log books covered the period 23 December 2013 to 27 December 2013. The original copies of the Leigh Control Room log book and the Operator's log books were available for inspection during the site visit and interviews in January 2015. The copies of the logs for the ABC, FIDO and the FWDO had the names of individuals redacted.

3.3. External forecast information available for operation

Flow forecasts for the River Medway catchment are produced as part of the Environment Agency National Flood Forecasting System (NFFS). This is a national operational system which receives information in real-time from river flow and level recorders, rain gauges and meteorological forecasts provided by the Met Office. The Flood Forecasting Centre (FFC) which operates the NFFS is a joint venture between the

Environment Agency and the Met Office, which was established following the recommendation of the Pitt Report into the summer floods of 2007.

In addition to providing catchment-specific flood forecasts the FFC provides Hydrometeorological Guidance to professional partners including Category 1 and 2 responders. The Hydrometeorological Guidance was available and updated daily to the operators of the Leigh FSA and generally provides regional-scale likelihood for issuing alerts for heavy rainfall and an assessment of coastal conditions in terms of potential for alerts for high tidal and wave conditions.

The FFC in fact did issue Heavy Rainfall Alerts for the EA South East Region on 25th December and 26th December which indicated the potential for additional accumulation of over 15 mm of rain in 6 hours or less over the Kent and South London area between 20:00 on 25/12 and 05:00 on 26/12.

The operators of the Leigh FSA received flow forecasts on a standard schedule (daily) from the NFFS and requested additional forecasts from the Medway Forecasting Duty Officer (MFDO) to inform the operational decisions for the sluices.

This audit has not considered the procedures for calibrating and updating the rainfall-runoff and river flow models for the Medway Catchment in the NFFS. It is understood the models are under review in light of the operational experience in the event.

3.4. Decisions and actions in the control room

3.4.1. Analysis of the log book records

A rota had been developed prior to 22nd December as is evident from the Operators' personal logs and the staffing of the control room shown in the Control Centre Log. The Procedures indicate that the rota may have been prepared by another member of the Agency Flood Resilience team given the scope of the weather event. Operators 1 and 2 were on duty on 21st December, with Operator 2 on duty overnight into 22nd December.

22nd December 2013

At 10:00 Operator 2 received an alarm from SETEL and placed the sluices in Manual Mode with flow set at 45 m^3/s. At around 10:09 to 10:15 Operator 1 spoke to Operator 2 to agree timing of hand-over of shift that evening around 19:00. The decision was to operate from home as no significant rain was forecast for next 24 hours and Vexour and Colliers Land gauges were at or had passed their peaks. These decisions are in line with procedures. Operator 2 went off duty at 19:30, handing over to Operator 1 as in the rota. Operator 1 monitored situation overnight. At 20:45 to 21:15 Operator 1 noted that the Medway model *[flows]* almost double what has actually gone through.

23rd December 2013

Operator 1 arrived in the control room at 09:45. The following actions were taken in line with the procedures:

- Went to control room whilst gates were in manual mode at 09:45;
- Requested a bespoke run of the Medway forecasting model from MFDO at 11:45;
- Reviewed implications of forecast using the Reservoir Balance Sheet (RBS) at 13:30;
- Discussed preliminary impounding warning with FWDO at 14:10 as flow expected to exceed 50 m^3/s;

- At 14:55 informed FIDO of Ensfield Road closure effective from 15:30 so that this was undertaken in daylight hours (previously this had been discussed and agreed with the ABC at 14:30 and 14:50, but, although entirely reasonable, the involvement of ABC is not required in the written Procedures);
- Informed the parties required in Annex B for closure of Ensfield Road from 15:00 to 15:15;
- Discussed situation with reservoir supervising engineer at 15:10 (however, this action was not inserted in the log until around 19:00);
- Continued to monitor and receive various alarms from SETEL.

The Leigh Barrier Monitoring Log spreadsheet contains half hourly entries after 15:30, with a value omitted at 23:00. This omission has no consequences as the gate openings are the same at 22:30 and 23:30 and the outflow only changed by 2 m^3/s as the level rose.

The outflow from the sluices was recorded as increasing from 16:00 having reduced somewhat earlier in the day but as at midnight the flow still was less than 50 m^3/s and so no other actions were required by the procedures.

During the day the NFFS forecasts were thought to be 20% too high (based on observations at Leigh and previous experience of the Medway forecasting model).

24th December 2013

There was clearly substantial pressure on the LBO team on 24th December as the flood developed rapidly, more so than experienced in more moderate events. Occasionally the log book has a blank line not crossed through between entries, there is no evidence however that anything has been omitted or redacted from the scanned copy provided for the Audit. The following decisions and communications are logged for the remainder of the event.

- At 01:30 there was a teleconference with the flood incident team on duty. The water levels are not high enough to increase flow above 60 m^3/s by raising the gates further (presumably the gates are out of the water).
- At 02:00 Operator 1 discussed forecasts with the MFDO, the forecasts still judged to be 20% too high and a joint decision made to continue using lower inflow estimates.
- At 03:50 Operator 1 discussed forecasts with the MFDO as forecasting model indicates 111 m^3/s but the observations at Leigh indicate only 55 m^3/s outflow, MFDO agreed to investigate.
- At 04:30 MFDO called to discuss discrepancy in flow estimates. Operator 1 agrees to continue to use 20% reduction.
- At 05:00 Operator 1 recorded the outflow has increased to 66 m^3/s. Contacted FIDO to issue impounding notice as required by procedures at the 70 m^3/s threshold flow.
- At 05:45 Operator 1 advised the field team of need to monitor on the ground downstream as required by procedures; the Reservoir Supervising Engineer was informed by text of decision to impound as required.
- The Powder Mill Stream penstock was closed at 05:50 as required by procedures.
- At 05:55 Operator 1 moved the Leigh sluice gates to commence impoundment, the outflow was recorded as 70m^3/s and upstream level was 24.83 m ODN.

Centre Gate opening data

At 05:58 the centre gate started to close with closure complete at 06:02. It remained closed until 20:40 on 26th December, by which time the water level upstream had remained between 24.1 and

24.2 m for three hours, and so the structure was returned to automatic mode in line with the procedures.

North Gate and South Gate opening data

Smaller adjustments began at 04:57 and 06:04 for the North Gate and at 06:21 for the South Gate. The gate openings were similar (but not identical) throughout the event. The intention was to provide an approximately even flow distribution downstream of the structure to reduce the potential for scour of the bed and banks.

- At 06:15 Operator 3 called – access to the control room was blocked by flood water.
- At 06:30 MFDO suggested data recording in Tonbridge to assist with model calibration. Supervising Engineer confirmed receipt of text advice.
- At 07:10 Operator 1 recorded adjustment of the North and South gates to give outflow of 74.83 m^3/s. The gate records show this movement occurring at 07:06 on the North Gate and 07:07 on the South Gate.
- At 07:30 MFDO called confirming levels in Tonbridge were consistent with recorded Leigh outflow. MFDO suggested Medway model is over-predicting. The log book has a blank line not crossed through before the next entry.
- At 08:30 Operator 3 took over duty role. Operator 3 spoke with MFDO to request an updated forecast in line with the procedures in order to review the operational strategy and plan for the sluice operations. The NFFS indicated a peak inflow of 192 m^3/s at 15:00, however, MFDO advised use of 170-180 m^3/s as model was likely to over-predict. MFDO suggested that flow gauging would assist. Operator 3 consulted Operator 1 and MFDO as deviation from default mode seems likely (i.e. outflow from Leigh FSA may exceed 75 m^3/s).
- At 09:00 Operator 5 called the control room and discussed with Operator 3. The RBS calculations suggested instantaneous inflows exceeding 300 m^3/s. Operator 3 asked Operator 5 to double check the numbers.
- At 09:19 Operator 3 concluded that without moving to deviation mode, the water level will exceed maximum impoundment permitted at 18:00.
- 09:22 LBO called the ABC to initiate a conference call as required in Step 4 of the procedures for authorising a deviation. The event logs show the LBO had discussed the situation with MFDO and had run the RBS model within the preceding hour as required in Steps 1 and 2 of the procedures. There is no documentation of separate dialogue with the FIDO on downstream consequences as laid out in Step 3. However, the ABC log at 09:15 includes reference to the ABC initiating discussion with four other colleagues to consider the implications of the increased releases. The FIDO log book records at 09:29 consideration of downstream flooding implications of higher release (over 135 m^3/s) from Leigh FSA affecting Hildenborough, East Peckham and Tonbridge.
- 09:30 Conference call (included LBO and FWDO) on the need for deviation agreed; FWDO to issue warnings immediately.
- At 09:42 Operator 3 initiated sluice movements for deviation from the default mode, outflow set to 100 m^3/s with plan to increase to 110 m^3/s. Operator 3 to revisit the plan for the event.
- At 09:42 Operator 5 requested Operator 4 to go to the control room.
- By 09:50 Operator 3 had produced plan for outflow to increase to 140 m^3/s, asked Operator 5 to review.
- At 10:07 Operator 3 opened gates to increase outflow to 107 m^3/s.

- At 10:10 Operator 3 asked two LBSO to inspect the embankment (twice daily inspection is required in procedures during an impoundment).
- At 10:14 Operator 3 called MFDO about a new NFFS forecast.
- At 10:20 ABC log records discussion with Operator 3 about need to increase outflow to 130 m^3/s, comments that the earlier conversation had confirmed this is in line with procedures and there were limited choices open.
- At 10:24 Operator 3 consulted Operator 5 on implications of new forecast.
- At 10:35 LBO contacted reservoir engineer to advise of the situation, reservoir 50% full, inflow about 200 m^3/s compared with 180-190 m^3/s from NFFS, LBO suggested increasing inflow to 20% above forecast for operational planning. Reservoir Engineer agreed on setting outflow to 140 m^3/s based on current rate of rise.
- At 10:48 Operator 3 contacted Operator 5 to run a 20% increase in NFFS forecast flows for planning to check the impacts. Operator 5 noted a further discussion at 11:10 with agreement to use 20% increase for the plan.
- At 10:50 Operator 3 was unable to contact FWDO.
- At 10:54 Operator 3 contacted ABC to alert him of possible need to increase outflow to 140 m^3/s sooner due to under prediction of inflows. The ABC log does not record this call.
- At 11:03 – the monitoring (required every 15 minutes) indicated inflow of 283 m^3/s, with average (using previous one?) of 230 m^3/s, rate of rise is 27-30 cm per hour. Operator 3 recorded that "*this all suggests the NFFS inflow predictions are too low*".
- Between 11:07 and 11:11 Operator 3 recorded checking flows against the LBO operational manual for the recorded rainfall which is consistent with the event being experienced. Operator 3 recorded revised assessment to increase outflow to 150 m^3/s.
- At 11:15 Operator 3 contacted ABC to alert him of need to increase outflow to 150 m^3/s. ABC agreed to do so when necessary. The ABC log does not record this call.
- At 11:20 Operator 4 arrived at Control Room. *[Having been delayed by deep flooding close to the site].*
- At 11:34 Operator 3 called FWDO to inform of increased outflow – now looks similar to the 2000 event.
- At 11:50 Operator 3 had tested assumptions against "old procedures" – these suggested inflows closer to NFFS amounts, new procedures still give 200+ m^3/s inflow.
- At 12:01 gates adjusted to increase outflow to 120.48 m^3/s, let this stabilise, monitor every 15 minutes before further change to higher flow in the plan.
- At 12:15 There was a teleconference on tactics with AIR. Tonbridge agreed to be the priority.
- At 12:45 Operator 3 reviewed rate of rise (200 mm/hr and water level 700mm below maximum) – need to increase outflow.
- At 12:50 Outflow increased to 140.21 m^3/s.
- At 13:05 and 13:18 Operator 3 recorded that photos received of some issues seen in embankment inspection and Operator 4 discussed inspection with the Supervising Engineer – would forward the photos.
- At 14:06 Operator 3 noted a report of high water levels against town *[Tonbridge]* walls.
- At 14:00 to 14:36 FWDO collated information from across the catchment, noted amongst others increased flow from Leigh and concern about Yalding as the Medway meets the Beult.

- At 14:36 the ABC called FWDO to discuss Severe Flood Warning for Yalding – the decision was to monitor and consider.
- At 14:49 FWDO noted Leigh outflow increasing to 160 m^3/s.
- At 15:00 Operator 3 noted inflow still showing as 200 m^3/s and continued rate of rise – increased outflow to 160 m^3/s. Notified FWDO and FIDO.
- At 15:28 Operator 4 participated in telecon with others (ABC? participants not all known); Operator 4 was instructed to use maximum storage volume available but not to go above 28.05 m, LBO to communicate with field team in Tonbridge – water level to be kept close to the crest of the town walls.
- At 15:40 Operator 3 reported to the Supervising Engineer.
- At 15:50 – 15:55 Operator 2 recorded conversation with FWDO regarding information request to Silver Control.
- At 16:00 Operator 4 noted town walls were leaky and level was 2 bricks from top.
- At 16:20 Operator 4 checked levels (with Operator 2) and assessed that there was scope to reduce outflow. Reduced to 150m^3/s with aim of moving to 140 m^3/s.
- At 17:10 gates raised to increase outflow to 160 m^3/s then reduced to 153 m^3/s. Upstream level 27.798 m no reasoning was given for these movements.
- At 17:15 FWDO noted that the town walls overtopped.
- At 17:20 and 17:30 Operator 2 noted locations of flooding in Tonbridge.
- At 17:45 outflow reduced to 145 m^3/s.
- At 18:00 upstream level now 27.877m.
- At 18:00 the ABC recorded that there was no benefit from issuing a severe *[flood warning].*
- At 18:30 gates lowered to reduce flow to 133 m^3/s.
- At 18:40 Operator 2 briefed ABC and FWDO.
- At 18:40 FWDO noted Leigh was discharging 142 m^3/s.
- At 18:45 outflow reduced to 130 m^3/s.
- At 19:00 outflow reduced to 126 m^3/s.
- At 19:15 outflow reduced to 121 m^3/s.
- At 19:30 Operator 4 had a telecon with the TAG; decision to increase outflow again because of concern about rate of rise of the impounded water level.
- At 19:45 Outflow increased to 147 m^3/s.
- At 19:50 FIDO noted barrier discharging 147 m^3/s and 95% *[full].*
- At 20:00 Operator 4 reported to AIR that reservoir level had stabilised.
- At 20:30 Operator 4 noted that reservoir level was decreasing slightly 28.02 m.
- At 20:37 FWDO noted that it was possible Leigh *[outflow]* would increase to 160 m^3/s or more as FSA at 98% capacity.
- At 21:00 Operator 4 reported to Area Manager (AM) that reservoir level had stabilised and it could be possible to reduce outflow.
- At 21:15 Operator 4 noted decision confirmed by AM to reduce outflow to 137 m^3/s.
- At 22:52 Operator 4 received 1-Day rainfall forecast from midnight onwards from FWDO – widespread 5mm, spot totals 10 mm.

25th December 2013

- At 00:00 Operator 2 noted conditions in Tonbridge.
- At 01:00 Operator 2 reduced outflow to 125 m^3/s to assist in Tonbridge, plan to maintain this flow for a few hours.
- At 01:05 and 01:20 Operator 2 received updates from the field team in Tonbridge and at 01:15 Operator 2 briefed the supervising engineer.
- At 01:20 Operator 4 left the control room, at 02:00 Operator 5 arrived in control room and took over as duty LBO from Operator 2 at 02:10, agreed to continue the current openings, with review at 06:00.
- Between 02:44 and 03:48 Operator 5 received reports of conditions in Tonbridge (level decreasing) and Yalding (flooded but levelling off) and reviewed telemetry information.
- At 03:52 Operator 5 reviewed recorded rainfall amounts 4.8, 5.2 and 5.6 mm recorded in 12 hours at 3 gauges.
- At 03:55 Operator 5 reviewed NFFS forecast – inflow to reduce to 100 m^3/s by 21:45, additional rainfall not yet showing an impact.
- At 04:20 FIDO requested update for rolling brief, Operator 5 gave capacity as 87% full.
- At 05:30 Operator 5 discussed situation at town defences, Town lock level 22.112 m AOD. Outflow was 122m^3/s. inflow was 70 m^3/s, upstream reservoir level was 27.799 m.
- Between 06:15 and 06:39 phone calls are logged relating to an incident at East Farleigh with a car swept into the river, emergency services notified.
- At 06:37 FIDO noted Outflow 121 m^3/s, max 20mm rain forecast, Leigh Barrier inflow 80 m^3/s, level 27.742 m; 87% full.
- At 07:16 Operator 4 called for an update, and Operator 4 advised Operator 5 of need to check location of potential bubbling through embankment during the AM inspection.
- Between 07:37 and 09:38, Operator 5 recorded conversation with Supervising Engineer and then arrival of two supporting staff who undertake an inspection of the embankment as required in the procedures.
- At 08:58 and 09:36 Operator 5 noted an update of situation in Tonbridge.
- At 09:20 Operator 5 noted difficulties with recording actual levels at 07:15, 07:30 and 07:45 due to phone calls – the less accurate information included in spread sheet (2 decimal places) had “strange impacts”.
- At 09:30 Operator 5 called FIDO and advised of need to be more pro-active with Leigh Barrier tweets *[i.e. public information through social media]*.
- At 09:35 FWDO called - Operator 5 busy on radio – called back at 09:40 to discuss outflow, capacity and review revisions of warnings.
- At 10:10 Operator 5 reviewed the flows downstream including that of the River Beult – levels were likely to remain the same in Yalding since the peak on the Beult should coincide with a reduction from Leigh. Levels peaked in Yalding during the night. Further reductions during the morning of 25 December from Leigh outflow assessed as bringing no benefits at Yalding.
- At 10:14 Operator 5 reviewed Met Office rainfall forecast 25 December 7 mm to 18 mm, 26 December 3 mm to 15 mm, 27 December 22 mm to 32 mm. Decided to review NFFS forecast. Operator 5 decided to maintain current outflow to empty the Leigh FSA as far as possible before the next rainfall arrives. NFFS did not yet capture any response to this future rainfall.
- At 10:31(?) Operator 4 records conversation about national and regional communications.

- At 10:45 FIDO called Operator 5 about evacuation in progress in Maidstone and the need to respond to tweets. Operator 5 reviewed tweets at 10:55, and recorded need to update key messages.
- At 13:15 Operator 2 took over duty role.
- At 13:29 FWDO requested update, current outflow 111.5 m^3/s, agreed to maintain outflows as 110-120 m^3/s. At 15:33 gates were adjusted, outflow increased to 119.76 m^3/s.
- At 13:30 Operator 2 consulted the AM who agreed the outflow should be maintained in the range 110-120 m^3/s.
- At 16:00 and 16:10 conversations between FWDO and the Leigh control room, on whether a reduction in outflow could be made to ease downstream flooding. Operator 2 informed FWDO of the AM decision to maintain outflow. FWDO asked for implications of reduced outflow. Reducing to 90 m^3/s calculated to give draining time of about 22 hours. Operator 2 obtains approval for no change from the ASM and informs FWDO.
- At 18:10, 20:36, 21:47 Operator 2 moved gates to keep flow at 120 m^3/s.
- At 18:24 Operator 2 updated Reservoir Engineer who is content with current plan. The reservoir should be emptied by 06:00 on 26 December. Reservoir Engineer planned to visit to inspect the embankment on 27 December.
- At 22:00 shift change, Operator 5 took over the duty role. Operator 5 reviewed the situation, no change in outflow plan, reported flooded roads to Kent CC highways because of continuing difficulties with access to the control room, confirmed shifts for next day.

26th December 2013

- At 00:53 Operator 5 discussed with FIDO plans for potential Ministerial visit on 27 December. Operator 5 was to prepare a briefing.
- At 05:00 Operator 5 noted that water level was now 24.79 m ODN and outflow down to 60 m^3/s.
- At 06:15 the staff gauge records show the water level had fallen to 24.689 m, which is below the indicator of impounding (u/s level value 24.7 m AOD) in the procedure for when to cease monitoring.
- Between 06:15 and 07:10 Operator 5 follows the steps to close down the control room – opened Powder Mill Sluice, and reviewed Ensfield Road – decided not to open yet as look-up flow estimate indicated the chance of flooding later in day. At 06:56 Operator 5 sent the spreadsheet to Operator 4.
- At 07:15 Operator 4 called and agreed to take on the phone and BT, with Operator 5 dealing with control room closure. Operator 5 agreed to resume as LBDO from Operator 4 at 17:00.
- At 08:30 the Control Room was closed down.
- At 20:40 the sluice gate records show the that centre gate began to open as the control mode passed from Manual back to Automatic, with the gate movement completed at 20:45.

27th December 2013

- At 06:20 Operator 1 reopened the control room and reviewed situation. The inflow was predicted as 55 m^3/s and Operator 1 requested a Forecast Model run with 25% increase in rainfall.
- At 09:45 the Reservoir Engineer arrived to inspect the embankment.
- At 11:30 Meridian News team arrived.
- At 13:40 Operator 1 reviewed situation for Ensfield Road – flow was still too high to open.

- At 14:24 Operator 2 took over duty role and continued to monitor flows and levels, the inflow was recorded in the range 37.33 m^3/s to 45.25 m^3/s and the outflow was reduced to 30 m^3/s, with potential reviewed for formal impoundment if the water level rose above 24.7 m ODN.

3.4.2. Were procedures followed for barrier operation?

As commented in Section 3.4.1 above the procedures were followed on 23rd December for the move from automatic to manual mode of operation, opening the control room, closing Ensfield Road, using the RBS to prepare an initial plan for the event based on forecast flows and dialogue with other Environment Agency functions (MFDO, FWDO, FIDO and also the ABC). The water level upstream of the embankment did not reach the threshold of 24.70 m for impounding on the 23rd December and the outflow remained below the 50 m^3/s threshold. Nevertheless the LBO had discussed issuing a preliminary impounding notice with the FWDO at 14:10 as the outflow was expected to exceed 50 m^3/s.

Early on 24th December, the flood developed rapidly and the decision to issue an impounding warning was made at 05:00 as is required by the procedures before the outflow reached 70 m^3/s. The field team were dispatched to monitor downstream although this action is recorded at 05:45 when the flow was about 10% higher than required by the procedures. The procedures give a threshold of 65+ m^3/s, for this action which was passed at about 04:45; however, no consequences can be attributed to this small delay. Impoundment commenced at 05:50 in line with the operational procedures with the closure of the Powder Mill penstock, the closure of the central sluice and adjustment of the two side sluices to regulate to outflow to 75 m^3/s.

Between 05:50 and 08:00 the Leigh FSA was operating in default mode with an outflow of approximately 75 m^3/s and the water level was rising behind. For any sluice gate at a fixed opening, as the water level rises, so will the discharge through the sluice since the outflow depends upon the upstream level. Thus as expected the side gates were moved to maintain the target outflow for default operational mode in this period.

At 08:15 on 24 December the capacity was 25% used and at 10:00 the capacity was 50% used. In this period the LBOs assessed the forecasts with the MFDO and reviewed the operational plan, and a conference call took place with the ABC at 09:30. The Control Room records together with those of the other functions (FIDO, FWDO, ABC) show that the downstream consequences were considered and so all the correct procedures had been followed for the move from default to deviation mode of operation as the outflow was increased from 09:42 onwards.

The Lead Operator took the decision at 09:42 on 24 December to double-up staffing of the control room to support robust decision making as the unusual nature of the event became apparent. This decision fell outside the standard staffing procedure, but is commendable since it facilitated double-checking to verify the operating plan.

Operation during the impoundment in deviation mode is obviously specific to the characteristics of the event which will determine the inflow, the rate of rise of the impounded level and the duration of the impoundment. The log book entries as set out in Section 3.4.1 above, show a regular dialogue between the LBOs at the Control Room and the forecasting, warning and emergency management functions of the Environment Agency, with discussions recorded with the ASM, ABC, FIDO, FWDO, MFDO and the independent Supervising Engineer. The impacts of the event on downstream communities is recorded on several occasions, with particular concern on the water level against the town walls in Tonbridge, which had been agreed to be the priority.

In particular there is ample evidence that the LBO discussed forecasts regularly with the MFDO including the assessment of MFDO's confidence in the forecasting model as required in the Procedures. It is important that the characteristics of the forecasting model should be taken into account alongside direct monitoring when developing an operational plan. The experience of the forecasting model is recorded in several places that it usually over-predicted flows by about 20% and this was built into the decision making at the early stages of the event. However, when the local data from the rate of filling of the reservoir indicated flows significantly in excess of the NFFS forecasts, the operators used the local information. At 11:00 on 24 December the Lead Operator instructed the LBO team to plan for a flood peak 20% above the forecast; given the information available at that time this decision was prudent and appropriate.

Operator 5 reviewed the downstream flood conditions at 10:10 on 25 December and then the Met Office future forecast rainfall for the catchment at 10:14 over the 3 days to 27 December. The total 3-day rainfall forecast was 32 to 65 mm with approximately half of that on 27 December. Operator 5 planned to empty the Leigh FSA before the next rain arrived. The Tabulation of the size of the developing flood given in the operational procedures manual for the Leigh Barrier indicates a flood discharge of between 70 m^3/s and in excess of 150 m^3/s associated with these depths of rainfall. Discharges in this range would trigger operation of the Leigh FSA in manual or default mode. Given the large flood that was just abating and the fact that the catchment would be wetter than average, the decision to maintain the outflow of 110 – 120 m^3/s was justifiable and appropriate. This decision was confirmed by the ASM in a phone conversation with Operator 2 at 13:30 and this planned outflow was used during the day; it was reconfirmed by Operator 5 at 22:00 and maintained until the reservoir was emptied at 05:00 on 26 December.

After the reservoir had emptied on the morning of the 26 December, the Powder Mill penstock was opened in accordance with the procedures. However, Ensfield Road was not reopened but the situation visually inspected later in the day.

3.4.3. Which communities were considered?

The principal concern evidently was the level in Tonbridge and the water level was actively monitored by the Environment Agency field team in relation to the top of the town walls. These levels were reported on several occasions to the LBO to assist in the operational planning for the outflow from the Leigh FSA sluices. This concern for Tonbridge first of all is consistent with the original purpose of the Leigh FSA as set out in the Act.

The impacts of operations on the communities downstream were considered by the ABC and the FWDO whose task it was to issue warnings and there was regular dialogue between the LBO and FWDO as implied by the procedures. The communities downstream of Leigh that were considered are recorded in the FWDO log include Hildenborough, Tonbridge, Yalding, East Farleigh and Maidstone.

3.4.4. Consideration of reservoir safety

The extracts from the control room and other logs set out in Section 3.4.1 above show that due consideration was given to the safety of the reservoir as required by the procedures. The Operators contacted the Reservoir Supervising Engineer as required by the procedures to inform the Engineer of the decision to impound. The Environment Agency staff at the site undertook regular (twice daily) visual inspection of the embankment, reporting conditions to the Supervising Engineer and maintaining dialogue during the event. In particular Operator 3 initiated a call to the Supervising Engineer at 15:40 on 24th December when the water

level was just below the 85% capacity threshold as stated in the procedures. The maximum water impounded at the Leigh FSA was kept within the maximum permitted (28.05 m ODN) by a few millimetres.

3.4.5. Interaction with flood warning service

The logs of the Leigh control room and the ABC, FWDO, FIDO and the MFDO show regular interaction between the LBO and these other functions so that the conditions at the Leigh FSA were taken into account for public warning and emergency management by the Environment Agency.

3.4.6. Record keeping in practice

As will be seen from the summary in Section 3.4.1 above the log book from barrier control room provides substantial detail on the actions and decisions during the event; the entries provide more detail than some of the other logs made available for the review. However, it is not always clear when staff arrived / left, these instances are recorded as query (?) in Table 3.1.

During the interviews with the Leigh Barrier Operators, attention was drawn to some minor changes that were made after event, these are clarifications that are signed and dated and are of no concern.

Not all gate movements are recorded in the log books since the policy is to adjust the gate openings to maintain specific flows within a specified target range. The gates move at a finite speed and so each adjustment may take some minutes to complete. A detailed electronic record of the gate positions is available from the telemetry system and these gate positions are plotted below. The position of the North gate was recorded approximately 6000 times on the 23rd to 27th December inclusive. The position of the South gate was recorded over 5600 times and the Centre gate over 3300. The plots in Figures 3.1, 3.2 and 3.3 below give the percentage gate opening recorded for each gate on common axes. The closure of the centre gate at 05:58 on 24th December is clearly evident as the water level control during the event was moved to using the two side gates as set out in the Operator Procedures.

One of the local representatives interviewed expressed concern about a gate movement at 07:46 on 24th December. The records of the gate positions show the centre gate as closed and the two side gates moved to have nearly equal openings 27.37% and 27.04% open on the North and South gates respectively at this time. The gate openings are reasonable given the rapid increase in inflow at this time and the decision to start impounding taken at 05:50.

The Environment Agency Leigh Barrier Operator Procedures (September 2013 edition) set out the need to record information every 30 minutes in manual and default modes in a Monitoring Log and every 15 minutes using the RBS when impounding. Both these records are maintained in EXCEL spreadsheets and electronic copies of these records were available for this Audit. The records have been properly kept, apart from an occasional value omitted early in the Monitoring Log for the event.

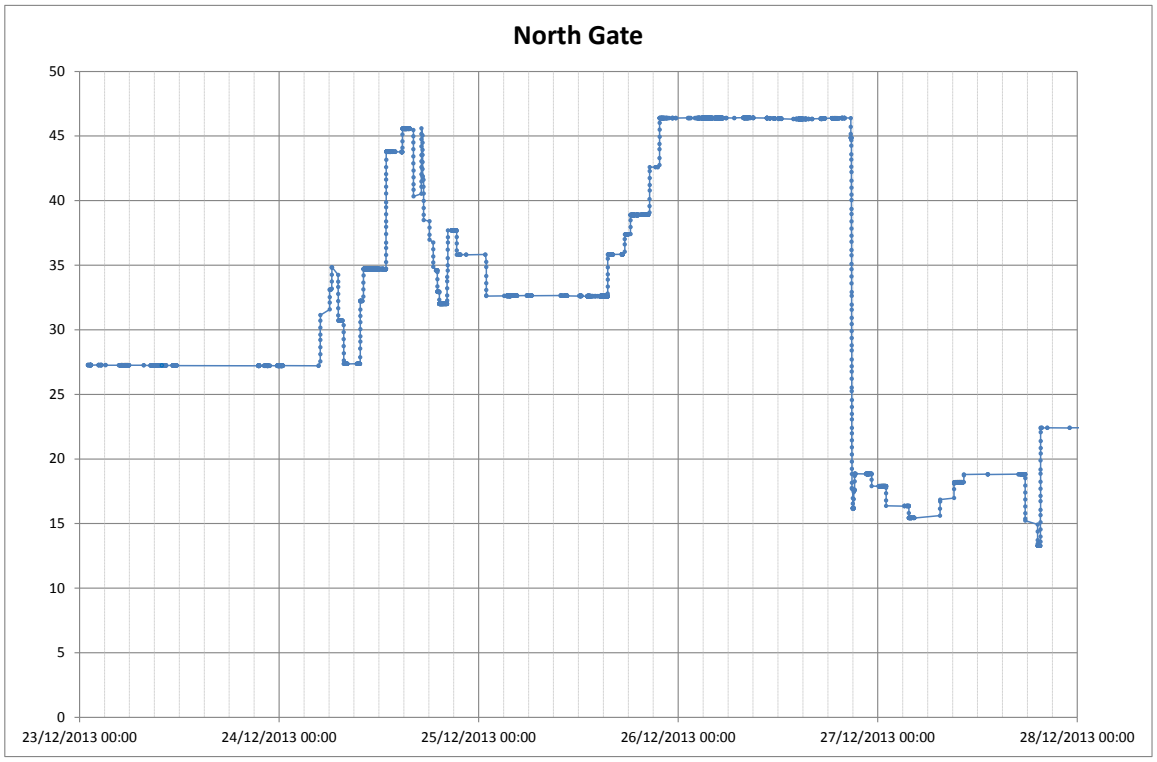


Figure 3.1: North gate movements as percentage open

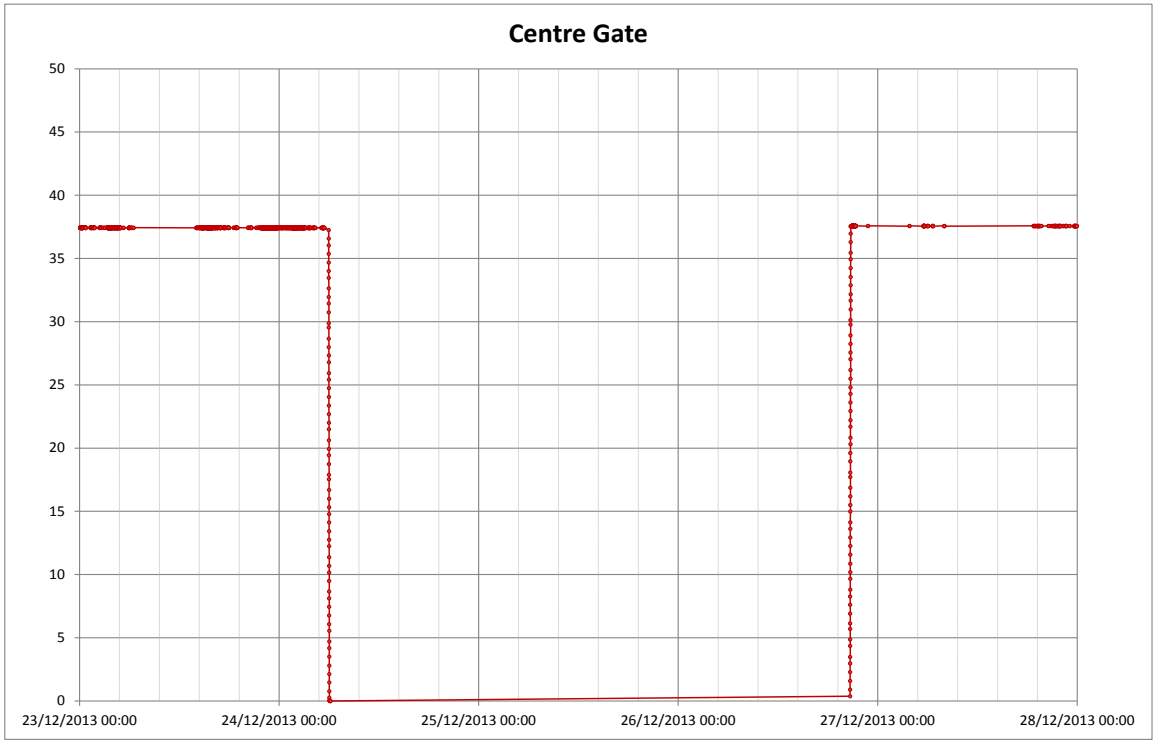


Figure 3.2: Centre gate movements as percentage open

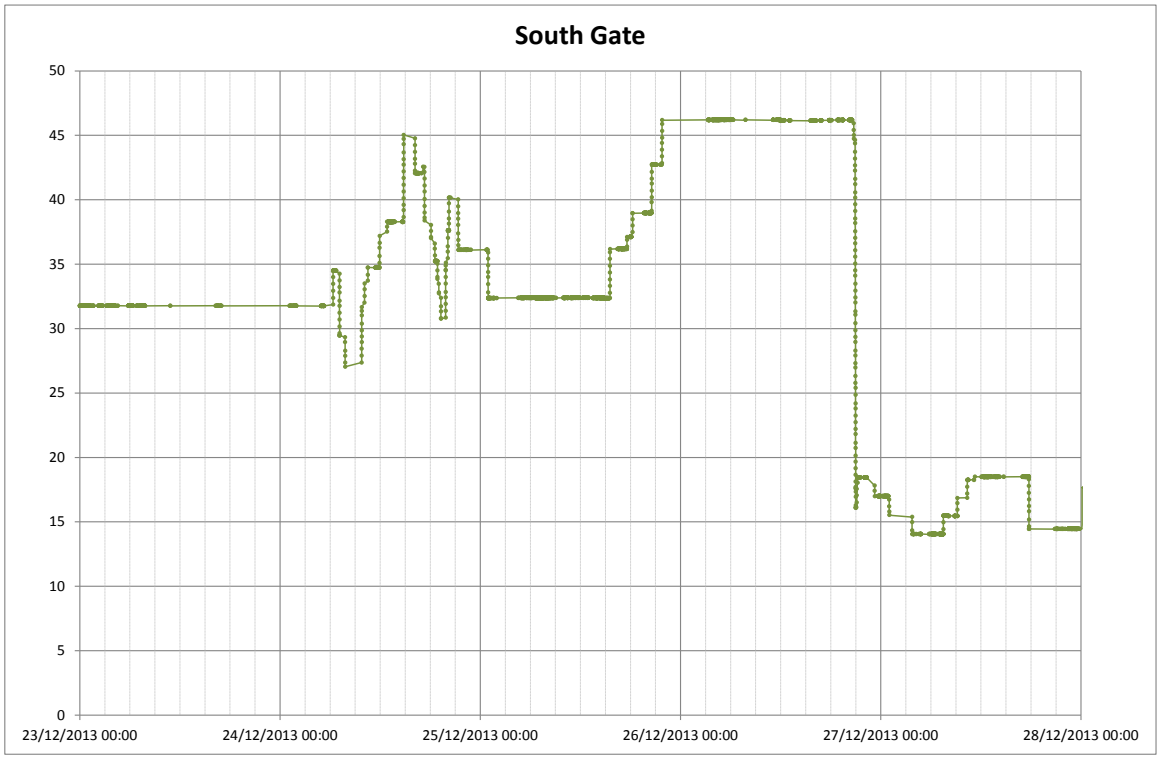


Figure 3.3: South gate movements as percentage open

3.5. Difficulties encountered

The following issues are evident from the records of the event and interviews with the operators:

- Early in the flood the FIDO was unable to pass on information on the extent of surface flooding in Tonbridge because of the volume of calls.
- Access to the Control Room was difficult on 24th December because of flooding. It is understood that this was due to a blocked highway drain.
- The daily rainfall forecasts were uncertain.
- The inflows predicted by the NFFS were uncertain and the uncertainty differed in character from other events, with the NFFS under-predicting the flood peak rather than over-predicting the peak as was usually found to be the case.
- The estimates of inflow to the FSA using the RBS varied substantially from observation to observation of water level and the Operators assessed conditions by averaging successive estimates.
- The LBO on duty was also asked to respond to distressed members of the pubic and to messages on social media, even with two operators in the control room it was difficult to keep pace with requests and the need to keep a good log of all information arriving.
- The LBOs on duty were rightly focussed on the operation of the sluices but found it difficult to form a picture of the event over the whole catchment.
- The external lighting at the Control Room was turned off at night.

3.6. Findings on question 1 - did the Environment Agency follow the procedures?

In summary from the discussion above it has been found that:

- The decision to move from Automatic to Manual mode of operation was in line with procedures.
- The decision made to open the control room on the morning of the 23rd December was appropriate and in line with procedures.
- The control room was properly staffed by trained, experienced operators throughout the event. The procedures require one LBO on duty in the control room whilst the structure is operating in Manual mode if the flow is likely to exceed 50 m^3/s (this was done on 23rd December) and the control room is closed once Automatic mode is resumed. Moreover, on 24th December decisions were made in agreement by two operators rather than the usual one on duty. The decision to have two operators in the control room went beyond the requirement of the procedures but improved the ability to verify operational calculations and respond to the circumstances as the event developed. Double manning should be considered as an appropriate procedure in future major floods.
- The decision on closure of Ensfield Road was taken earlier than required by procedures, but was appropriate based on the forecast and the safety consideration of effecting the closure in daylight hours.
- The decision to commence impoundment at 05:50 on 24th December was taken in line with procedures and the appropriate actions followed prior to commencement, with the exception that the field monitoring team should have been dispatched to Tonbridge at about 04:40 rather than at 05:40. This one hour delay appears to have had no adverse consequences.
- On 24th December the decision to deviate from the default mode of operation at 09:42 was made in accordance with the procedures including consideration of the impacts on communities downstream, the decision was made in consultation with the relevant Environment Agency functions.
- The procedures for operating the reservoir safely were followed with the required inspections and interaction with the Supervising Engineer.
- During the event the gates were operated as necessary as water level varied in the FSA to maintain the outflow rate from the sluices in the range agreed for the operational plan developed by the operators in consultation with the wider team in the Environment Agency.
- On 25th December the decision to empty the reservoir was confirmed by the area manager in consultation with operator 3 and authorised at the ASM level in the Environment Agency in view of the forecast rainfall in subsequent days. This decision was appropriate given the information available.
- The control room was closed down in accordance with procedures on the morning of 26th December and was reopened on 27th December, again in line with the procedures.
- The record keeping of operational data and decisions at the Barrier followed the requirements of the Environment Agency Leigh Barrier Operator Procedures with some minor exceptions, including an occasional missed reading in the Monitoring spread sheet, leaving occasional blank lines between entries in the manual log books, and two post-event corrections to the log.

4. Impact of the Leigh FSA operation

4.1. Introduction

This section of the Audit examines in more detail the basis of the principal tool (the reservoir balance sheet or "RBS") used for decision making in the operation of the Leigh FSA and whether an alternative operational strategy was possible which could have led to greater risk reduction during the December 2013 flood. This will provide context to consider the second and third questions posed for by the Environment Agency:

- Did our operations worsen or cause flooding elsewhere in the catchment?
- Could we have done better?

The underlying principle of the RBS calculations is that the volume of water is conserved. The Leigh FSA acts like a bath tub. In a given period of time if the volume of water flowing in exceeds the volume flowing out then the water level rises and if the water flowing out exceeds the water flowing in then the level falls. Moreover in any time period the total volume of water is preserved, water can neither be created nor destroyed.

For the RBS to mimic the behaviour in practice of the Leigh FSA it is important to know three quantities:

- The relationship between the stored volume in the reservoir and the water level;
- The inflow to the reservoir from the River Medway catchment upstream;
- The outflow from the reservoir to the River Medway valley downstream to Tonbridge and beyond.

Section 4.2 below considers the volume in the reservoir, which is determined by the area of land inundated over the range of water levels, and the land areas are determined primarily from standard topographic survey. A secondary factor is influence of the slope on the water surface, although this slope is not visible to the eye, water will generally be flowing downhill, and it is possible to take account of this additional influence in the set-up of the volume-level relationship for the Leigh FSA even if a single point of observation of water level is used.

Section 4.3 below describes a reconstruction of inflow to the Leigh FSA from the information provided for this Audit. It is evident from the control room log during the event (See Section 3.4.1 above) that there were substantial changes in the estimated inflow to the reservoir as the event progressed. In Section 4.3 the underlying natural variation in time of the inflow (called the inflow hydrograph) is presented and the potential causes of the variations in the data are discussed.

Having identified the inflow to the Leigh FSA from the River Medway catchment upstream, it is possible to identify the reduction in the flood flow (or attenuation) by the operation of the Leigh FSA and to quantify the substantial risk reduction achieved for the communities downstream. This is presented in Sections 4.4 and 4.5.

To identify whether further reduction in flood risk might have been possible, Section 4.6 constructs an hypothetical operational strategy for the sluice gate openings that could have been made with the **critical assumption** that there had been perfect foreknowledge of the water flowing into the Leigh FSA from the Medway catchment upstream. Section 4.7 discusses why this hypothetical operational strategy, in fact, could not have been implemented in practice.

4.2. Volume of water in the Leigh FSA

Three volume-elevation relationships for the Leigh FSA have been made available for this audit from the time of the original construction of the Leigh FSA, from the RBS tools prepared after the 2000 floods and from a new survey made in the summer of 2014.

The original operational procedures from 1985 contained a tabulation of storage volume in millions of m^3 from 24.50 m ODN to 29.10 m ODN in 0.1 m intervals, this is plotted in Figure 4.1 below.

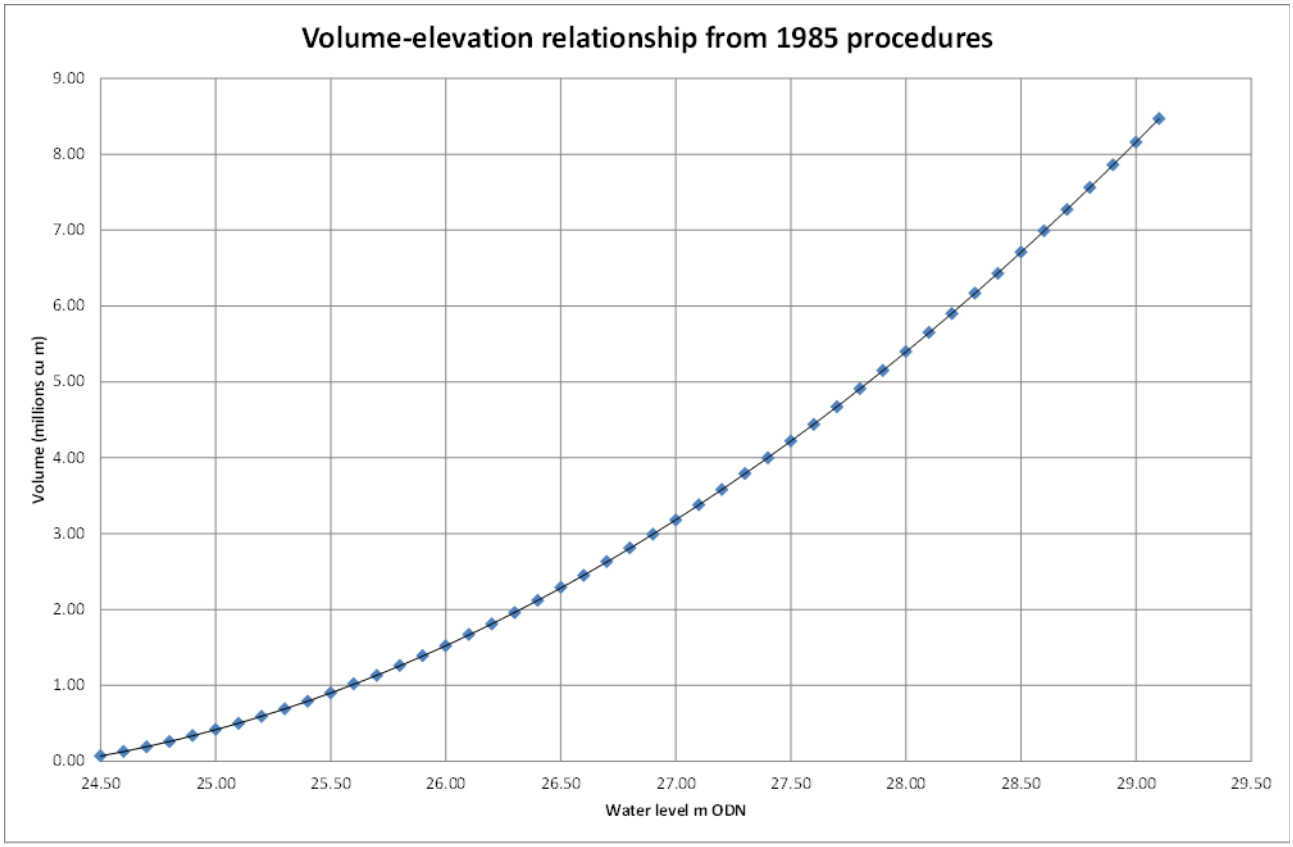


Figure 4.1: Original volume-elevation relationship

Source: River Medway flood relief scheme computerised operating procedure, Rofe, Kennard & Lapworth, May 1985

The origin of the volumes is not described in the 1985 procedures but can be expected to have been from usual topographic land survey and will represent volumes under a horizontal water surface at each of the tabulated levels.

The volume-level relationship in the RBS, shown in Figure 4.2 below, has been derived from the data in the industry standard ISIS one-dimensional hydraulic model of the Medway and using an assumption of flow at the hydraulic "normal" depth at each section represented. This method will incorporate the effects on stored volume of a water surface gradient along the storage area, rather than using a level-pool assumption. The tabulation of volume is not at the evenly spaced points of the original 1985 survey, however, this should have no effect on the accuracy of its use in estimates of the inflow to the Leigh FSA.

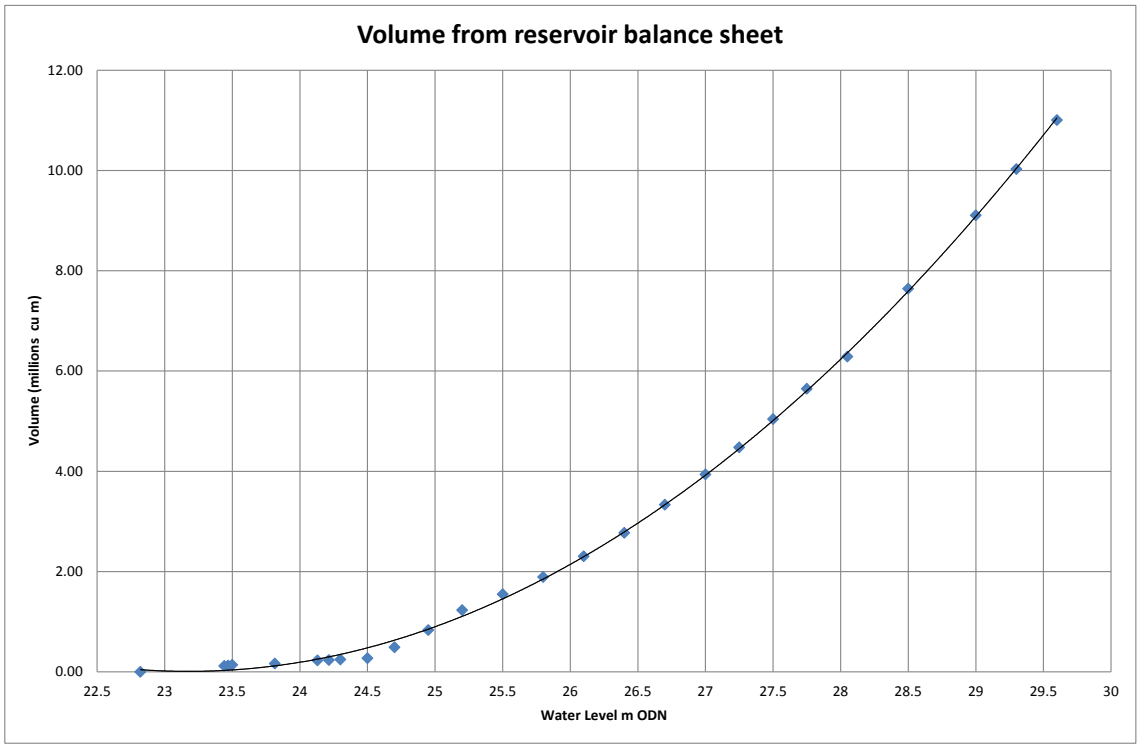


Figure 4.2: Volume elevation relationship in the reservoir balance sheet (RBS)

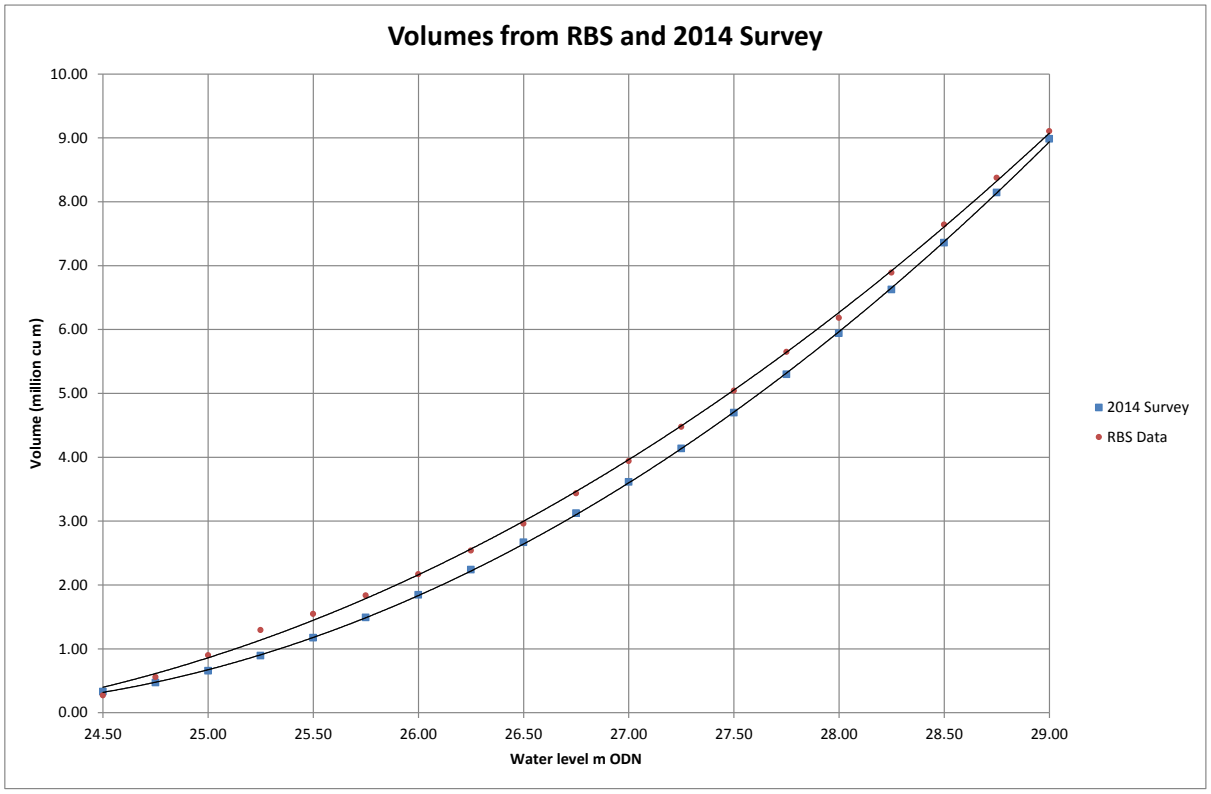


Figure 4.3: Volume comparison between the RBS volume data and the 2014 survey

Figure 4.3 shows a comparison between the volume from the 2014 survey at 0.25 m intervals and that in the RBS tabulation (interpolated as necessary).

The volume in the 1985 procedures is generally less than that in the RBS and the new 2014 survey. As expected, the RBS includes a greater volume than either the 1985 or the 2014 data since it has a storage "wedge" associated the sloping water surface upstream of the barrier.

A consequence of the greater storage volumes represented in the RBS is that for a given difference in water level and outflow rate the calculations in the RBS will produce a larger mean inflow rate than that of the old 1985 procedures, or an equivalent calculation based on the 2014 survey.

The RBS method that includes a representation of water surface gradient is likely to be superior for small to moderate flows, but for larger floods the assumption of a horizontal water surface becomes progressively more realistic as the flood storage area fills to its maximum level.

The RBS data, however, shows a degree of scatter around the general trend line and whilst this might appear to be minor when plotted as in Figure 4.2 and Figure 4.3, the variation can have unwanted influence on the calculated inflow rates in the RBS. Figure 4.4 below shows the water surface area implied by the RBS volume data.

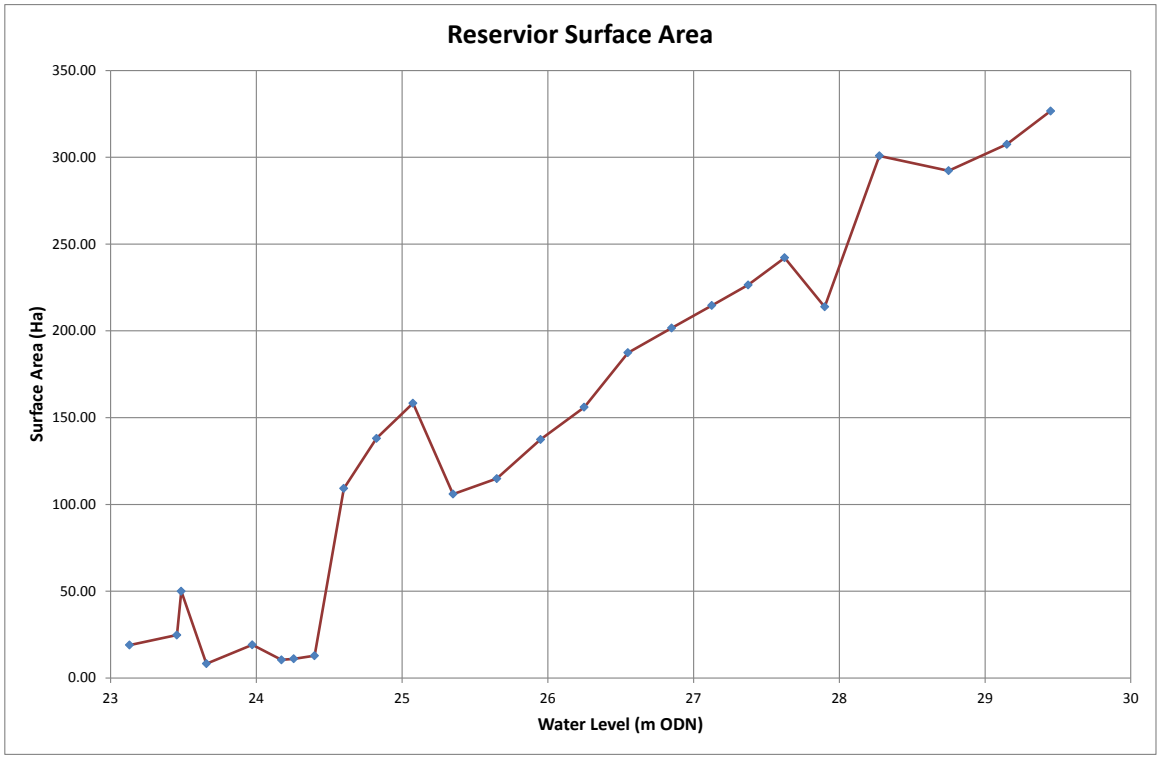


Figure 4.4: Water surface area (Hectares) calculated from RBS volumes

The volume data in the RBS increases in all cases as water level increases as is required. However, the water surface area is seen to decrease as water level rises at several places including about 0.5 m above the point of impoundment (water level 24.70 m) and just below the maximum operating level (28.05 m). Such a decrease in area as level rises is not realistic for an open watercourse and flood plain.

The basis of the stored volumes in the RBS must be reviewed to ensure that surface area of the storage reservoir is represented as increasing with water level. The basis of the revision could be the recent (2014) survey, coupled with appropriate assumptions on water surface gradient as the water level in the FSA rises. Alternatively, a more comprehensive investigation of the hydrodynamics of the filling of the reservoir could be undertaken before a revised operational model is derived for the RBS calculations.

4.3. Reconstruction of inflow to the Leigh FSA

The inflow to the Leigh FSA is not recorded by any flow gauge but is estimated or reconstructed from other information. In periods of normal flow the gauging on the rivers Medway and Eden at Colliers Land Bridge and at Vexour respectively are used with an appropriate allowance for travel time for the runoff from the intervening catchment.

Under high flows when the reservoir is impounding the inflow hydrograph can be reconstructed from a volume balance using the water levels at sequence of times; and this is done within the Reservoir Balance Sheet (RBS). The water levels allow computation of the outflow rate through the sluices from their rating equations and of the change in stored volume from the volume-elevation relationship for the reservoir. Figure 4.5 below shows the estimated inflow hydrograph and the outflow hydrograph from the copy of the RBS provided for this audit.

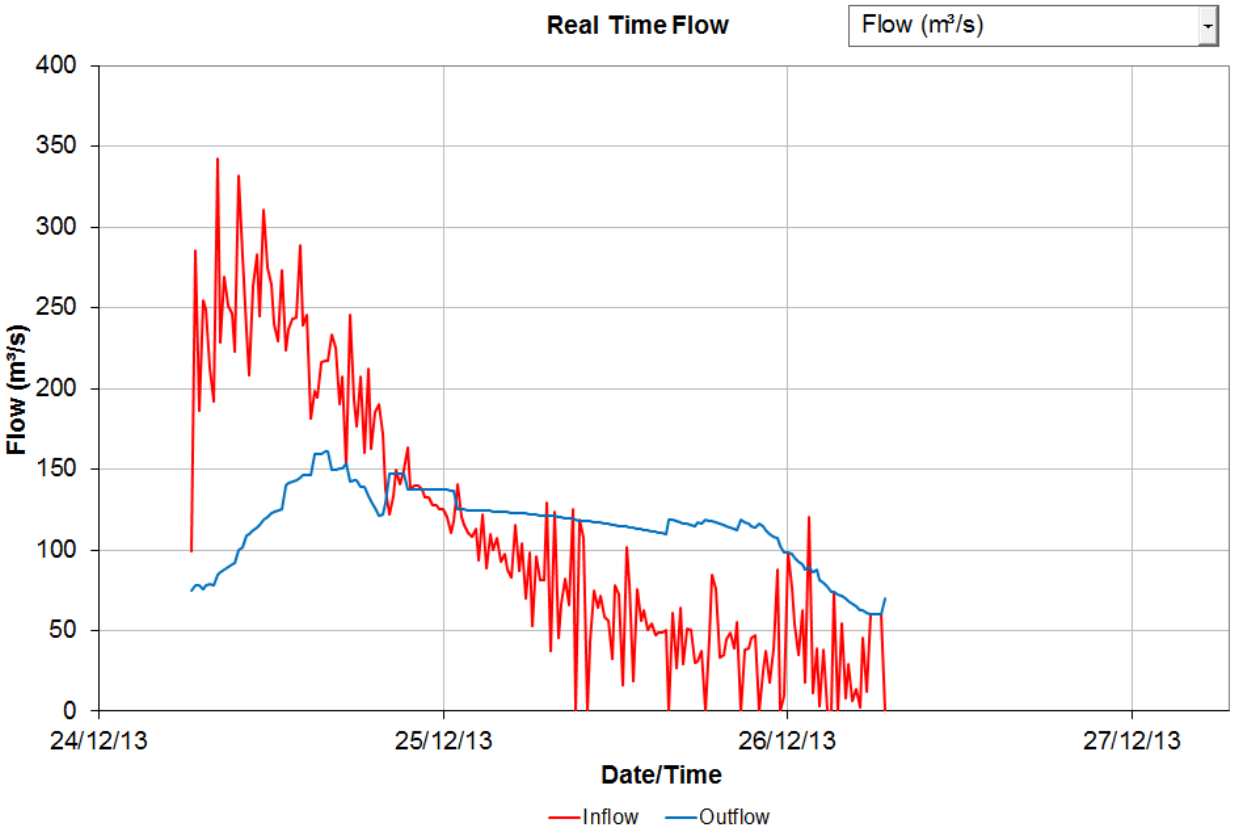


Figure 4.5: Hydrographs from the RBS

The accuracy of these hydrographs will depend upon the reliability of the rating equations for the sluices, the accuracy of the volume relationship of the reservoir, the accuracy of the water level measurement and the accuracy of the timing records of the water level measurements (Section 5.3 below discusses the structure performance). The estimated inflow hydrograph shown in Figure 4.5 shows considerable variations around the typical shape expected for the flood response of a natural river catchment. The origin of these variations probably lies in two factors – the accuracy of the time recording for the water level observations and the representation of volume-elevation relationship for the reservoir (See Section 4.3 above). In the RBS, it is assumed that the water level measurements are at 15 minute intervals, and if the measurements used are not precisely every 15 minutes, this in general will cause a saw-tooth pattern from reading-to-reading to arise superimposed on the underlying hydrograph, this potential cause was identified by Operator 2 during the initial interviews. For this type of pattern however, the underlying total volumes will be correct and a good strategy for reducing the uncertainty in the inflow rate will be to average successive values, as was done by the Operators during the event. Lack of precision or error in water level measurement will result in a similar type of saw-tooth variation, and this is probably the cause of Operator 5's comment of the effects of only having two decimal places rather than three available at 09:20 on 25th December.

Recognising the potential for two sources of uncertainty in the data to lead to oscillatory values of inflow assessment, filtering methods have been applied to the raw estimates of inflow to the FSA in the period. The filters were constructed so that the total volume in the hydrograph was not affected by the filtering and that no systematic time shift was introduced. Figure 4.6 and Figure 4.7 show the raw data and the application of filtering for the flow series starting from 05:15 on 24 December. The solid lines are high-order polynomial curves fitted within EXCEL to illustrate the general trend of the data.

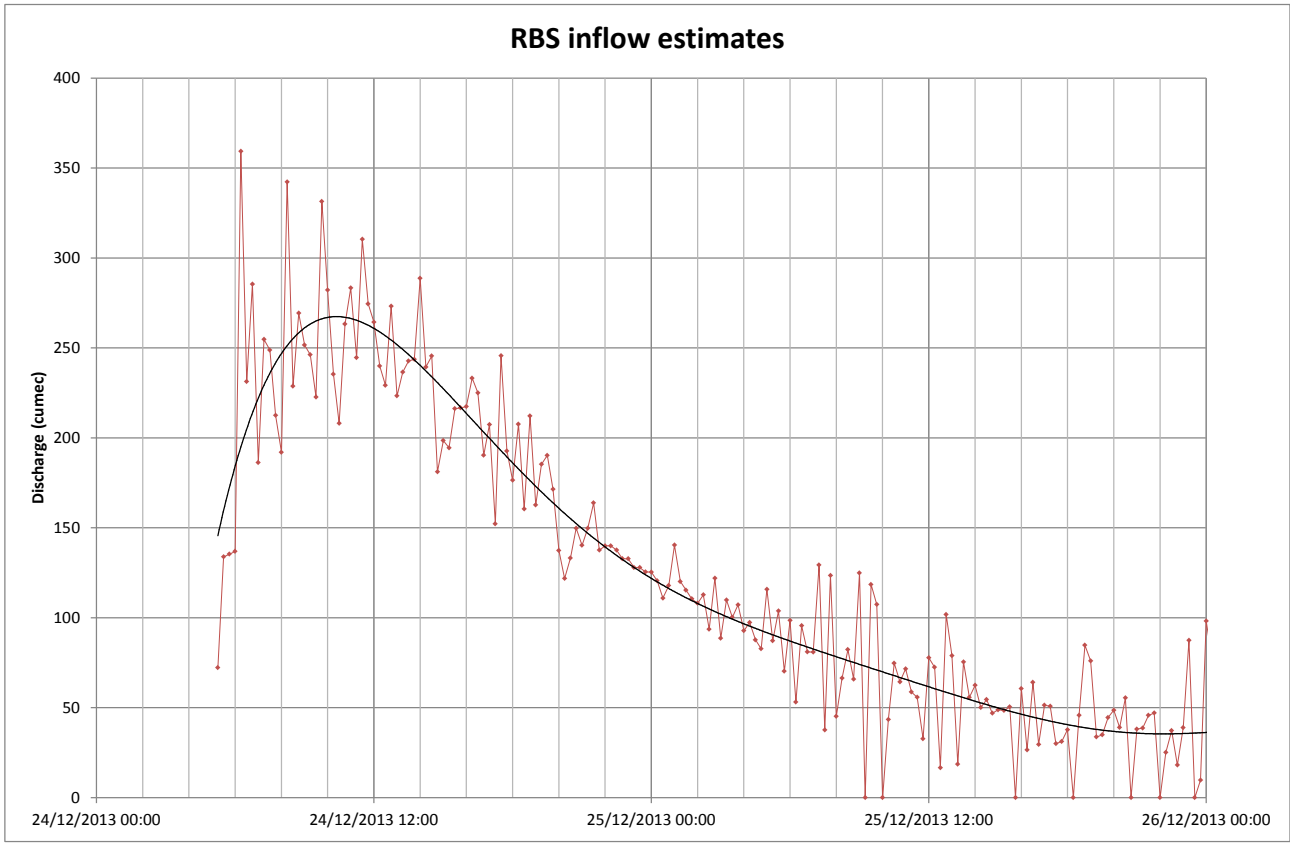


Figure 4.6: Raw estimates from the RBS and a fitted hydrograph

It is clear that the RBS raw estimates of the inflow vary considerably around the best-fit curve, in places by over 100 m^3/s. The filtering method was chosen to remove typical saw-tooth variations and the strength of the filter was adjusted by trial and error until the interim results shown in Figure 4.7 were obtained. Again the standard EXCEL options were used to fit a high-order polynomial through the filtered data. Two features of note are that an oscillation of period about 2 hours remain in the filtered data series, and the underlying fitted curve has changed little except that the goodness-of-fit metric was substantially improved.

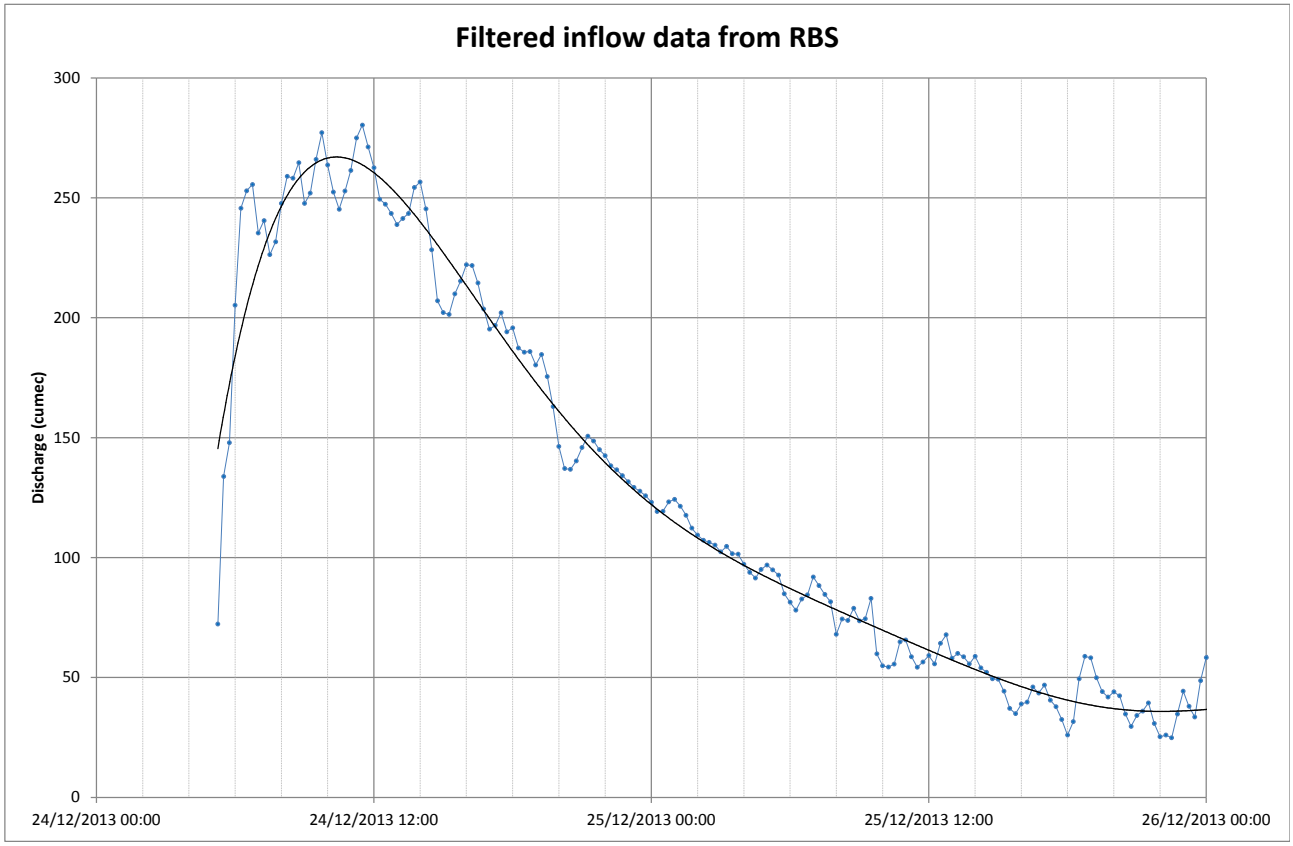


Figure 4.7: Interim filtered data

Next the residual differences were examined between the EXCEL fitted polynomial and the raw inflow and further adjustment made to discharges during the event recession since there was evidence of a second contribution to the inflow peaking at about 16:00 on 24th December. This is reasonable since it is likely that the peak flows on the Medway and Eden did not coincide exactly. The polynomial coefficients normally available from EXCEL are rounded to 5 digits precision and this proved insufficient for reliable representation of the recession when coded to generate data for the RBS, thus a quadratic curve was fitted for discharge below 110 m^3/s, with the two methods blended smoothly together for discharges between 170 and 110 m^3/s.

As a final step, all inflow values were reduced by 0.2% so that the total volume for the reconstructed event was the same as that in the raw data. The final reconstruction of the inflow to the Leigh FSA for the event is presented in Figure 4.8 below. The peak inflow on the reconstructed hydrograph occurs at 09:00 on 24th December with a value of 260.9 m^3/s. This final value for the peak is approximately 10 m^3/s lower than the peaks of the EXCEL fitted polynomials obtained before after the initial filtering of the raw data (Figure 4.6 and Figure 4.7) and occurs about one hour earlier than with the EXCEL fitting.

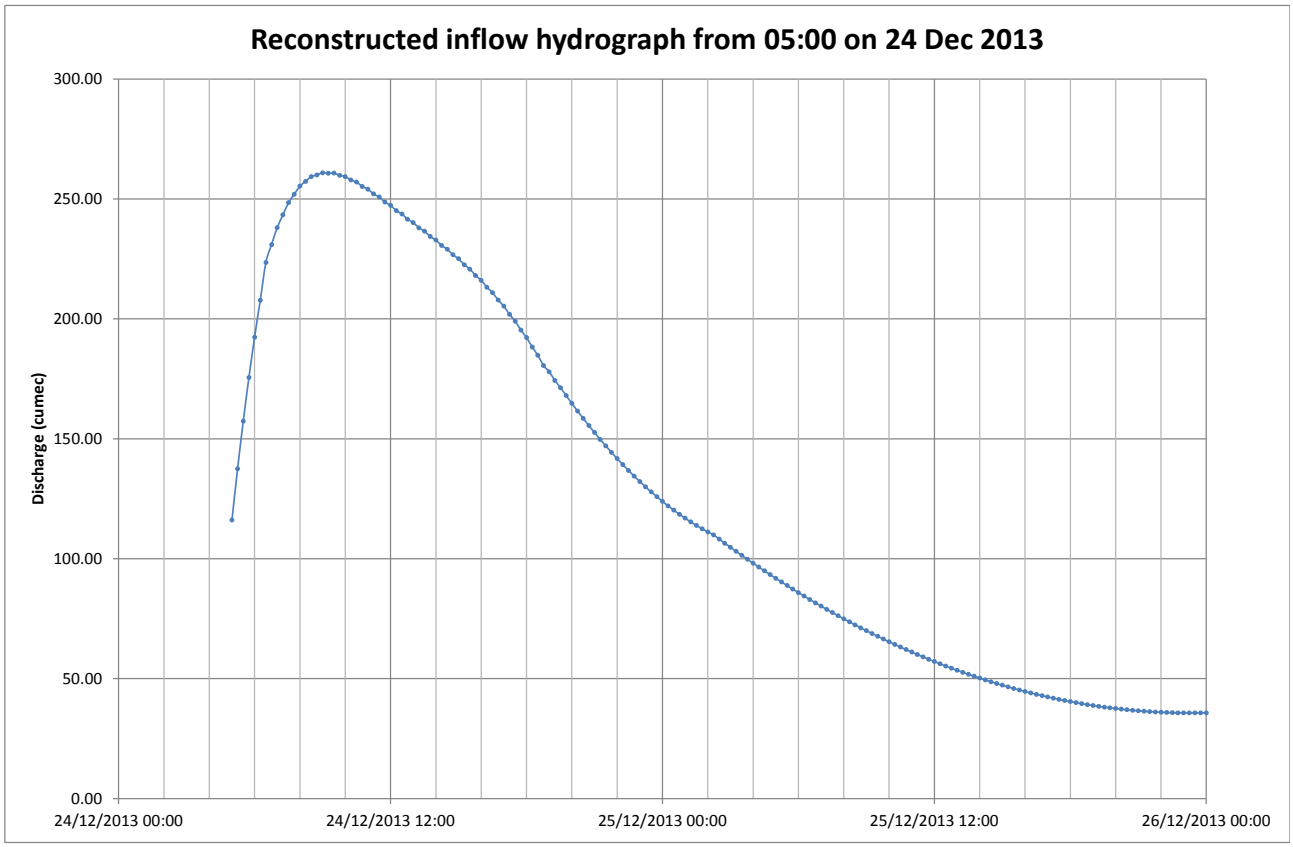


Figure 4.8: Reconstructed inflow to the Leigh FSA

The raw flow data combined for the Medway and Eden from the Colliers Land and Vexour gauging sites shows a peak of 246 m^3/s also at 09:00, however, recent reassessment of the rating curves at these two sites has reduced the estimate of the peak to 228.4 m^3/s, as reported by JBA Consulting in their review of the severity of the 2013 flood. Either of these estimates for the combined peak at the two upstream gauging sites would give credence to the reconstruction shown in Figure 4.8 since some additional flow (often estimated as about 10%) can be expected from the intervening ungauged catchment between the gauging stations and the Leigh FSA.

Moreover despite the sources of uncertainty that affect the individual inflow estimates from the RBS, the method is soundly based. The uncertainties could be reduced by some refinement of the RBS procedures.

4.4. Attenuation achieved

As argued in Section 4.3 above the peak inflow to the Leigh FSA was about 261 m^3/s and the operational records show that peak outflow was about 160 m^3/s from 15:00 to 16:00 on 24 December. Hence there was an attenuation of approximately 100 m^3/s (38%) in the peak flow immediately downstream of the Leigh FSA. This undoubtedly reduced the severity of the flooding experienced in Tonbridge and further downstream in the Medway valley.

4.5. Risk reduction achieved

The Environment Agency has provided water levels and flow rates derived from the Mott MacDonald hydraulic modelling at Tonbridge Town Lock and near Yalding, and the Environment Agency also provided the rating curve for the River Medway at East Farleigh gauging station. These allow a broad-brush estimate to be made for the reduction in maximum flood level that can be attributed to the operation of the Leigh FSA. The basis of the estimation is that the 100 m^3/s attenuation of the flood peak at Leigh was also the influence at sites downstream at the times the flood peaked at these locations. Table 4.1 presents the values estimated by applying a 100 m^3/s increase to the flood flows at these points and using the local rating information to associate an increase in maximum water level to this increase in flood flow. They do not depend upon the inflow from the tributaries downstream of the Leigh FSA.

Table 4.1: Estimated maximum flood level reduction through operation of the Leigh FSA

Location	Peak flood level in the event (m ODN)	Origin	Maximum reduction attributable to Leigh FSA operation (m)
Tonbridge	22.44	Model output for 159 m^3/s	0.6 m
Yalding	11.734	Gauge records	1.0 m
East Farleigh	9.367	Gauge records	0.7 m

These estimates are the maximum amounts that can be attributed to the operation of the Leigh FSA as they take no account of two important factors that would diminish the influence of the Leigh FSA on flood levels at Yalding and East Farleigh. Firstly some additional reduction of the peak flood discharge would come from natural attenuation processes associated with flood plain storage. This could be determined by detailed hydraulic modelling but is unlikely to exceed 10 m^3/s (i.e. 10% of the reduction at Leigh) in the reach concerned down to East Farleigh. Secondly, and possibly of greater importance, will be the relative timings of the contribution of the flood waters from the Leigh FSA and that from other rivers such as the Teise and the Beult, meaning that the flood from the upper Medway may have peaked at an earlier time relative to the peaks on downstream tributaries. Again this could be explored through detailed modelling, but this lies beyond the brief of the current audit.

4.6. Hypothetical attenuation possible

The Environment Agency provided a copy of the RBS tools that were used in the Control Room to explore scenarios for planning the outflow from the Leigh FSA during the event. It is now possible to examine the optimal operational strategy that could have been developed for the December 2013 flood, if there had been a perfect flow forecast available for 48 hours ahead say in the early hours of 24th December.

The strategy is considered “optimal” if the outflow from the sluices is not restricted until as late as possible, then the outflow is held constant through the flood and the water level in the reservoir just achieves the maximum permissible level (28.05 m ODN) as the inflow on the recession of the flood equals precisely the outflow rate maintained in the event. In other words no storage is used up by impounding the river flood until the very latest time possible. Another factor in finding the optimal strategy is the effects of the standard procedures for impoundment that require the centre gate to be closed during impoundment with water levels managed by the two side gates. The free discharge possible through these gates depends upon the upstream water level and for a rapidly rising flood flow, it may not be possible to discharge the full amount of inflow through the two side gates with the prevailing water level upstream. The RBS identifies whether this

situation occurs in exploring operational scenarios and restricts the outflow to the maximum achievable in such cases (i.e. the two side gates are clear of the water surface).

Figure 4.9 and Figure 4.10 below show the RBS output for discharge through the sluices and level impounded behind the embankment for the hypothetical optimal scenario and the other cases included as standard (two sensitivity cases for ±10 m^3/s in outflow from that planned as the "Deviation Outflow" and the barrier "Default" mode of operation).

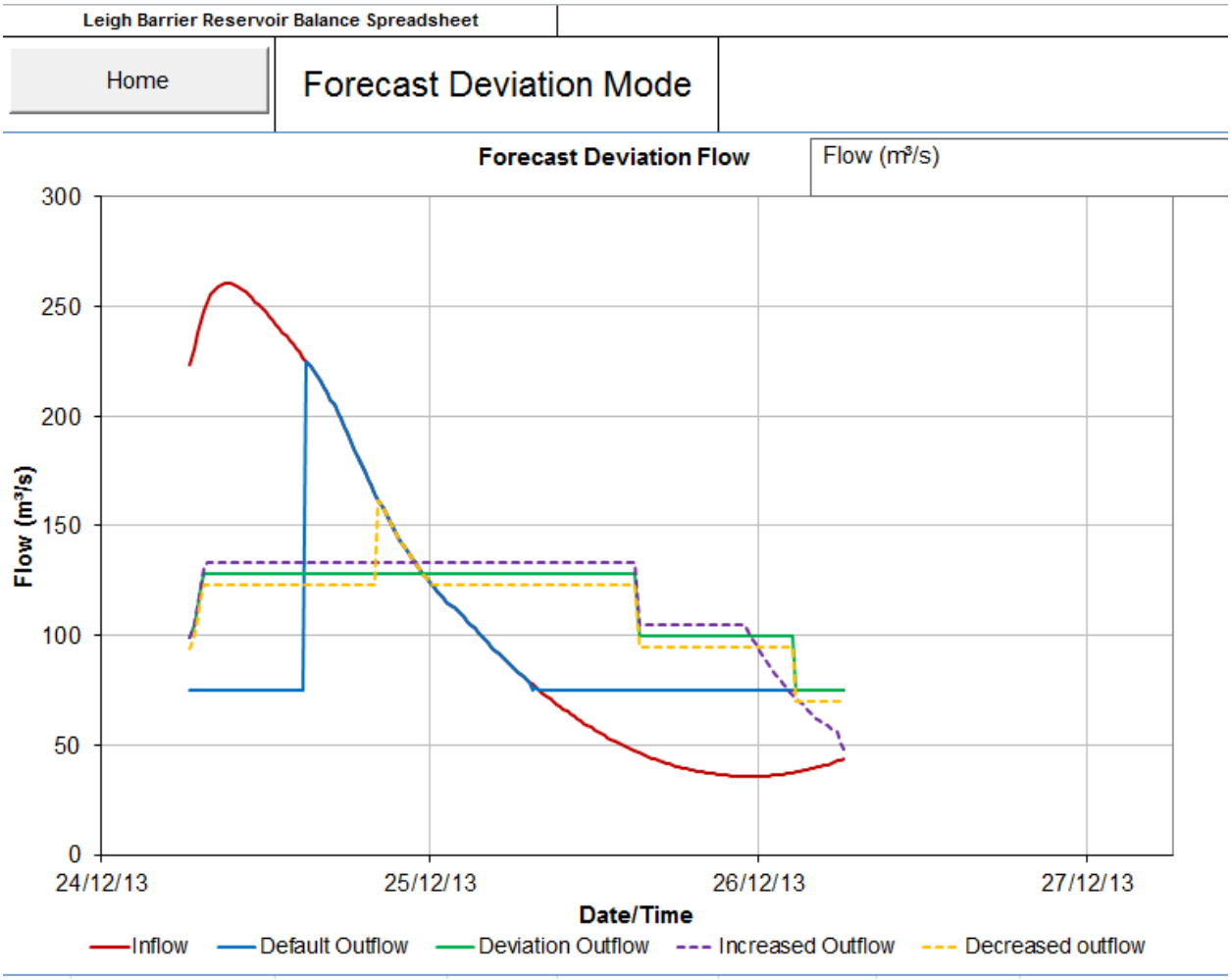


Figure 4.9: Discharge plots from the RBS for the hypothetical optimal strategy

The scenario explored starts using the conditions recorded during the event at 06:30 on 24th December as these were the earliest available in the RBS data for the event. Up to this point the outflow through the structure had been unconstrained by the gates except for about 35 minutes from 05:55 during which time about 31,500 m^3 of water would have been stored. This volume of storage would have raised the maximum level in the reservoir by approximately 11 mm at the peak of the impoundment.

Using the reconstructed inflow hydrograph of Figure 4.8 as the hypothetical forecast of inflow available, the optimal strategy is to discharge the total inflow freely through the side gates at the structure until 07:30 on 24 December and then to restrict the outflow to 128 m^3/s through the flood peak. This implies that a decision would have been made to move from manual operation mode to a deviation mode without operating the

structure in default mode where the outflow is constrained to be less than 75 m^3/s which is the onset of flooding downstream. In the actual event the structure operated in default mode from 05:50 to 09:30. The scenario also included an operational plan to empty the reservoir after the flood by the same time as was achieved in the actual event.

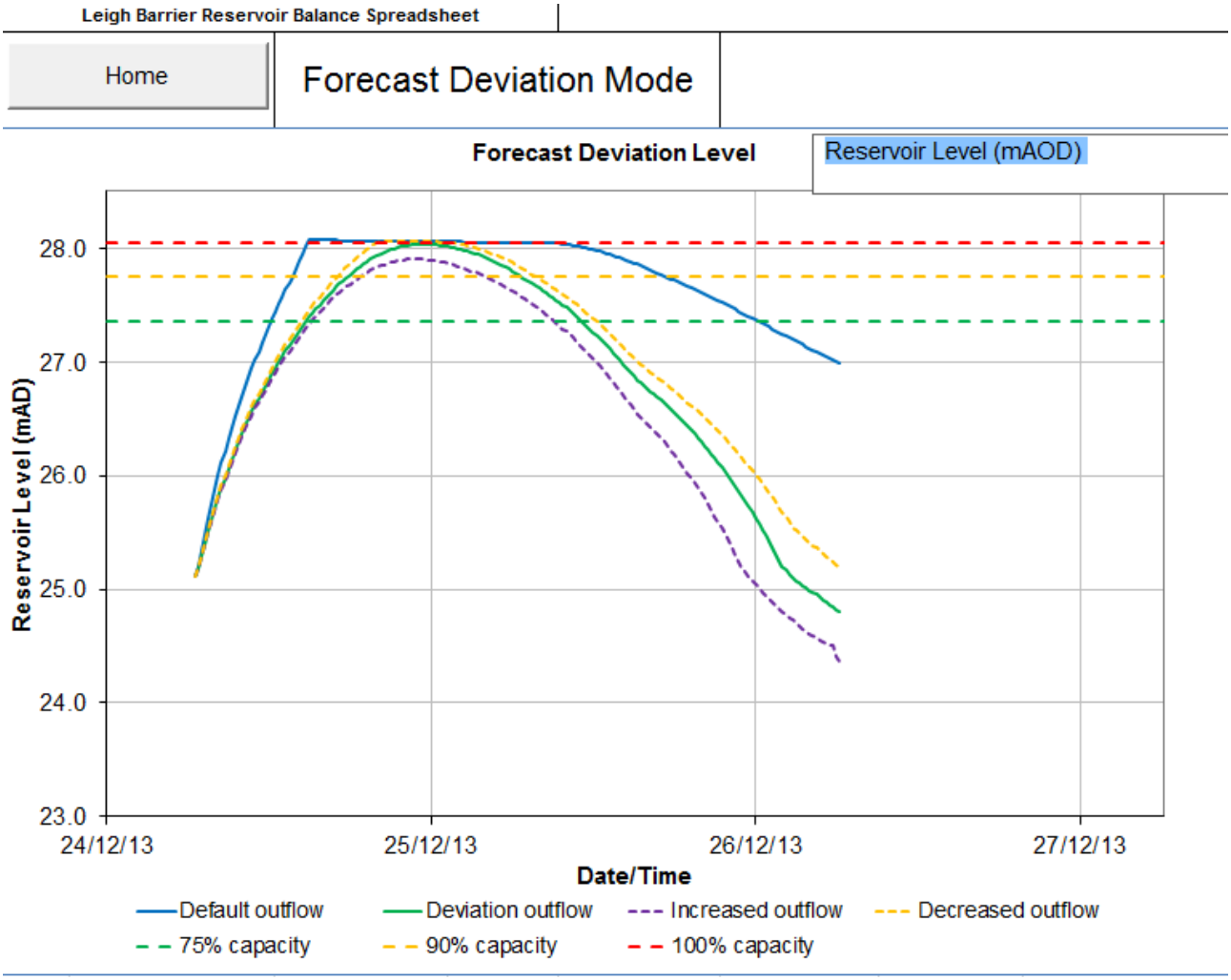


Figure 4.10: Impounded water level from the RBS for the hypothetical optimal strategy

The maximum additional reduction in outflow achieved in this scenario is 32 m^3/s from that of the 2013 flood. Using the same methodology as described in Section 4.4 above the maximum additional reduction in peak flood level has been estimated at the three locations downstream as shown in Table 4.2.

Table 4.2: Estimated maximum additional flood level reduction achievable

Location	Peak flood level in the event (m ODN)	Origin	Estimated additional reduction from changed operation (m)
Tonbridge	22.44	Model output for 159 m^3/s	0.2 m
Yalding	11.734	Gauge records	0.4 m
East Farleigh	9.367	Gauge records	0.2 m

It must be emphasised that the additional reductions shown above are the maximum possible; to establish the actual value, more detailed modelling must be carried out. It is probable that the reductions in levels found by modelling this optimal scenario will be less than that shown above at Yalding and at East Farleigh.

4.7. Practicality of the further risk reduction

It has been shown in Section 4.6 that, with a perfect flood forecast, in the optimal scenario the onset of impounding could have been delayed by about one and a half hours, reducing the maximum outflow to a little under 130 m^3/s. **However no current technology can deliver a perfect flood forecast sufficiently far in advance for such an operational plan to be devised with any confidence**. There are several well-known reasons for this including:

- Inherent uncertainty in the representation of physical processes of rainfall generation and the grid resolution of Met Office models used for weather forecasting;
- Uncertainty in "observed" precipitation rates from weather radar available to the NFFS;
- Variability in estimating the spatial distribution of rainfall estimated from point measurements of rainfall using a rain gauge network (and the measurement uncertainty in storm conditions);
- Uncertainty in flow estimation at gauging stations in major floods since there may be no historic observations available of flows in comparable events;
- Uncertainty in the distribution and degree of wetness of the catchment prior to the storm;
- Natural variability in the relative hydraulic performance of river and floodplain which are represented as fixed in the hydrological and hydrodynamic forecast models;
- Extrapolation of hydrological and hydrodynamic forecast models in major ("unprecedented") floods beyond their range of calibration.

All these uncertainties contribute to the overall reliability of a flood forecast and the confidence to be placed in it for operational purposes. Although flood forecasting has been an active area of research for many years, leading to significant improvements, limitations in knowledge of processes, computing power available for weather and flow forecasting, and, the density of observations all mean that forecast uncertainty cannot be eliminated.

This review has identified in Section 3 above that initially given the tools and procedures the correct actions were taken, on the assumption that the NFFS forecasts represented an over prediction of about 20% in accordance with the Operators' experience. When the Operators appreciated from the RBS calculations (based on local information) that the inflows from the NFFS were under predictions, they made appropriate adjustments in the inflow scenarios used to develop the operational plan for the event.

The optimal scenario also requires the operation to move from manual mode to a decision to deviate from the default operation of the structure; this decision pathway is not included in the Leigh Barrier Operator

Procedures. Thus if the perfect forecast had been available and the optimal scenario developed in advance, it could not have been implemented in the context of the currently written procedures.

If the optimal scenario had been available, a consequence of its implementation would have been earlier and more rapid inundation of the lower-lying areas of Tonbridge, such as the sports field with the river being out of bank by dawn, a condition that would have been experienced on 24th December 2013 if the Leigh FSA had never been constructed.

4.8. Findings for Questions 2 and 3

4.8.1. Question 2

The second review question posed for this Audit was "*Did our operations worsen or cause flooding elsewhere in the catchment?"*

- Given the inflow from the rainfall over the Medway catchment, it was inevitable that Tonbridge, Yalding, Maidstone and other locations along the Medway would have flooded on 24th and 25th December 2013. The capacity available at the Leigh FSA was insufficient to prevent flooding.
- Without the Leigh FSA there can be no doubt whatsoever that the flooding in communities adjacent to the River Medway from Tonbridge to Maidstone would have been significantly greater; its operation did not cause or worsen flooding downstream. The only area in which flood levels were raised above those which would have occurred in the absence of the structure is in the storage reservoir itself.
- The proportionate reduction from the operations of the Leigh FSA was greatest close to the structure and decreased downstream. The exact amount of reduction in peak water level can best be determined using a hydraulic model.
- The operation of the Leigh FSA reduced peak flood levels in Tonbridge by approximately 0.6 m, in line with the rationale for the construction of the structure in accordance with the original Medway Flood Relief Act.
- The benefits of the operation of the Leigh FSA for communities further downstream to Yalding and beyond are likely to have been similar, but without detailed hydraulic modelling it is not possible to quantify the effects precisely. Table 4.1 gives broad-brush estimates of the maximum reduction in peak flood levels that could be attributed to the Leigh FSA; if commissioned, it is to be expected that detailed modelling will show the actual effect to have been smaller than the upper bounds given in Table 4.1.
- The operation of the Leigh FSA reduced the initial rate of rise of flood level in Tonbridge from that which would otherwise have been experienced during the event with unrestricted flows.

4.8.2. Question 3

The third review question posed for the Audit was "*Could the Environment Agency have done better?*" This section states conclusions based on the analysis in Section 4.5 above.

- The hydrograph for the inflow to the flood storage area has been reconstructed from the information provided for this review. It shows maximum inflow of approximately 261 m^3/s at 09:00 on 24th December 2013.
- As shown in the hypothetical optimal scenario, developed with the RBS in Section 4.5, further risk reduction might have been achieved but this would have required:

- The availability of a perfect forecast of the flood hydrograph – in particular for the volume of flood water coming down the river in excess of the threshold at which the sluices discharge the maximum amount in the plan for the event.
- Procedures and decision structures to be in place to move from manual mode of operation to the "deviation" mode of operation without the restriction of outflow to 75 m^3/s of the "default" mode.

- In this optimal scenario the onset of impoundment would have been delayed by about 95 minutes. The benefits would have been for a reduction in flood level of 0.2 m in Tonbridge and potentially of a similar nature downstream. However, without detailed hydraulic modelling it is not possible to quantify the effects precisely. Table 4.2 gives broad-brush estimates of the upper bound of any additional reduction in peak flood levels downstream.

Without perfect foreknowledge this hypothetical optimal scenario could not have been found with any confidence that would have enabled its implementation.

- The operators and the flood forecasters used their previous experience that the forecasting model tended to over-predict the flood peak, whereas for the December 2013 flood the model under-predicted the flood peak. In fact the LBOs used their observations of the local inflow estimates to develop an operational plan that achieved a substantial reduction of the peak discharge passed downstream. As shown in Figure 4.9, maintaining the default mode of operation for as long as possible would have resulted in a flood peak about 70 m^3/s higher than was achieved by the operational plan used during the event.

5. Future issues and actions

5.1. Environment Agency post-reviews and actions in progress

The Environment Agency has commissioned several investigations and actions following the experience of the December 2013 flood. In addition to the Audit described in this report the following are in progress or have been completed:

- A review of the severity of the event drafted by JBA Consulting;
- Collation of the event records into a factual report, in progress by the Environment Agency;
- A survey of the Leigh FSA topography, completed and made available;
- An internal debrief of the LBO team identified 59 lessons to learn from the operators' experience of the event and an action tracker is in place to ensure their implementation;
- Computational Hydraulic modelling of flood movement in the Medway valley in progress by JBA Consulting;
- Review of the flood ratings at gauging stations;
- Review of the flood forecasting model, particularly for the River Eden.

5.2. Hydro-meteorology and flood forecasting

It is clear from the comments in the Control Room log book and the forecast model results made available for this Audit that the flow forecast as inflow to the Leigh FSA from the Upper Medway and River Eden was underestimated, with the flood peak being later and lower than that experienced in the actual event. Also, the Control Room log records occasional difficulty in obtaining forecasts from the NFFS via the MFDO, and this issue was also raised in the interviews with the Operators. The Environment Agency should consider how better access to updated forecasts can be ensured when requested for operation of the Leigh FSA.

A review of the flood forecasting model is underway. Issues that could be considered in this review are:

- Real-time updating algorithms in the forecast model to account for differences between local observations and forecast – for example at Colliers Land Bridge and Vexour;
- Sufficiency of the rain gauge network;
- Runoff estimation for severe storms of a range of durations, particularly in conditions of above average catchment wetness as occurred in December 2013;
- Verification of model performance against the data for the December 2013 flood.

It is acknowledged that forecasting precipitation at the catchment scale (100 to 500 km^2) is technically difficult, however, as better resolution meteorological forecasts become available over the medium to long term the operation of the Leigh FSA could benefit from more specific catchment information up to 48 hours ahead than is currently provided in the Hydrometeorological Guidance and High rainfall Alerts available from the Flood Forecasting Centre.

One potential future development of flood forecasting is the availability of probabilistic forecast information either as an ensemble of forecasts or a central estimate and confidence limits based on quartiles or variances about the mean. The Environment Agency should consider the potential for the use of probabilistic forecast information in the operation of the Leigh FSA.

5.3. Hydraulic performance of the Leigh FSA

The hydraulic performance of the sluice gates at Leigh FSA is based on theoretical equations from the ISIS modelling software rather than from local measurements at the structure. The theoretical equations may differ from the actual performance, perhaps by 5%. The flows assessed from the Leigh FSA are generally consistent with measurements elsewhere in the catchment (see for example the JBA report on flood severity) indicating that there is no gross error in the theoretical calculation of flow through the gates. The Environment Agency could consider undertaking a flow measurement exercise to calibrate the local installation of the gates, through temporary impoundment and controlled release within the terms permitted by the Medway Flood Relief Act. However, the operational decisions for the Leigh FSA will be robust (i.e. insensitive) to this degree of uncertainty in the calculation of the sluice gate performance. This arises because the FSA has a large surface area and so the difference in the rate-of-rise of water level over the 15-minute observation period, due to these uncertainties, is unlikely to be measureable.

During the interviews with the Operators, specific mention was made of the different character of filling of the reservoir in the December 2013 flood. Filling took place initially from the river banks overtopping at the upstream end rather than close to the main reservoir embankment. Such a situation is consistent with the "flashy" nature of the December flood and its rapid rate of rise. In such cases the calculation of the volume of storage used based on the level at the structure alone will tend to under-estimate the volume used. An alternative would be to incorporate a second level gauge at the upstream end of the FSA into the volume estimation. It would however not be practical to have frequent visual checks on a remote gauge during an impounding event and procedures for operating with the water level at the barrier only should always remain available.

The Environment Agency could consider commissioning a detailed 2D hydraulic model investigation of the filling and draining of the Leigh FSA for a variety of scenarios to verify the simplified approach used in the RBS, particularly if a second water level is to be used in the operational procedures as suggested above. A suitable spatial resolution for 2D modelling would be of the order of 10 m.

5.4. Technical improvements to the Leigh FSA tools

The RBS procedures gave inflow estimates on 24th and 25th December that fluctuated significantly around the underlying inflow hydrograph. The potential origin of these fluctuations are uncertainty or lack of precision in the water level measurement, and the use of a fixed 15-minute time interval in the RBS in the flow estimation rather than a recorded interval. An immediate improvement would be to enable recording of both level and time for each observation and use of the actual time interval in the volume balance calculations.

The volume-elevation table incorporated in the RBS must be reviewed. The current tabulation implies that the surface area inundated decreases as water level increases. Physically this is incorrect. The levels at which this occurs include just above the onset of impoundment and close to the maximum operating level, both of which are trigger points for decisions in the operation of the structure. It is noted that the three surveys available for this Audit differed for the volume of water stored at the maximum level of impoundment, 28.05 m ODN; the values are as follows:

1985 Procedures	**5.5208 million m^3**
RBS tabulation	**6.2887 million m^3**

2014 topographic survey **6.0771 million m^3**

As noted in Section 4.2 above, the RBS Tabulation is intended to include a wedge of storage to account for the usual surface gradient along the FSA. If a detailed 2D hydraulic model investigation of the filling and draining of the Leigh FSA is commissioned as suggested in 5.3 above then the RBS representation of volume should be reviewed on the basis of the outcome of that modelling.

5.5. Management and operation

5.5.1. Systems redundancy and resilience

The Leigh FSA could be viewed as critical infrastructure in that its continued operation and flood defence service it provides influence the lives and livelihoods of the residents and businesses in communities downstream, particularly at Tonbridge. It is important therefore that the operation should be ensured in all conditions that are reasonably foreseeable. Although the concept of resilience in flood risk management has only recently come to professional prominence, the need for system redundancy was recognised in the original design of the Leigh FSA. For example, although the gates are powered normally from the national grid, there are back-up arrangements for operation in the event of power failure, with manual operation of the gates possible as a last resort. However, effective operation of the whole system depends on many other factors such as availability of LBO staff to join a rota, ability of staff to reach the Control Room, the availability of telemetry, and communications with dispersed offices and field teams.

It is important from a resilience perspective that a safe operational plan can always be developed and implemented, as is the current practice, based upon local observation of water level, so that the structure will continue to fulfil its flood defence function should power be lost to the information and communication systems as well as for moving the gates. The flooding incident on Canvey Island in Essex in July 2014 (Essex County Council, 2014) demonstrated the vulnerability to power disruption of that flood defence infrastructure which was based on automatic operation and level sensing. A power surge during the storm caused several pumps to trip-out and Environment Agency staff found access difficult to restart the pumps because local roads were flooded.

It is noted that action has already been implemented from the operators debriefing to address the access difficulties experienced in December 2014 from surface water flooding of the road to the control centre.

5.5.2. Staff availability and their professional development

The decision to double up the staffing in the control room on 24th December was sound and facilitated effective management of the Leigh FSA, providing additional capacity to verify operational plans and interact with other operational functions of the Environment Agency. The Environment Agency should consider incorporating into the Operator Procedures the circumstances that would justify for double manning during major floods.

In December 2013, there were 7 licensed operators available, but due to personal circumstances only 5 were placed on the duty rota.. Although this staffing proved sufficient during the event, several operators worked long shifts on successive days. For example, it is noted in the log of Operator 5 that 24th December had been designated a rest day but they were active in planning the event during the morning before starting an 11 hour shift in the control room at 02:00 on 25th December. The Environment Agency should consider

the appropriate number of authorised operators to retain, to ensure that sufficient operators are available for duty rotas.

It was evident from the interviews with the Operators that regular training is undertaken; the Operating Procedures Manual prepared by Mott MacDonald includes many historic floods as examples. The data for the 2013 could provide a valuable addition to the set of information for professional development and training since it appeared to have a different, more flashy, hydrological response than is usually experienced. In addition, irrespective of improvements made to the forecasting models, the scenarios should include in training how to respond to a change in forecast model behaviour from over predicting flow to under-predicting flow.

Although the operators spoke about the training they had undertaken, no formal central training record or log was available. It is recommended that the Environment Agency should consider maintaining a personal record of training and a professional development plan for each operator so that the availability of experienced and fully trained staff can be readily identified in the event of future public scrutiny.

It is good practice that regular contingency planning exercises should continue to be undertaken to maintain skills and rehearse decision procedures. In addition an operators' debrief should follow any major event as was done after the December 2013 flood to identify any weaknesses in procedures or unusual combinations of events that had not been experienced before.

5.5.3. Dealing with public information requests

The Control Room log and the interviews with the Operators identified that in addition to their primary function of operating the structure and planning the outflows, the LBO was also asked to contribute to the preparation of public information during the event, for example at 10:45 on 25th December Operator 5 received a request from the FIDO to respond to tweets and later Operator 5 was involved in preparation of a ministerial briefing. It is acknowledged that good quality, accurate information for the public is important in an emergency; however, the Environment Agency should consider whether the LBO should take an active role in the preparation of a social media commentary and responding to other public requests, since their primary duty is to plan and implement the operational strategy for the sluices. An alternative might be to base a member of staff as a communication specialist at the Control Room to filter and respond to information requests.

5.6. Findings on question 3

The third review question posed for the Audit was "*Could the Environment Agency have done better?*" and some issues have already been identified in Section 4.7.2 above. The Operators' debrief and subsequent Action tracker documents 59 specific actions based on their experience in the event. Although many are already listed as complete, the Environment Agency should ensure that a plan is in place to implement the remaining actions.

Additional areas which the Environment Agency should consider for potential improvements to the future management and operation of the Leigh FSA are:

- Revising the RBS tools to include the actual time of all observations made in deviation mode (rather than the assumption of a fixed 15 minutes schedule) and ensuring that the underlying volume relationship does not imply surface area decreases as level increases at any point.

- Consider undertaking a more formal systems failure mode analysis of the whole operation of the Leigh FSA to enhance the resilience of the operations to external influences than may occur in an extreme event. The whole system depends on many factors such as availability of LBO staff to join a rota, ability of staff to reach the Control Room, the availability of telemetry, and communications with dispersed offices and field teams. The electrical and mechanical sub-systems have been considered in this way during their design with the back-up arrangements for moving the gates in the event of a power failure.
- Consider the merits of incorporating a second level gauge at the upstream end of the FSA into the volume estimation.
- Consider commissioning a detailed 2D hydraulic model investigation of the filling and draining of the Leigh FSA for a variety of scenarios to verify the simplified approach used in the RBS.
- Consider the potential for the use of probabilistic forecast information in the operation of the Leigh FSA as the science of probabilistic forecasting is now well developed.
- Consider how better access to updated forecasts can be ensured when requested for operation of the Leigh FSA.
- As the science and technology develops to deliver better resolution meteorological forecasts, the operation of the Leigh FSA could benefit from more specific catchment information up to 48 hours ahead than is currently provided in the Hydrometeorological Guidance and High rainfall Alerts available from the Flood Forecasting Centre.
- Consider undertaking a flow measurement exercise to calibrate the local installation of the gates and include any local calibration within the RBS tools.
- Consider incorporating into the Operating Procedures the circumstances that would justify for double manning of the Control Room during major floods and ensuring there are sufficient authorised LBOs for this to be achieved in exceptional events.
- Consider the appropriate number of authorised operators to retain, to ensure that sufficient operators are available for duty rotas.
- Consider the extent to which the LBO should take an active role in the preparation of a social media commentary and responding to other public requests, since their primary duty is to plan and implement the operational strategy for the sluices.
- Augmenting the training scenarios to include the experience of the 2013 flood.
- Maintaining a training and professional development log for each operator.

6. Conclusions and recommendations

6.1. Summary of conclusions

6.1.1. Did the Environment Agency follow the procedures?

- The procedures for operating the Leigh FSA are well documented with clear lines of authority for effective decision making. The procedures identify routes of consultation between operational staff in specified roles so that the basis and consequences of decisions on the operation of the sluices are considered.
- In December 2013 there were seven trained Leigh Barrier Operators available for duty. Between 23rd and 27th December 2013 five Operators undertook shifts in the control room to operate the structure during the flood; their individual length of experience as Operators varied between 5 and over 7 years.
- The Lead Operator took the decision to double-up on operators in the control room since the flood was clearly an unusual event. Although not covered in the Operator Procedures, this decision was entirely appropriate and contributed to the effective operation of the structure.
- The Control Room log and logs provided for other Environment Agency functions have been examined and compared with the Environment Agency Leigh Barrier Operator Procedures dated September 2013 and it is found that:
  - The decision to move from Automatic to Manual mode of operation was in line with procedures.
  - The decision made to open the control room on the morning of the 23rd December was appropriate and in line with procedures.
  - The control room was properly staffed by trained, experienced operators throughout the event.
  - The decision on closure of Ensfield Road was taken earlier than required by procedures, but was appropriate based on the forecast and the safety consideration of effecting the closure in daylight hours.
  - The decision to commence impoundment at 05:50 on 24th December was taken in line with procedures and the appropriate actions followed prior to commencement, with the exception that the field monitoring team should have been dispatched to Tonbridge at about 04:40 rather than at 05:40. This one hour delay appears to have had no adverse consequences.
  - On 24th December decisions were made in agreement by two operators rather than the usual one on duty. The decision to have two operators in the control room went beyond the requirement of the procedures but improved the ability to verify operational calculations and respond to the circumstances as the event developed. Double manning should be considered as an appropriate procedure in future major floods.
  - On 24th December the decision to deviate from the default mode of operation at 09:42 was made in accordance with the procedures including consideration of the impacts on communities downstream; the decision was made in consultation with the relevant Environment Agency functions.
  - The procedures for operating the reservoir safely were followed with the required inspections and interaction with the Supervising Engineer.
  - During the event the gates were operated as necessary as water level varied in the FSA to maintain the outflow rate from the sluices in the range agreed for the operational plan developed by the operators in consultation with the wider team in the Environment Agency.

- On 25th December the decision to empty the reservoir was taken by the lead operator and authorised at the ASM level in the Environment Agency in view of the forecast rainfall in subsequent days. This decision was appropriate given the information available.
- The control room was closed down in accordance with procedures on the morning of 26th December and was reopened on 27th December, again in line with the procedures.
- The record keeping of operational data and decisions at the Barrier followed the requirements of the Environment Agency procedures with some minor exceptions as set out in Section 3.

6.1.2. Did the operations worsen or cause flooding elsewhere in the catchment?

- Given the inflow from the rainfall over the Medway catchment, it was inevitable that Tonbridge, Yalding, Maidstone and other locations along the Medway would have flooded on 24th and 25th December 2013. The capacity available at the Leigh FSA was insufficient to prevent all flooding from occurring.
- The hydrograph for the inflow to the flood storage area has been reconstructed from the information provided for this review. It shows maximum inflow of approximately 261 m^3/s at 09:00 on 24th December 2013.
- Without the Leigh FSA there can be no doubt whatsoever that the flooding in communities adjacent to the River Medway from Tonbridge to Maidstone would have been significantly greater. Its operation did not cause or worsen flooding downstream. The only area in which flood levels were raised above those which would have occurred in the absence of the structure is in the storage reservoir itself.
- The proportionate reduction from the operations of the Leigh FSA was greatest close to the structure and decreased downstream. The exact amount of reduction in peak water level can best be determined using a hydraulic model.
- The operation of the Leigh FSA reduced peak flood levels in Tonbridge by approximately 0.6 m, in line with the rationale for the construction of the structure in accordance with the original Medway Flood Relief Act. The operation of the Leigh FSA reduced the rate of rise of flood level in Tonbridge from that which would otherwise have been experienced during the event with unrestricted flows.
- The benefits of the operation of the Leigh FSA for communities further downstream to Yalding and beyond are likely to have been similar, but without detailed hydraulic modelling it is not possible to quantify the effects precisely.
- Table 4.1 gives broad-brush estimates of the maximum reduction in peak flood levels that could be attributed to the Leigh FSA; if commissioned, it is to be expected that detailed modelling will show the actual effect to have been smaller than the upper bounds given in Table 4.1.

6.1.3. Could the Environment Agency have done better?

- The Operators' debrief and subsequent Action tracker documents 59 specific actions based on their experience in the event. Although many are already listed as complete, the Environment Agency should ensure that a plan is in place to implement the remaining actions.
- The description of the modes of operation, although clear for trained staff might cause unnecessary public concern and in particular the use of the word "deviation" is open to widespread misinterpretation.
- A reconstruction of the inflow during the event is presented in Section 4.6 of this report and a hypothetical operational scenario has been identified which could have offered additional risk reduction; however, this would have required:

- The availability of a perfect forecast of the flood hydrograph – in particular for the volume of flood water coming down the river in excess of the threshold at which the sluices discharge the maximum amount in the plan for the event.
- Procedures and decision structures to be in place to move from manual mode of operation to the "deviation" mode of operation without the restriction of outflow to 75 m^3/s of the "default" mode.

- In this optimal scenario the onset of impoundment would have been delayed by about 95 minutes. The benefits would have been for a reduction in flood level of 0.2 m in Tonbridge and potentially of a similar nature downstream. However, without detailed hydraulic modelling it is not possible to quantify the effects precisely. Table 4.2 gives broad-brush estimates of the upper bound of any additional reduction in peak flood levels downstream.

Without perfect foreknowledge this hypothetical optimal scenario could not have been found with any confidence that would have enabled its implementation.

- The operators and the flood forecasters used their previous experience that the forecasting model tended to over-predict the flood peak, whereas for the December 2013 flood the model under-predicted the flood peak. In fact the LBOs used their observations of the local inflow estimates to develop an operational plan that achieved a substantial reduction of the peak discharge passed downstream. As shown in Figure 4.9, maintaining the default mode of operation for as long as possible would have resulted in a flood peak about 70 m^3/s higher than was achieved by the operational plan used.

6.2. Summary of recommendations

- The Environment Agency should commission a revision of the RBS tools as a matter of urgency to include the actual time of all observations made in deviation mode (rather than the assumption of a fixed 15 minutes schedule) and to ensure that the underlying volume relationship does not imply surface area decreases as level increases at any point.
- The consequences of the NK FIDO informing the ABC that they were unable to appoint a LBDO when needed are not described in the Operator Procedures. It is understood that the ABC will take action to rectify any conflicting responsibilities the LBOs have so that sufficient are available for being assigned in turn as LBDO. The procedures could be updated to make it clear that this is in fact the case.
- The Environment Agency should reconsider the use of the descriptors "default" and "deviation" in the context of any public communications regarding an event. Alternatives could be "Active" or "Manage" for "default" and "Defend" or "Flood" or "High Flood" for "deviation".
- The operating procedures do not provide specific guidance for the exceptional case where the deviation mode of operation of the sluices cannot keep the water level from exceeding the maximum operating level. The Environment Agency should consider whether some additional guidance on exceptional conditions should be prepared for Chapter 5.
- The Environment Agency should ensure that a plan is in place to implement the remaining actions from Operators' debrief as recorded in the Action tracker.
- Additional items that the Environment Agency may consider are:
  - undertaking a more formal systems failure mode analysis of the whole operation of the Leigh FSA to enhance the resilience of the operations to external influences than may occur in an extreme event. The whole system depends on many factors such as availability of LBO staff to join a rota, ability of staff to reach the Control Room, the availability of telemetry, and communications with dispersed

offices and field teams. The electrical and mechanical sub-systems have been considered in this way during their design with the back-up arrangements for moving the gates in the event of a power failure.

- the merits of incorporating a second level gauge at the upstream end of the FSA into the volume estimation.
- commissioning a detailed 2D hydraulic model investigation of the filling and draining of the Leigh FSA for a variety of scenarios to verify the simplified approach used in the RBS.
- the potential for the use of probabilistic forecast information in the operation of the Leigh FSA as the science of probabilistic forecasting is now well developed.
- how better access to updated NFFS forecasts can be ensured when requested from the MFDO for operation of the Leigh FSA.
- whether, as the science and technology develops to deliver better resolution meteorological forecasts, the operation of the Leigh FSA could benefit from more specific catchment information up to 48 hours ahead than is currently provided in the Hydrometeorological Guidance and High rainfall Alerts available from the Flood Forecasting Centre.
- undertaking a flow measurement exercise to calibrate the local installation of the gates and include any local calibration within the RBS tools.
- incorporating into the Operating Procedures the circumstances that would justify for double manning of the Control Room during major floods and ensuring there are sufficient authorised LBOs for this to be achieved in exceptional events.
- incorporating into the Operating Procedures the circumstances that would justify a decision to move from manual mode of operation to the “deviation” mode of operation without the restriction of outflow to 75 m^3/s of the “default” mode.
- the appropriate number of authorised operators to retain, to ensure that sufficient operators are available for duty rotas.
- the extent to which the LBO should take an active role in the preparation of a social media commentary and responding to other public requests, since their primary duty is to plan and implement the operational strategy for the sluices.
- augmenting the training scenarios to include the experience of the 2013 flood.
- maintaining a training and professional development log for each operator.

7. References

Environment Agency (2015) “Kent and South London Winter 2013/14 Floods”, Draft, Confidential.

Essex County Council (2014), Flood Investigation Report - Canvey Island, Castle Point Borough, October 2014.

JBA (2015), “*Severity analysis of December 2013 flood, Medway catchment*”, Final Report, , JBA Consulting, Haywards Heath, RH16 4NG, April 2015.

Appendices

A. Glossary of abbreviations and acronyms

Abbreviation	Meaning	Comments and location (if relevant)
ABC	Area Base Controller	Designated role at EA offices in Addington
the Act	River Medway (Flood Relief) Act (1976)	Sets the legal basis for the construction and operation of the Leigh FSA. Also termed the River Medway Act if necessary to avoid ambiguity
AIR	Area Incident Room	Operational base for the event at EA offices in Addington
AM	Area Manager	Most senior post in EA area offices in Addington
ASM	Area Strategic Manager	A designated role based at EA offices in Addington. The ASM is above ABC in command and control hierarchy
EA	Environment Agency	
FFC	Flood Forecasting Centre	Jointly operated by the EA and the Met Office
FIDO	Flood Incident Duty Officer	Designated role at EA offices in Addington. Directs EA resource to ensure effective operation of EA flood management assets
FSA	Flood Storage Area	
FWDO	Flood Warning Duty Officer	Designated role at EA offices in Addington. The FWDO monitors catchment response and decides on activities related to warning and informing public and professional partners
GOC	Gate Opening Calculator	Bespoke EXCEL spreadsheet that calculates gate openings and flows.
LBO	Leigh Barrier Operator	A designated member of EA staff trained to operate the Leigh FSA; there were 7 designated LBOs in December 2013.
LBDO	Leigh Barrier Duty Officer	The LBO assigned to operate the structure for a particular period during an event. Located in the Control Room when the structure is not in automatic mode, unless the flow is under 45 m^3/s.
LBSO	Leigh Barrier Support Officer	Member of EA staff rostered to assist the LBDO during an event. A LBSO is not trained or authorised to operate the structure
MFDO	Monitoring and Forecasting Duty Officer	A designated role based at EA offices in Worthing. Acts as the interface between the EA and the Met Office. Runs the forecasting models.

Abbreviation	Meaning	Comments and location (if relevant)
MM	Mott MacDonald and Partners	Consulting Engineers who have prepared advice for the EA on the Leigh FSA operation.
NFFS	National Flood Forecasting System	The EA operational flood forecasting software.
NKFIDO	North Kent Flood Incident Duty Officer	A designated role based at EA offices in Addington; see FIDO above, covers the Medway Catchment
RBS	Reservoir balance sheet	Bespoke EXCEL spreadsheet that models the operation of the Leigh FSA
SETEL	South East Telemetry system	Software that collates and presents rainfall, level and flow conditions monitored in the South East region
TAG	Tactical Advisory Group	A high level advisory cell in the EA comprising the manager of the Thames barrier, the AM and the ABC

B. Executive Summary of JBA report on event severity

Executive summary

During the winter of 2013-14 a series of Atlantic depressions brought heavy rainfall and stormy conditions to much of England and Wales, including the Medway catchment in the southeast, where the largest flood occurred on 23 December 2013.

To assess the severity of the event in the Medway catchment the Environment Agency (EA) commissioned this study to look at the return periods of rainfall and river data. The results will feed into post-event reports being prepared by EA staff.

Rainfall during December in some parts of the Medway catchment was extreme, having a return period in excess of 250 years (30-day duration, based on single-site analysis using 60 years of data) in the Upper Medway, and 88 years in the Upper Eden (based on observed record of 84 years). On top of this ground-saturating rainfall, during the storm on 23 December the catchment received rainfall over 19-21 hour period which in some places had a return period greater than 20 years (based on observed record of 23 years). Uncertainty of return period estimates greatly increases once the length of the observed record is exceeded.

Results of the analyses carried out suggest that the December 2013 event in the Medway catchment was most severe in the south western part of the catchment, the Upper Medway. In the Upper Eden (north-west) the rainfall and resulting flows were somewhat lower. Below the Eden/Medway confluence the high flows seen in the Upper Medway, combined with lateral inflows, produced a significant overall flow. The southern tributaries, the River Teise and River Beult also experienced high flows. Despite the effective operation of the Leigh FSA the peak flow in the Medway at East Farleigh was still the largest on record, just slightly greater than that seen in 1968 before the scheme was built.

Flows seen in the Medway rivers were amongst the highest ever recorded, in several cases larger than the previous largest gauged event in 1968. The very wet antecedent conditions, combined with an intense storm on 23 December, produced flows with FEH single-site return periods of 133 years (Upper Medway, rank 1 in a record of 47 years), 34 years (Upper Eden, rank 2 in an observed record of 47 years), 29-48 years (Teise and Beult, rank 2 in observed records of 47 years), and 68-80 years (Middle and Lower Medway, rank 2 and rank 1 respectively in records of 47 and 41 years). Note that uncertainty of return period estimates greatly increases once the length of the observed record is exceeded.

C. Summary of third-party comments and responses on report MCR5376-RT001-R02-00

Summary of third-party comments and responses on report MCR5376-RT001-R02-00 (dated 14 May 2015)

	Comments from Mike Grasby	HR Wallingford Response
1	Firstly, it is quite clear that a very thorough audit has been carried out by the Consultant and that is something the public should be made aware of as the information is promulgated.	• EA to consider how the Audit is disseminated.
2	On the body of the Report it would be wrong to try to test the many statements on data collected through interviews and from records/logs so I have confined my views to suggested improvements in presentational style. Here I have three to offer. 1. Throughout there are many references to abbreviations (FSA, GOC, LBO LBDO et al) , which whilst being easily used by all involved, to the one off reader, research of pre read text becomes the norm. In a past life we would have listed these on a separate sheet at the back of the Report such that it could be folded out for easy reference. 2. In reference to procedures the word 'appear' is used. This leaves doubt in the readers mind that they are open to debate. Procedures should be fit for purpose, or not. If the latter, then clearly they must be reviewed - this is inferred in Recommendations. 3. Table 3.1 requires some concentration to assess staffing during the event. Redrawing it as a time based line diagram it is immediately obvious that at certain periods staffing just one Operator, e.g. O1 on 23/12 during 15.15 to 22.00, O3 on 24/12 during 08.30 to 11.20 and O5 on 25/12 during 02.10 to 10.30 was present.	• A glossary is included • A search was undertaken for “appear” and the suitability of its use re-assessed. • A simple diagram is included as Fig 3.1

	Comments from Mike Grasby	HR Wallingford Response
3	Section 3.4 is very informative, and by redrawing 3.1 as suggested, it is becomes much easier to assimilate the details of the events and demands placed on the Operators. Of particular note are the three periods mentioned above: • Operator 01, 23/12, 15.15 to 22.00 - activity seems low but it was very clear to the public that something was amiss in the weather forecasts regarding expected incoming rain. This begs efficacy of the forward looking analysis by the EA. • Operator 03, 24/12 during 08.30 to 11.20 - The Report lists multiple entries and comments of events during this period. It suggests that Operator 3 could have been overwhelmed (Fig 4.5 clearly shows the massive flow rate during this period) and clearly he should have been supported sooner than requested when Operator O5 was called upon at 09.42, but not arriving until 11.20. It cannot be acceptable to say " it was according to procedures' when the immensity of the event was obviously beyond any previous experience - this is tantamount to saying "we followed procedure so it must have been correct" but the event outturn clearly indicates inappropriate decision making. • Operator O5, 25/12 during 02.10 to 10.30 - whilst the worst was over with respect to volumes of data, there does seem to be many telephone calls requesting updates, so still an onerous period for one person. Section 3.6, third bullet point states that the Control Room was properly staffed. I find this difficult to understand set against the above analysis.	• Certainly the flood forecasts were not precise – with the peak lower and later for this event. However, I cannot comment on whether the public was aware of the weather forecast being amiss. • As the flood progresses there were different phases of activity, but Section 3.4 1 is not the right place to comment on this – it analyses the log book records. • I have added that the procedures are designed to cover the full range of floods and not just those of recent experience in 3.1 • I have added a note in 3.1 [*and a parenthetical comment against the 11:20 record*] that access was hindered by deep flooding on both approaches • I have explained further my reason for my opinion of “Properly Staffed” by adding text and re-ordering bullet points in Section 3.6
4	It is clear that many discussions between the Control Room was by telephone to remotely located relevant staff. Where were these people located? Omission of this suggests that they were inconveniently placed, probably because it was Christmas!	• The new Glossary includes locations of the various functions – mostly in the EA Addington office • There is good evidence from the Log Books that operations were maintained despite the holiday. • Added to Section 1.1 *“It is of prime importance that the Leigh FSA can be operated locally to the site under all conditions.”*

	Comments from Mike Grasby	HR Wallingford Response
5	The reference to years' service of the Operators suggests that their experience was acceptable. Since the last serious flood was in 1968, before the barrier was built, it cannot be sensibly suggested that any of the 5 of 7 staff could have any relevant experience set against the data emanating from weather forecasts and EA measurements.	• The key issue is effective training and contingency planning practice. • An analogy is that an airline pilot may have no direct experience of an engine failure mid-flight, but will have trained in what to do by using a flight simulator.
6	Clearly there are many lessons to be learnt and both the EA and the staff will benefit. It is interesting that '59 specific actions' emerged from the Operators debrief. This is most encouraging and it would be helpful to the reader if they were listed as an Appendix.	• Recommend that the EA publishes this separately from the Audit review, since I have had no hand in its preparation.

Prepared by

Paul Samuels

	Symonds Lane and Hampsted Lane Flood Action Group Comment	HR Wallingford Response
1	**Exec summary – did the EA follow the procedures**? We consider that this paragraph should include a comment that the procedures were not followed in their entirety because there was a 'manual override' of the outputs of the model, which in hindsight were unfortunate. This should be made clear at this point. Furthermore, there are not established procedures when in deviation mode so this statement could only apply up to and until this stage was reached. We also consider that Yalding was not subject to a sufficient duty of care, in contravention of the procedures.	• This is a misunderstanding. The flood forecasting model is a guide for the operators who need to assess the importance of the inherent uncertainty in the forecasts (See Section 4.7) and the current observations at the site when making decisions. • The Procedures to follow in "deviation" mode are defined. • Yalding was considered in the decision making (see Section 3.4.3 and Bullet 7 of Section 3.6)
2	**Exec summary Bullet 3** – it should be made clear here that the experience of the operators on duty was not sufficient to ensure that there was someone present who had real experience of operating the FSA during a major event	• The key issue is effective training and contingency planning practice. • An analogy is that an airline pilot may have no direct experience of an engine failure mid-flight, but will have trained in what to do by using a flight simulator.
3	**Exec summary** – Did the operations worsen or cause flooding elsewhere? Bullet 2. "Its operation did not cause or worsen flooding downstream" This point cannot be substantiated since elsewhere the report says that there is the existing models cannot determine the impact on Yalding. As a maximum this point should say that it 'probably didn't cause or worse flooding downstream as far as existing models can determine'	• This is my professional, expert opinion that I fully expect to be substantiated through modelling if it is undertaken. • I have based my opinion on the magnitude of the reduction of peak flow (38%) as set out in Section 4.4.
4	Furthermore, the report also states that there is a hypothetical procedure that could have reduced flooding in Yalding. These point should properly be reflected here to give balance since they make the claim here cannot be substantiated.	• Added to Bullet 1 in "Could the EA have done better"
5	1.1.1 and 1.1.2 the act makes specific reference to Tonbridge and Hildenborough, but NOT Yalding. Our point is that it SHOULD, given that we are also impacted. This point should be made in the report with a recommendation that the act is reconsidered.	• The Act as passed into law sets the statutory requirements for the Leigh FSA and the EA as the operating authority. • Clause 17(1)(a) of the Act on the operation of the control structure refers to flooding and inundations downstream, and so is drawn very widely • It would require an amendment to the Act to refer to Yalding in the preamble or elsewhere and I cannot see this receiving the required Parliamentary time.

	Symonds Lane and Hampsted Lane Flood Action Group Comment	HR Wallingford Response
6	1.1.3 the act says that there is a general duty of care and an obligation in sub-section 17(1a) to consider downstream impacts. Yet section 3.4.1 says that Yalding was first considered by the operators at 14.00 on 25th. It should be made clear that the flooding in Yalding was well in progress by this time, therefore there is no evidence that a duty of care was exercised for the residents of Yalding during the event. This is reinforced by the log book entry of 09.22 on 24th Dec which shows Yalding was not considered although other communities were. Furthermore, even if there was consideration on the day, there was no model prepared ahead of time that would have enabled operators to provide a required duty of care to Yalding. This is a very serious point which could presumably be the subject of further reports so it would be highly remise not to make any reference to it in the report.	• It is my understanding that where an organisation has the power to take some action, then it has a duty of care to others when exercising that power that they do not suffer harm or loss arising from that action. This is implied by the inclusion of Clause 17(4) of the Act and the need to consider downstream communities set out at key trigger points in the procedures. • This comment appears to be a misreading of 17(1)(a) which permits operation of the sluices to reduce flooding generally downstream (as opposed to specific communities) • The absence of evidence in the logs of consideration of Yalding cannot be taken as evidence of absence of consideration in the discussions and decision making. • Yalding would have flooded earlier and more deeply in the absence of flood attenuation by the Leigh FSA
7	1.2.1. for balance the report should state the rainfall in the Beult catchment and resultant flows were much less than in other events (e.g. 2000) yet the flood height here was much higher together with an estimate of the relative impact of the two in flows to Yalding. It is clearly meaningless to consider Yalding in the context of Medway flows without Beult flows and the report would lack credibility within our community without this point.	• No change needed. Section 1.2.1 is about the historic analysis by JBA of records of the severity of the flood. • The extract of the JBA report appended does comment that the Teise and Beult experienced “high flows”; the body of the JBA report identifies these as the second highest in 47 years of record. • The discussion in Sections 4.5 and 4.6 is at a location that does include the Teise and Beult flows at Yalding
8	1.3.1 my name should be removed and our flood group name inserted in its place	• Changed to “Symonds Lane and Hampsted Lane Flood Action Group”
9	2.3. reference is made to the fact that the GOC has not been calibrated. The potential impact of this on calculations should be highlighted here.	• This is mentioned in Section 5.3. • The key to the operation is that it is done on the local levels and rate of rise. • Added a comment in Section 5.3 on effect of non-calibration

	Symonds Lane and Hampsted Lane Flood Action Group Comment	HR Wallingford Response
10	2.4.4 it is not clear if the gate strategy specifically includes the impact of the Beult (presumably it has not given the absence of a suitable flow model). If it is not, this point should be highlighted and aligned against the requirements of the act (see above).	• The gate strategy is based locally on the inflow to the Leigh FSA assessed from water level observations and informed by simulations from the Medway catchment flood forecasting model. • In hydraulic terms the Beult is far downstream and does not influence the storage in the Leigh FSA.
11	2.5. it is highly significant that no flows are recorded downstream as without this the operator is acting blind in relation to Yalding (see point 6 re general duty of care and the absence of consideration of Yalding within the act.	• The outflow from the gates via the GOC is the flow downstream. • The effect on Yalding is based on good information (better than NFFS forecasts) • The decision procedures incorporate a critical outflow for considering flooding at Yalding.
12	2.6 if is surprising that the operating procedures do not cover what action to take in the event that sluices cannot keep the water below the max. operating level. This presumably means that the procedure is ad hoc and this could undermine the assertion that the procedures were followed - see point 1	• This would be for reservoir full and inflow > 300 cumec • The written Procedure is to contact the Reservoir Inspecting (Panel 1) Engineer. • Bullet 4 in Section 6.2 already makes a recommendation on this issue. • In these circumstances a severe flood warning will almost certainly be in force and the event managed in coordination with other Category 1 emergency responders.
13	Table 3.1/ para 3.2 the operators on duty on Christmas eve appear to have been highly influential on the outcome but do not appear to have provided their personal logs (operators 3 and 4). There should certainly be an explanation of this.	• All logs were supplied. • See Para 3 of Section 2.5 on record keeping – the personal logs are only kept if the LBO is actively on duty and not in the control room • Add “Control room log” to list of data supplied in Section 1.4
14	Para 3.3. the probability of rainfall on 25/26 Dec should be included along with the magnitude. It should be clear in the comments that in the event the rainfall was not as predicted and why confidence was given to this forecast but not others as part of decision making	• It is clear that the LBDO took a precautionary view, given the volume of rain experienced in previous days potentially leading to higher than usual runoff-rates from the saturated catchment. • The probability of rainfall is not relevant to the decision making

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15	Para 3.3 it is stated that the models for the Medway catchment are under review. There should be an explanation of why this is being undertaken and the expected improvement that should result	• Outside scope of the Audit commissioned • I consider it to be good practice to review the forecast model performance as part of the review of any major event
16	3.4.1 22nd Dec. it is evident that the model was already proving inaccurate by this stage. An explanation is needed as to what was done with this information, how it was subsequently appraised and acted upon given that findings later on regarding the model accuracy and also why there was so little faith in the forecast. Were the forecasts of the NFFS accurate in the end or not?	• No forecasting model is precise (See Section 4.7 for a discussion) • The Control Room Log shows that there were regular interaction with the MFDO as required in the procedures throughout the event. See the discussion in Paragraph 7 of Section 3.4.2 • Decisions were made by the LBDO in consultation with MFDO based on forecasts and local observation.
17	23rd Dec. Ditto	• See 16 above in general
18	24th Dec. given the above, it is not clear why the assumed 20% estimate of model inaccuracy is maintained. As above, this needs exploration and explanation. The report states in section 4.6: " the optimal strategy is to delay impounding until as late as possible so that the FSA reaches its permissible level just as the inflow rate falls to equal the outflow rate. By disbelieving the NFFS forecasts and underestimating the size of this flood event, LBOs were induced to start impounding too soon and were led away from the optimal strategy identified by HRW. It is true that we cannot have perfect foreknowledge of the ultimate size of a flood event, but in this case by wilfully disregarding the NFFS forecasts, LBOs made the flood worse than it needed to be.	• See 16 above in general • You do not operate on forecasts alone but on local observation since a forecast is not a prediction. • If the NFFS forecast had been used for operation then impounding would have started much earlier since the forecast flow at 03:50 on 24th Dec was 111 m^3/s. However, the actual flow at this time was 55 m^3/s and so not sufficient to trigger impoundment. • If impoundment had started at 04:00 or earlier, it would have led to premature filling of the Leigh FSA and a higher peak outflow than that actually achieved. • The NFFS forecasts underestimated the peak flow that actually occurred and the LBDO based their plan on a 20% increase to the NFFS estimate at 10:48 on 24th Dec. See the discussion in Paragraph 7 of Section 3.4.2 • By following the procedures the LBDO achieved greater downstream risk reduction than would have been obtained from using the NFFS forecast as the basis of operation.

	Symonds Lane and Hampsted Lane Flood Action Group Comment	HR Wallingford Response
19	24th 09.22. "there is no documentation… regarding downstream consequences". See also point 6.	• Under this entry it is noted that: "*The FIDO log book records at 09:29 consideration of downstream flooding implications of higher release (over 135 m^3/s) from Leigh FSA affecting Hildenborough, East Peckham and Tonbridge*". • Hence the EA in its operation of the Leigh FSA did consider the downstream consequences at the time of the decision to operate in deviation mode was made.
20	11:03 entry; given the rate of rise of water behind the FSA it should have been very clear by now that the model was wrong. An explanation is needed as to why it took so long to reach this conclusion, especially given point 16.	• In this note Op 3 is recording what has been evident from 09:00 that the actual flows exceed the NFFS forecast, validating the decision at 10:48 to plan using an increase on the NFFS forecast flows by 20%
21	3.4.2 see points above re operation of procedures in the event of deviations	• See Point 1
22	3.4.2 there is no explanation as to why the model was working so differently to other occasions. This is a major omission since it could very plausibly be that this is due to changes in the river characteristics which is a very fundamental point in relation to how well the FSA was managed (was it being managed based on erroneous and out of date data?)	• The model performance is outside the scope of this Audit. To me, a change in the NFFS model behaviour from over prediction to under prediction in a major flood is quite believable. • See Section 4.7 for a discussion of forecast uncertainty • **The key issue is that decision making and operation are robust to forecast uncertainty, data errors, power loss etc.**
23	3.4.3. this should state clearly that the logs evidence that Yalding was not considered until after serious flooding had occurred or was by now inevitable as a result of previous actions– see above	• The absence of evidence in the logs of consideration of Yalding cannot be taken as evidence of absence of consideration in the discussions and decision making. • See point 6 above - flooding in Yalding was delayed and less severe due to the operation of the Leigh FSA
24	3.4.6. reference to large numbers of automated gate recordings gives the impression this is actively considered 'live' but this is not consistent with the log entries	• Explain further in 3.4.6 Para 3 the control strategy is to keep flows within a target range. • Explain in 3.4.6 Para 3 that gates move at a finite rate, not instantaneously.

	Symonds Lane and Hampsted Lane Flood Action Group Comment	HR Wallingford Response
25	3.4.6. reference is made to our concerns about the gate movement at 07:46. Given that the optimal hypothetical strategy would have been to move the gate in the reverse direction at this time, it should be made clear that this was done with the best data available at the time, but in hindsight this was a very undesirable decision	• These gate movements are consistent with regulating the flow within a range of 75±5 m^3/s as in the Procedures (See Section 2.4.3) whist operating in default mode. • Under these conditions the centre gate should be closed and the two side gate opened approximately equal amounts. • The trigger in the Procedures to operate in deviation mode had not then been reached.
26	3.5. again it should be made clear why the model was more inaccurate than before on this occasion	• This section is intended to list all issues I can identify • Bullet point 4 covers the NFFS flows, the uncertainties are discussed in Section 4.7
27	4.2. this is a very serious point that should be given more prominence in the exec summary and conclusions	• The **first** recommendation in Section 6.2, repeated in the Executive Summary, is that: "*The Environment Agency should commission a revision of the Reservoir Balance Sheet tools as a matter of urgency to include the actual time of all observations made in deviation mode (rather than the assumption of a fixed 15 minutes schedule) and to ensure that the underlying volume relationship does not imply surface area decreases as level increases at any point.*"
28	4.3. given that all calculations are dependent on the uncalibrated flow formula through the gates, later comments on the impossibility of the optimal strategy being followed cannot be entirely substantiated	• Added a reference forward to Section 5.3 which discusses this factor. • As in point 22 above , the key issue is that decision making and operation are robust to forecast uncertainty, data errors, power loss etc.
29	4.6. it should be made clear that the gate movement at 07:46, while made with the best of intentions was exactly the opposite of what the optimal strategy would have required.	• No need to discuss this in detail as the actual operation was in line with the Procedures. • Under the optimal scenario, impoundment starts at 07:30 and so the centre gate will be closed and the two side gates opened. • This is similar to the configuration in the actual event but with larger openings on the side gates to accommodate the higher flow in the deviation mode of operation rather than default mode.

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30	Table 4.2 the potential reduction in Yalding is not consistent with a figure of 0.2m given elsewhere	• Values have been checked and do not need correction. • There is less confidence in the additional reduction of 0.4 m at Yalding than in the 0.2 m additional reduction at Tonbridge because of the effects of the additional inflows between the two locations
31	4.7 the conclusion that the hypothetical strategy could not have been found is very much over stated because: a. It is clear that the river model is inadequate and is therefore now being re-worked to produce a more effective forecast b. The gate flows are not calibrated c. The flow model was working differently than thought and there was evidence that assumptions on inaccuracy could have been taken on board earlier d. There was no accurate modelling of the impact on Yalding available at the time, a situation which is now being corrected e. There are simple amendments to the RBS which would have improved analysis and knowledge which are very clear in the recommendations Therefore the statement in 4.8.2 that "without perfect foreknowledge the optimal scenario could not have been found" should be re-cast and say "with better knowledge, some of which could and should have been available at the time, and will be available in the future as a result reviews of this experience it is more likely that the optimal strategy could have been found. This will also require amendments to procedures."	• The issue is that implementation of the strategy requires 100% certainty and absolute confidence that the NFFS forecast is a 100% precise prediction. • However, the NFFS produces forecasts: these are not predictions. • Even with improved NFFS flows, uncertainties in the forecasts will not be eliminated (e.g. precipitation forecast uncertainty will remain) • The decision procedure that uses a 15 minute review will tend to compensate for uncertainty from using hypothetical relationships for the gates rather than a field calibration • My conclusion is correctly stated even if NFFS is improved as all uncertainty cannot be eliminated • Local decision making based on local observation of water level ensures robust operation of the structure.
32	4.7 the list of uncertainties should include any potential changes to the river capacity as a result of possible silting	• Added a bullet point to cover this and other similar factors: "*Natural variability in the relative hydraulic performance of river and floodplain which are represented as fixed in the hydrological and hydrodynamic forecast models.*"

	Symonds Lane and Hampsted Lane Flood Action Group Comment	HR Wallingford Response
33	4.8.1 Bullet 5; as above, it is not possible to state that the actions taken had no negative impact on Yalding without hydraulic modelling so statements contrary to this should be modified throughout	• See point 3 above (Executive Summary) • This is my professional, expert opinion that I fully expect to be substantiated through modelling if it is undertaken. • I have based my opinion on the magnitude of the reduction of peak flow (38%) as set out in Section 4.4.
34	4.8.2 any conclusions that the EA could not have done better are invalidated by the above and the para should therefore be re-phrased accordingly including the repeated highlighted point that “without perfect foreknowledge.. etc”	• I have re-read these conclusions and I am content that they are appropriate.
35	5.1 refers to 59 lessons learnt. These should be included in an appendix.	• Suggest the EA publishes this separately from the Audit review
36	Section 5. This will need a fairly substantial re-write and a shift in emphasis to take account of the above	• Section 5.3 Para 1 has been revised • Minor changes in wording to remove ambiguity (phases that incorporated “appear to” have been reviewed)
37	Section 6. Ditto	• Minor changes in wording to remove ambiguity (phases that incorporated “*appear to*” have been reviewed)

Prepared by

Paul Samuels

HR Wallingford
Working with water

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