Water Resource Associates

A network of consultants in hydrology, water resources and environmental issues

Review of the Environment Agency Modelling Associated with the Oxford Flood Alleviation Scheme and the Downstream Reaches of the River Thames from Sandford to Reading Bridge

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Official Sensitive

Review Undertaken for the Vale of White Horse District Council

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Signed on behalf of Water Resource Associates:

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Executive Summary

A total of 23 documents were provided to Water Resource Associates (WRA) for an academic review of the modelling undertaken for the Oxford Flood Alleviation Scheme (OFAS).

The modelling study undertaken was a detailed programme of works providing output in terms of estimates of flows in river channels using hydrological models and estimates of water levels over the flood plain using hydrodynamic modelling.

Models were thoroughly tested and calibrated using measured data from observed flood events.

The modelling work was undertaken by a specialist consultancy company on behalf of the Environment Agency (EA) and an independent peer review was undertaken by a different specialist consultancy company.

The initial review by WRA in April 2016 found that the work undertaken followed approved modelling approaches and was of high quality.

The April 2016 review also identified that the study had only covered the reaches of the River Thames and tributaries within the immediate area of Oxford itself and did not provide any information further downstream than Sandford on Thames.

A second review was undertaken in August 2016 on the specific downstream impacts of the modelling which were covered in a technical note.

The technical note described a less detailed modelling approach although still made use of standard methodology including calibration against observed events.

The downstream effects of the preferred OFAS were shown to give either a decrease or very slight increase in water levels of less than 0.01m in the downstream water levels for the majority of the modelled scenarios. Mapped flood extents were however not presented in this technical note.

A final review of documents was undertaken in April 2017, which covered the modelling of the downstream reach of the River Thames from Sandford to Reading Bridge in more detail.

Following the submission of a draft review report by WRA in April 2017, a demonstration of mapped flood outlines for downstream reaches of the Thames including the effects of the OFAS was given by the EA in July 2017.

WRA believes the downstream impacts of the OFAS in terms of an increased flood hazard will be very minimal.

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1. Background

1.1 Introduction

WRA was first engaged by the Vale of White Horse District Council (VOWH) in April 2016 to conduct a review of the hydrological and hydrodynamic modelling undertaken by consultants on behalf of the Environment Agency (EA) for the proposed Oxford flood alleviation scheme (OFAS). The documents associated with this first review did not include the effects of the scheme on the downstream reaches of the River Thames. A second review was undertaken in August 2016 which included a report of modelling the impacts of the OFAS on downstream reaches, however it was evident the document was just an interim output in the form of a technical note. Final reports documenting the modelling of downstream reaches of the River Thames were not provided for review until March 2017. This current report is a combination of each of the three reviews.

1.2 Purpose of the Review

The purpose of the review is to confirm that the appropriate methodology, software and data had been used for the modelling and that adequate attention had been paid to the question on how settlements on the River Thames located downstream of the flood alleviation scheme may be affected. This report documents the findings of the WRA review and includes background information of the different components in order to assist with the understanding for a non-specialist audience.

1.3 General Modelling Approach

Computer modelling is now widespread within the field of hydrology, where specialist computer software is used to enable rapid calculations of a variety of equations representing the natural processes within a river and its catchment. Such models are routinely used to for a range of applications such as forecasting flooding, mapping areas of flood risk, designing flood defences and other water infrastructure, and identifying the potential impacts of a proposed scheme. The common modelling approach is broken down into three components:

1. Hydrological modelling, primarily to estimate the flow in the river at a particular location over a specific time period;
2. Hydrodynamic modelling (also called hydraulic modelling*) where the estimated flows are then fed into the study reach of the river and the water levels at particular times and locations are generated;
3. Mapping using GIS (Geographical Information Systems) where the extents and depths of the predicted water levels are then mapped over the land surface.

*Hydrodynamic modelling is used for this review as the words hydraulic and hydrological are similar and often confused when spoken.

Each of these components will be calibrated using observed data on river flows, levels and flood extents to ensure a degree of confidence in the model performance. A significant application of this modelling approach is scenario testing, meaning that once models have been set up for the current river and catchment characteristics, they can then be changed to test the impacts of different proposed schemes on flows, levels and flood extents. For some studies an additional groundwater modelling component is undertaken where there is concern over the impact on the local groundwater conditions. This part of the modelling is a separate study but it can be used to define certain parameter values for the hydrodynamic modelling.

This type of approach has been used for the OFAS to consider the current baseline conditions and various options for flood alleviation. The WRA review will cover how the modelling has been undertaken for each of the aspects listed above but will not comment on the different options for flood alleviation. The review will also comment on the EA peer review of the modelling.

1.4 Overview of Model Documents

A total of 23 documents including detailed reports, draft reports, technical memoranda and meeting records were provided by the EA in electronic format as shown in Table 1. In addition some of the reports also included separate appendices. The reports were written by the consultancies working on behalf of the EA. The main modelling study was undertaken by CH2M and the EA's peer review of this study was undertaken by Capita. The groundwater modelling was undertaken by ESI and two background reports were provided for some of the earlier work undertaken as part of the OFAS by Black and Veatch and Mott MacDonald. A demonstration of the final downstream flood outline maps was provided by the EA and CH2M in July 2017 using the flood slider software tool which enabled easy viewing of the outlines in GIS format. Copies of the flood outlines in GIS format were also provided as GIS format files to WRA.

Table 1.1 Document Record

Id	Document Title	Contents	Review Date
1	IMSE500177-HGL-00-ZZ-RE-N-000094-Interim_Modelling_Report_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling interim report March 2016	April 2016
2	Report A IMSE500177-HGL-00-ZZ-RE-N-000074-Model_Update_Report_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling update report November 2015	April 2016
3	Report B IMSE500177-HGL-00-ZZ-RE-N-000075-Model_Calibration_Report_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling calibration report November 2015	April 2016
4	Report C IMSE500177-HGL-00-ZZ-RE-N-000076-Model_User_Manual_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling user manual report November 2015	April 2016
5	Report D IMSE500177-HGL-00-ZZ-RE-N-000077-Hydrology_Final_Report_March2016	CH2M final hydrology report March 2016	April 2016
6	Report H Oxford_23_3_16_Modelling_Sensitivity_Tests_OFFICIAL_SENSITIVE.	CH2M hydrodynamic modelling sensitivity test technical memorandum March 2016	April 2016
7	Report I IMSE500177-HGL-00-ZZ-RE-N-000091-Flow_GaugingOFFICIAL_SENSITIVE	CH2M flow gauging technical memorandum February 2016	April 2016
8	Report J IMSE500177-HGL-00-ZZ-RE-N-000092-Low_Flow_Modelling_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling of low flows technical memorandum February 2016	April 2016
9	IMSE500177-HGL-00-ZZ-RE-N-000078-Modelling_Do_Min_and_Do_Nothing_Final_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling do-nothing and do-minimum assumptions technical memorandum March 2016	April 2016
10	IMSE500177-HGL-00-ZZ-RE-N-000102-Draft_Option_Model_Manual_OFFICIAL_SENSITIVE	CH2M hydrodynamic modelling draft option user manual report April 2016	April 2016
11	63294 R1D2_DRAFT_Issued CapitaAECOM comments-v2	ESI groundwater flood modelling draft report December 2015	April 2016
12	Oxford_FAS_Review_Modelling_Stage3Design_20160311	Capita review of CH2M baseline hydrodynamic modelling March 2016	April 2016
13	Oxford_Peer_Review_Meeting_Summary_&_Key_actions_26-jan-16	CH2M model peer review record of meeting March 2016	April 2016
14	Oxford_FAS_Stage4_Review_Options_Modelling_Fluvial_OFFICIAL_SENSITIVE_20160412	Capita review of CH2M options hydrodynamic modelling March 2016	April 2016
15	B&V Model Report 2014	Black and Veatch background report on the initial assessment August 2014	April 2016
16	Oxford_Flood_Mapping_Study_Report_FINAL	Mott MacDonald background report on Oxford flood risk mapping January 2014	April 2016
17	Oxford FAS – Analysis of Potential Downstream Impacts	CH2M technical note on modelling the downstream impacts June 2016	August 2016
18	Abingdon _FAS_Thames_Model _Modelling _Report_v1	CH2M Draft technical report hydrodynamic modelling of the downstream reaches of the Thames	April 2017
19	Abingdon _FAS_Thames_Model _Manualv0	CH2M Technical memorandum River Thames (Sandford to Maple Durham) Model User Manual	April 2017
20	Abingdon_hydrology_interim_report_v1	CH2M Draft Interim Hydrology Report for Abingdon Flood Schemes	April 2017
21	2016s3844_Abingdon_Technical Review_v2 (Mar 2017_p1	JBA Technical Model Review Report proforma 1	April 2017
22	2016s3844_Abingdon_Technical Review_v2 (Mar 2017_p2	JBA Technical Model Review Report proforma 2	April 2017
23	Oxford FAS – Downstream Impacts Summary Table	CH2M Hill Technical memorandum	July 2017

1.5 Review Structure

The review is divided into two sections, the OFAS modelling and the downstream impacts modelling. The first section concentrated on documents 1, 2, 3, 4, 5, 6, 9, 10, 12, and 14 which were all the main modelling reports. The groundwater modelling report investigated the impact of the potential flood alleviation options on the groundwater levels in the immediate vicinity of the flood alleviation works and was not considered necessary for the review. Likewise, the background reports were not considered in the current review as they were separate studies. Generally, a greater amount of information is presented in the first section since it also includes definitions of particular terms and approaches. The second section covered documents 17 to 23, with the interim technical note (document 17) on the modelling of downstream impacts and more detailed downstream modelling reports (documents 18-20). Both sections cover the hydrology, hydrodynamic modelling, GIS and EA peer review, although the GIS is not included as a separate sub-section in section 2. Conclusion are also given for both sections and the key points are listed in the executive summary at the start of this document.

2. Review of OFAS Modelling

2.1 Hydrology Background

The hydrology report appears to be a review of a number of previous hydrological reports:

a. Black & Veach, Oxford Flood Risk Management Strategy, Hydrology Report, December 2009 (document 15).
b. Mott Macdonald, Oxford Flood Risk Mapping Study, January 2014 (document 16).
c. Environment Agency, Oxford Flood Alleviation Scheme, Strategic Outline Case, November 2014.

However, Appendix A of the report shows that there have been numerous previous preliminary studies starting in 2005, and this latest CH2M report builds upon an earlier May 2015 report by CH2M on hydrological and hydrodynamic modelling where detailed scheme designs for the flood alleviation scheme were undertaken.

The hydrology report provides considerable background information on the study with a description of the Thames catchment at Oxford, a review of historical flooding with reference to observed flows and levels, and information on how changes in the structures along the river (such as weirs and bridges) may have affected the flows over time. The main focus of this report is to provide estimates of the flood flows which will be used to optimise the design of the flood alleviation scheme.

The severity of a flood on a river is expressed in terms of the probability of such a flood occurring in any given year. It is most common to refer to the probability by its return period e.g. a “1 in 100 year” flood. This means that a flow of this magnitude is expected to occur on average once in a period of 100 years, and has a probability of occurrence of 0.01 in any one year. It does not mean though that the interval between events of this magnitude will be 100 years. Flows for a range of return periods are normally estimated for this study e.g. 2, 5, 10, 20, 50, 100, 200 etc. The reason being that for a particularly vulnerable area such as Oxford with a high density of population and a high economic value at risk of flooding a high level of protection should be afforded (e.g. protection against the 1 in 100 year flood). For other areas such as agricultural land a lower level of protection and hence less cost is appropriate (e.g. protection up to the 1 in 20 year flood). The return periods are abbreviated, so the 1 in 100 year flood is written as the 100-year flood. The report includes two components to estimate the severity of the flood the peak flow value for a given return period and the flood hydrograph (i.e. the representation of flow over time for a flood event). These are described in the following sections.

2.2 Hydrological Analysis of Available Flow Data

The March 2016 report describes exhaustive analysis of all available gauged flow records for all stations available within the study area. The main upstream inputs are the Thames at stations 39129, Farmoor and 39008, Eynsham, the Evenlode at station 39034, Cassington, the Cherwell at 39021, Enslow Mill and the Ray at 39140, Islip. The downstream outflow limit of the model is at Sandford where modelling by Black & Veach in their 2009 report developed a rating curve for tail water levels. In addition, Eden Vale Modelling Services (2007 and 2008) have produced revised rating curves through modelling for Farmoor, Eynsham, Cassington, Enslow Mill and the Thames at Pinkhill Lock close to the Farmoor gauging station.

Thus, there appears to be adequate flow records of good length for the study although several different flow series have been compared, these being:

- The flow data held by the National River Flow Archive (NRFA) operated by the Centre for Ecology and Hydrology;
- Flows from the 2009 Black & Veach report;
- 15-minute flow and tail water levels provided by the EA from their WISKI database;
- HiFlows-UK database values.

In Section 2 of their report CH2M undertake a comparison of annual maximum flood flows (AMAX) from all of these various sources for each station (where it is available) and there are significant differences in many cases for the mainstream Thames stations and at Cassington. Such differences in the median annual flood (Qmed) are often due to different record lengths available from each source. However, in some cases there are marked differences between say the NRFA and the EA WISKI data, often exceeding 10% of AMAX, and in some cases differences can be as much as 40% (e.g. 2006 at Eynsham, although it should be remembered that hydrological years are being used and this flow value is for the July 2007 flood).

Despite these somewhat concerning differences in AMAX estimates CH2M have made sensible choices over which data series to use for individual station frequency analysis and also in their choice of stations for pooling groups. The analysis of the hydrological data for estimation of flood peaks of the range of return periods required (2 to 1000 years) is robust.

2.3 Design Hydrograph Analysis

The normal practice in the UK for estimating flood hydrographs is to apply software from the Flood Estimation Handbook (FEH) which was published in 1999 by the Institute of Hydrology. The CH2M report argues that use of the FEH rainfall runoff or revitalised flood hydrograph approach, each using the unit hydrograph model and assuming uniform rainfall over the catchment, is not appropriate as the combined upper Thames catchment plus Evenlode catchment is approximately 2,000 km^2.

CH2M used an approach developed by Archer and colleagues at JBA consultants where a series of observed hydrographs are averaged to produce a characteristic design hydrograph that is then scaled to the appropriate peak value for each return period event required. The approach was applied to hydrographs at 39007, Thames at Eynsham, 39021, Cherwell at Enslow Mill, 39034, Evenlode at Cassington and 39140, Ray at Islip.

Overall the fitted average hydrographs looked reasonable although the July 2007 hydrograph at Eynsham was markedly different to the other events used, being much peakier and rising to peak very quickly. The 2007 hydrograph was also somewhat atypical at Enslow Mill although it compared well with the large flood of April 1998. The Cassington hydrograph for 2007 had a peak over twice that of any other event, a much faster time to peak and was of much shorter duration than other events considered. In the case of Islip, the 2007 event was not used possibly due to backwater problems from the Cherwell.

The averaged hydrographs used for design were compared to those used in previous studies and generally compared well, although the Eynsham peak was now some 20 to 30 hours later than in the 2014 study whereas for Enslow Mill the peak occurred some 50 hours earlier than the 2014 study hydrograph and the new hydrograph is much peakier and has less total volume. At Cassington the new hydrograph is also peakier with reduced volume and the time to peak is some 25 hours earlier than in the 2014 study. The relative timing of peaks at each station were compared for a significant number of events with the Evenlode at Cassington being the first to peak followed by the Ray at Islip with a peak about one hour later and the Thames at Eynsham and the Cherwell at Enslow Mill reaching their peak about 10 hours after Cassington. These relative timings were used in the hydrodynamic model design studies. Four small later inflow hydrographs were also included to the hydrodynamic model using the Cherwell hydrograph shape and using 3.29% of the Cherwell flow for each of these four inputs. Details of this topic were purported to be in Appendix C, but the review could find no such evidence.

The hydrodynamic model does not extend to the gauging stations so routing of the various upstream hydrographs to the upper limit of the model was achieved using the EA's Oxford Flood Forecasting model. Resulting hydrographs compared well with the previous 2014 work by Mott Macdonald.

Finally, consideration of the timing of hydrograph inputs to the model was examined to test the sensitivity of this to Sandford flows and levels. Three scenarios were examined:

- Coincident peaks – all tributary inflow peaks were adjusted so that they entered the Thames channel as the Thames is at its peak flow. This results in largest flows at Sandford.
- Early non-coincident peaks – tributary inflows applied to the Thames at the earliest time they have been observed relative to the Thames peak.
- Late non-coincident peaks – tributary inflows applied at the latest time they have been observed relative to the Thames peak.

The results of this sensitivity are plotted in Figures 3-13 to 3-15 of the report.

A further sensitivity test was applied looking at the proportions of total flow contributed to total flow in particular observed events. Unsurprisingly the upper Thames catchment provides 55% of the total flow on average, with the Evenlode providing 15%, the Cherwell 18% and the Ray 11.6%. However, when the modelled design hydrographs are used, the upper Thames contribution falls to 44.6%, the Evenlode and Cherwell both increases to 18.9% and 26% respectively whilst the Ray is relatively unchanged at 10.5%. Due to of these differences sensitivity model runs were made for the 100-year event with upper Thames inflow proportions of:

- 31.75% - the minimum observed contribution,
- 43.5% - based on the design event figures,
- 55.25% - similar to the average observed contribution, and

- 67% - the maximum observed contribution.

Tributary inflows in each case were scaled such that the total flow matched the original value. Figure 3-17 of the CH2M report shows results of this test and showed that peak flows at Sandford were relatively unaffected by the proportion of total flow contributed by the upper Thames, although there is a noticeable change in hydrograph volume.

2.4 Hydrology Review Conclusions

The CH2M report seems to have undertaken a very careful re-examination of the available high flow data and the derived design flood peaks are as good as can be expected, although they state that there are still uncertainties over the peak flows estimated for each return period.

The hydrograph analysis is believed to be appropriate and has made best use of available data. However, as CH2M point out there could be many combinations of inflow hydrographs from the four main tributaries that could generate say the 100-year peak flow and hydrograph at Sandford. Nevertheless, the sensitivity trial varying the proportion of flow contributed by the upper Thames (Figure 3-17 of their report) suggests that the Sandford peaks may not be overly sensitive to this issue.

The derived flood volumes at Sandford have been compared with those derived by Black & Veach in 2009 and found to agree to within ±10% across all scenarios, which is reasonable.

2.5 Hydrodynamic Modelling Background

The hydrodynamic modelling undertaken by CH2M consisted of a combined 1D/2D modelling approach. This type of approach is where the model is set up so that the level of the water within the river channel is estimated at a number of cross sectional lines along the course of the study reach. Each cross section represents the shape of the river channel and is defined from channel depth measurements taken from field surveys. A line has a single dimension so the modelling is described as 1D. All structures in the channel networks (i.e. bridges, weirs, culverts) and other network features such as channel joins, flow inputs are represented as such cross sectional lines and referred to as node points within the model files. At the point in time of the simulation at which water levels rise above the level of the river banks (as defined by the cross sections), the water will then spread across the surface of the floodplain in 2 dimensions. The ground surface is represented as a grid of equal sized square cells, each with a defined altitude, and is known as a digital terrain model (DTM). The spreading of the floodwater across the DTM is also represented as a grid at the same cell size, with each cell having a depth of floodwater. This spreading of the floodwater is the 2D component of the modelling.

There are a number of commercial software packages which are used for this type of modelling. The CH2M study has used the *Flood Modeller Pro* 1D component coupled with a *TUFLOW* 2D component. *Flood Modeller Pro* is a CH2M software package and was originally developed jointly by HR Wallingford and Halcrow Group (now CH2M) specifically to undertake hydraulic simulations on the River Thames. The *TUFLOW* software was jointly developed in Australia by WBM Pty and the University of Queensland for coastal and estuarine studies. Although these components are from two different software packages they were dynamically linked for a study on the Thames estuary in 2004 and have since been benchmarked by the EA and have become the EAs preferred 1D/2D modelling approach.

Unlike the review of the hydrology which could focus largely on just a single report, the hydrodynamic modelling was documented in seven different reports and technical memoranda. These often covered particular aspects of the modelling such as the calibration and scenario testing. It was apparent however from reviewing the reports that the 1D/2D hydrodynamic model files were not generated from scratch by CH2M for the purpose of this study. Entering all of the data for a hydrodynamic modelling simulation is a very time consuming exercise therefore it is normally much easier to take an existing model file and modify this to meet the requirements of the study. The baseline 1D/2D model file for the current study was modified from that generated by Mott MacDonald for the EA flood mapping study undertaken in 2012-2014 and reported in document 16 from Table 1.

2.6 Baseline Hydrodynamic Modelling

The CH2M model update report (document 2) described how the Mott MacDonald model files were updated to meet the requirements of the flood alleviation scheme study, which included adding further channels with more cross sections and structures, increasing the density of cross sections on existing channels with new survey data and checking some of the existing cross section surveys. It would be of benefit if this was made clear in the CH2M hydrodynamic modelling report or included in an overview report.

The objectives were specified in terms of developing a “Do minimum” model for the Oxford FAS. This would normally indicate that only works required to maintain the current standard of flood protection would be considered within the scope of the modelling. It was not clear if this would this include climate change. The review of the Mott MacDonald modelling included site visits and identified areas in which survey data was of variable age and quality. Inappropriate model schematisation was identified on Eastwyke ditch. Issues such as over-enthusiastic filtering of LiDAR data (described in the GIS section) involving removing features of significance to flooding were identified. No further ground surveys were carried out but older parts of the model were checked against newer survey data where available.

The model review concluded that the model needed to be updated “making use of all new survey data” and that, where surveys indicated “silt level” as well as “hard bed”, the silt levels should be used in preference. The latter issue appeared principally to relate to the Osney Reach of the Thames and it was noted that mobility of the Thames bed would need to be considered via sensitivity testing at scheme design stage.

The representation of buildings in the 2D domain is said to have been carried out using a 2D roughness of 1.0 and with buildings otherwise entirely removed. This approach has the potential to significantly underestimate the effect of buildings on flood flow by disregarding their restraining effect on the passage of floods whilst overestimating the flood storage capacity of the built-up area. Together, these effects may lead to the underestimation of flood depths in built-up areas in general and could also lead to incorrect flood extents where flood conveyance is significant.

Hydraulic structure coefficients and channel roughness coefficients were presented and the process of adopting consistent assumptions for these values across the model was described. Model calibration typically involves making global adjustments to coefficient values in an

attempt to make the model reproduce relatively sparse observed flood level and flow data so it was appropriate to ensure that the base case against which changes are made is of uniform quality.
The model revisions were clearly described and illustrated by graphics showing a substantial increase in the number of model nodes in the updated model as well as significant increases in the lengths of channel modelled explicitly in 1D. Flood mitigation works which have been carried out since the occurrence of key calibration flood events were identified so that model calibration was carried out with those works removed from the model.
Model performance was demonstrated to be reasonable in the 100-year event but started to be problematic in the 1000-year event. The latter was reported to relate to localised 1D flow instabilities. Damage costs for events greater than the 100-year flood are not likely to be significant to economic assessments but, if the 1000 year results are found to be critical to the assessment of an option, this issue may need to be revisited.
The "Do-Minimum" and "Do-Nothing" modelling scenarios were reported in document 10 from table 1. Running the model with these scenarios provided baselines for the economic assessment of flood mitigation proposals including both structural and operational measures. The report defined these scenarios although there was an error in the section on "Do-Nothing" where the text reads "Do-Minimum" when "Do-Nothing" is intended.

2.7 Hydrodynamic Model Calibration and Sensitivity

For detailed hydrodynamic modelling studies such as the CH2M work for the OFAS, it is common practice to calibrate the model files once they have been set up with all the correctly defined river reaches, cross sections, structures and parameter values. The calibration involves inputting observed flood hydrographs from historical flood events and comparing the outputs in terms of downstream flows, level and flood extents with the same observed data from the event. Once calibrated based on a selected historical event the model files are then validated using one or more additional historical events. Very good calibration data is available for the River Thames given the long history of monitoring flows and levels and also the detailed mapping of more recent flood events.

A separate CH2M model calibration report was written, document 3 as shown in Table 1. The calibration used the July 2007 event and validation used the winter 2013/14 event and the January 2003 event. In the report the range of data available for calibration was set out clearly and the inevitable problems with that data were discussed. Results were presented in terms of the accuracy of modelled maximum water levels and flood extents in comparison to observed flood extents. The accuracy of reproduction of water levels was shown to be very reasonable within the 1D areas of the model. Some significant differences in predicted water level were reported at specific locations in flood plain areas. It was not made evident whether these errors were significant to the damage assessment and/or could be ascribed to the reliability of the flood level data.

The report noted that the modelling of the 2D areas with buildings entirely removed was necessary to reproduce the observed flood extents in some places where flood depth was relatively small. Where flood depth was small, the amount of flowing water would also have been small and the effect of such a change to the 2D modelling on the overall results would have been small. Localised shallow flooding could also have been due to local drainage issues, however. The effect of the change on flood depth in other areas was not, apparently, considered. In addition to the calibration of the hydrodynamic model files further simulations were run where key parameter values were changed to give an understanding of the sensitivity of the parameters. This component is reported as a CH2M technical memorandum, document 6 in Table 1 and describes a range of sensitivity tests which were carried out. The key uncertainties covered including the channel and floodplain roughness parameters, weir coefficients, blockages of bridges and culverts, influence of the design hydrograph shape, and timing/relative magnitude differences between tributary flows and main river flows. The results however were not presented, neither was a consideration of the way in which sensitivity analysis outputs would be used.

2.8 Hydrodynamic Modelling Flood Alleviation Scheme Options

The hydrodynamic modelling of the proposed options for the Oxford Flood Alleviation was presented by CH2M in a further report (document 10 in Table 1). Following the EAs request the actual option details were not discussed in this review as further work is to be undertaken to determine the preferred option and the CH2M report stated that model files will be updated during the study to support the design.

The changes to the model were set out clearly, including maps of the proposed options showing the new channels and cross sections included in the model files. No guidance was given as to the objective of each change, or the overall aim of the project, other than the implied objective of reducing flood extents. Some of the changes looked like conveyance increases but some seemed more like the provision of additional storage but this was not made clear. Proposed new flood defence lines were indicated but it was not made clear how these are being modelled.
The model results were presented as graphs, maps of flood extend and tabulated values. A comparison of flows and levels with the baseline scenario was given in Tables 13 and 14 of the report but the presentation of the results is confusing. The model results table columns headed “Peak Water level (mAOD) and” or “Peak Flow (m^3/s) &” seemed to be incomplete. The note at the foot of the tables tried to explain the left alignment of large numbers and right alignment of small numbers but the significance of those numbers was not clear. The note also referred only to 1D flows and it was not clear how total flows compare.
The only consideration of downstream impacts seemed to be in terms of the model outflows (section 4.1). The model results were, as with the other hydrodynamic modelling studies, limited to the downstream extent of the model at Sandford Lock. The options showed that the rising limb of the hydrograph at Sandford Lock to be higher than the baseline scenarios. Accelerating the rising limb of a hydrograph could lead to higher flood levels in downstream tributaries, even if the peak flow is slightly reduced.

2.9 Hydrodynamic Modelling Review Conclusions

A description of the overall modelling approach is lacking and the study would benefit from a single report outlining the approach the different background studies through which the model has been developed and the sources of input data. With so many different modelling documents this review had to undertake a form of an audit trail to find that the CH2M model was based on the earlier Mott MacDonald model for flood mapping. It is accepted that the EA would have a reasonable knowledge of the different stages in the modelling as part of this whole programme but that is not clear to other organisations and independent reviewers.

Overall the approach is correct using approved software, and following the standard sequence of compiling model files, simulation, calibration and validation, sensitivity, and scenario testing for the flood alleviation options. The modelling reports have described each of these components in detail. There is some concern about how buildings in the floodplain are represented and that the model shows instability under high return period flows.

The main issue with the modelling however is that impact of the model on areas downstream of Oxford has not been addressed. The downstream limit of the model is Sandford lock so it is not possible to provide a definitive assessment of the impact on areas downstream such as Abingdon, Culham, Sutton Courtenay, and Appleford. The results for Sandford Lock showed a slight reduction on flows with the flood alleviation options but also an increased rising limb of the hydrograph. Further modelling of this flow into the downstream reaches should be undertaken to properly identify the potential impacts. It is understood however that the requirement of the CH2M study was to model the flows, levels and flood extents in Oxford.

2.10 Review of OFAS GIS and Survey Data

A review of the GIS and survey data was considered important since this is the base data which underlays the OFAS study. GIS is software which allows the generation, analysis and display of spatial data in digital format. It is essentially a form of computerised mapping but instead of just allowing the drawing and display of maps as pictures, all the data is georeferenced so that it is shown in its real world location. In addition, each data element which is graphically displayed has associated attribute data. This is not just a description of the drawing such as line colour and thickness but any form of numerical or written information. For example, a line on a GIS data layer representing the section of the River Thames from Eynsham to Sandford could have the river name, a unique reach identifier, the start location, end location, monitoring start date, end date, mean flow, peak flow, date of peak etc. as attribute data.

An important feature of GIS is that mapped data layers can be overlain and combined to form new data. GIS data, analysis and presentation form an important component of the hydrological and hydrodynamic modelling. The *Flood Modeller* software has a GIS component whereby all the node points of a model file are plotted on a base map using a defined coordinate system. The *TUFLOW* software also has GIS capability to map the spreading of the floodwater over the land surface. Background maps used in *Flood Modeller* to display the model structures and flood extents are from Ordnance Survey map tiles, incorporated in the software.

In addition to the built-in GIS components of the modelling software stand-alone GIS software packages are used in these studies for generating and mapping data. One of the key GIS data layers used in the study was the DTM, which ultimately defined the extent of flooding from different scenarios. The CH2M interim modelling report listed a number of GIS files in different formats and describes the DTM as ascii format but has no information on the source of the DTM. It is only in the Mott MacDonald flood mapping report that the DTM was defined as being derived from LiDAR (Light Detection and Ranging) which is an airborne survey where a light beam is reflected from the ground at different time intervals, depending on the ground height. The DTM has a 1m cell resolution (i.e. a height point every 1m) for most of the study area although in some places the resolution was only 2m. It is quoted as having a vertical accuracy of +/- 0.15m. It is assumed this data was provided by the EA geomatics group, but not specified in any of the reports. This is probably the most accurate data available at the time of the study, but it was a weakness of the CH2M reporting that no information is given about the DTM. Also there was no mention of how the DTM was imported into the software. Ascii format is a raw data format, and usually needs processing using GIS software to be of use in other software packages. The flood alleviation options modelling report did not include any information on how the DTM has been edited to incorporate proposed features.

A similar situation existed with the river channel survey data. Much of the 1D/2D modelling was based on existing survey data used in the Mott MacDonald study, where surveys were undertaken in 2004 and 2005. Further surveying was undertaken by CH2M and described in the CH2M model update report, but the study would benefit from having a GIS layer showing all of the surveyed cross sections with the date and source as attribute data. This could be plotted as a series of maps in a report appendix.

2.11 OFAS Peer Review

With detailed modelling studies undertaken by consultants on behalf of the EA, it is normal practice for a peer review to be undertaken by another consultancy company which has sufficient expertise in the field but is not part of the original project team. In this case Capita were selected to undertake the peer review, and this conformed to a standard proforma which is used by the EA for these purposes. The peer review reports (documents 10 and 12 from Table 1) provided by the EA only included a review of the part of the hydrodynamic modelling which simulates the flow from defined return period flood events and for the flood alleviation options. Other components of the study such as the overall methodology, the hydrology, groundwater modelling and hydrodynamic model calibration were covered in separate earlier reviews.

The peer reviews included checking all of the model files and the reports associated with the hydrodynamic modelling. With access to the model files and adequate time available the peer review was able to take a much more detailed review of the modelling than the current WRA review which was limited to reviewing just the modelling reports. In essence where the current review of modelling reports by WRA was able to comment on the general approach, the software used, and data sources, the peer reviews were able to pin-point errors in the model files. Under the synopsis of model review findings, the peer review of the flood event simulations stated that the model is generally well built and the calibration results provided a reasonable fit to observed data. This assessment corresponds with WRA review (see the Hydrodynamic Model Review Conclusions section). It also noted the model instabilities which were raised in the WRA review. The peer review observed that that there should be an overall modelling report, something also identified in the WRA review.

In more detail the peer reviews identified a number of aspects of the modelling which needed to be checked. They also listed actions which were colour coded depending on how they would impact on the model. Actions given in red were classed as having a high impact on the modelling and model amendments were recommended. Actions given in amber were classed as may having an impact on the modelling and model amendments could be required or justification given in the modelling report. Actions given in green were classed as having a negligible impact on the study outcome but the issue to be noted and included in the modelling report.

From the peer review of the flood event simulations, points of concern included identifying that not all cross sections are georeferenced, inconsistency between the location of channel bank lines in different model components and some areas of "glass walling". The latter point indicated areas where the model files had not been correctly set up so that as water levels in a channel rose above the bank level, the water remained within the channel as if being bounded by glass walls. Obviously, this does not happen in reality so the model parameters need to be corrected.

Other points identified specific areas where flood extents were questionable such as flooding over raised roads and railways (e.g. the A34 near Seacourt Stream and the railway embankment between Grandpont and Abingdon Rd). Further areas were identified based on the model node-point id so without the model files the actual location could not be identified.

The peer review of the flood alleviation options also identified areas where the 1D and 2D component elevations did not agree, the continued inconsistency between locations of channel bank lines in different model components and the lack of a structure in the model to allow flows under Abingdon Road. Another concern was raised about the potential impact in downstream reaches of the Thames, which was a key finding of the WRA reviews of the modelling reports. The peer review, with access to the model output files, noted that although the peak flow from modelled flood alleviation options is lower than with the baseline scenarios, the rising limb showing flows leading up to the peak is higher. The implications in respect to the timing of other tributaries downstream should be given some thought and that lower return period peaks should also be simulated.

2.12 Conclusions

The WRA review of the CH2M modelling studies associated with the OFAS has the following conclusions:

The study is detailed and conforms with the standard approach for flood modelling. It includes a number of reports for the main consultant (CH2M) and a thorough peer review of the modelling undertaken by an additional consultancy (Capita).

An overview report is required which documents the full history of the OFAS modelling including the origins of the hydrological and hydrodynamic modelling, the consultancy companies involved, and the data sources including dates of surveys.

The hydrology is covered in adequate detail and the hydrological modelling is appropriate and makes use of the best available data.

The hydrodynamic modelling is documented in particular detail with separate reports describing the initial model, calibration and validation, sensitivity analysis and testing of the flood alleviation options. The peer review of the hydrodynamic modelling is also documented in detail.

The WRA review did not examine the hydrodynamic model files but some issues relating to these were raised by the peer review. It is expected that further amendments to the modelling will be undertaken to address these issues.

Other issues noted were concern over how building within floodplain areas were represented, model stability at high return periods and whether the DTM is modified to incorporate features of the proposed flood alleviation options.

The current study does not provide adequate information on the downstream impacts of the OFAS. The hydrodynamic model downstream limit is Sandford Lock and a further modelling study is required to consider the impacts on settlements located downstream on the River Thames. This observation is supported by the Capita peer review.

3. Review of the Downstream Modelling

3.1 General Approach

The initial downstream modelling reported in document 17 consisted of a 1D hydrodynamic model of the River Thames which was based on two existing flood forecasting models for the Thames from Sandford to Sutton Courtenay and from Sutton Courtenay to Mapledurham. The model was run for observed historical floods and simulated flood events for set return periods (2, 10, 100 and 1000 years) for the current situation and for the OFAS preferred option of the Western conveyance channel. The model provided output in terms of levels for 16 downstream locations: Abingdon, Sutton Courtenay, Appleford, Long Wittenham, Clifton Hampden, Burcot, Dorchester, Shillingford, Benson, Wallingford, North Stoke, Mouslford/South Stoke, Goring/Streatley, Whitchurch/Pangbourne, Purley/Mapledurham and Reading/Caversham. No maps showing the flood extent were produced.

Additional more detailed modelling was undertaken and reported in the later documents (18 - 20). This included the hydrological and hydrodynamic modelling of the River Ock through Abingdon in some detail as a precursor to an additional flood alleviation scheme for Abingdon. The modelling also included a more detailed 1D/2D hydrodynamic modelling of the River Thames from Sandford to Reading Bridge (downstream of Mapledurham). The model was run for observed historical floods (2003, 2007, 2012 and 2014) and simulated flood events for set return periods (2, 5, 10, 20, 30 50, 75, 100, 100 plus climate change, 200 and 1000 years). The model report provided output in terms of levels for 22 downstream locations namely the locks at: Sandford, Abingdon, Culham, Sutton Courtenay, Clifton, Days, Benson, Cleeve, Goring, Whitchurch, Maple Durham and Reading Bridge. As the modelling also included the 2D element, level, flow, velocity, mass balance and UK Hazard outputs are generated on a cell by cell basis across the model extent. Flood extents have been generated from the 2D output and converted into GIS format but these were not provided in any of the documents. Instead a demonstration was given of the predicted flood outlines in July 2017 by the EA and CH2M using the flood slider software. This enabled a rapid comparison of outlines generated from the same magnitude flood event with the baseline scenario and the preferred OFAS scenario. A full summary of the impacts of the OFAS in terms of absolute water levels and the water level differences at the 22 downstream locations was provided in document 23.

3.2 Hydrological Modelling

Very little new hydrological modelling was undertaken for the initial assessment of the downstream impacts of the OFAS. Input hydrographs already existed from the flood forecasting models and the OFAS model. The flood hydrographs which feed into the hydrodynamic model were taken from the OFAS hydrodynamic model outputs, existing observed hydrographs at gauging stations on the River Ock and River Thame, and hydrographs for the remaining areas were generated based on an area scaling method. The OFAS hydrographs included those generated with and without the western conveyance channel (WCS) in place. Plots of the input hydrographs are included in the technical note which show very little difference between the pre- and post- WCS, for both the observed and the design flood flow scenarios.

The hydrological modelling described in the later modelling report (document 20) includes more detailed estimates of flows in the River Ock and its tributaries. This report focuses primarily upon options for flood alleviation within the Ock catchment, including a potential flood storage area, and flooding impacts on Abingdon. Although the model extent is from Sandford Lock to just downstream of Mapledurham, the modelling does not address the area of primary interest to VOWH; namely what impact might the OFAS have on communities downstream of Sandford. Thus, the report does not materially improve knowledge of whether the OFAS scheme might cause adverse downstream impacts.

The hydrological data used in the study and the approach adopted are both sound and hence the model outputs in terms of flood hydrographs on the Thames between Abingdon and Mapledurham appear to be reasonable. Unsurprisingly given the purpose of the report considerable attention has been given to distributed inflows to the Ock upstream of Abingdon, where the river has been gauged at station 39081 since 1979.

Four calibration events were used: January 2003, July 2007, November 2012 and Winter 2014 (a multi-peaked event commencing on 30th December 2013). Three of these events were used in previous studies, but the 2012 event was included because the ANMAX data was included in the Hiflows database for gauging stations at Abingdon, Pangbourne and Reading Bridge.

Design hydrographs were derived using the Archer's method, essentially scaling a number of historical hydrographs to a common peak and using a mean hydrograph shape from these recorded events. This is an appropriate approach, although Figure 4-1 of the report demonstrates that the Archer's approach produces earlier peaks than previous OFAS design hydrographs and that the 0.1% (1000-year) event also having a somewhat higher peak.

Surprisingly there is no discussion of inflow hydrographs from the Thame catchment, yet with an area of 535km^2 this is 3 times larger than the Pang (176km^2) and where its median annual flood (Qmed) of 21.2m^3/sec is over 9 times that of the Pang's 2.3m^3/sec (source National River Flow Archive, NRFA). The special treatment of the Pang may be because it is a highly permeable catchment with rather different hydrological characteristics to that of the rest of the upper Thames basin. Nevertheless, the fact that there has been no obvious hydrological analysis of the flow data from the Thame catchment is surprising.

The report includes details of extensive statistical analyses of historical ANMAX data and this work has been undertaken using the most up-to-date methods and tools. Table 4-6 of the report presents estimates of statistical floods for Abingdon, Days Weir, Pangbourne and Reading, and comparison of these with observed maximum flows from the NRFA is somewhat surprising with the Table 4-6 values for the 0.5% (200 year) event for the first three stations being almost identical to, or even lower than, the observed maxima at these sites. In our opinion the January 2003 event, the highest recorded at Abingdon was a less extreme event than a 200-year flood, as was the December 2000 flood on the Pang. For the Reading site, the observed maximum flow in January 2003 corresponds almost exactly with only the 2% (50 year) event, which seems more realistic.

3.3 Hydrodynamic Modelling

The initial technical note (document 17) included few details about the hydrodynamic model, only that it was a 2D model and that it was based on existing flood forecasting models. Further information was obtained through correspondence with the CH2M Team Leader. The model extends a distance of 47 km from Sandford to Mapledurham and it includes 284 cross sections. This gives approximately 6 cross-sections per km. It is assumed the key hydraulic structures such as locks, weirs and bridges are all included as cross sections although this was not explicitly stated by CH2M. Unlike the OFAS modelling where existing cross sections were checked and new cross sections surveyed, the downstream modelling was based purely on the existing flood forecasting models. The argument from CH2M being that as these are currently used by the EA to predict levels and the timing of flood peaks, they were confident in the model performance and auditability. Such flood forecasting models are often challenged by operational use therefore this is a reasonable position taken by the CH2M modelling team. The modelling does not go as far as to simulate the extent of floodplain inundation, there is no mapping of flood extents and the schematisation of the floodplain is simplified compared to the 1D/2D modelling. Therefore, there is no requirement for the use of GIS and underlying data such as a DTM.

The later 1D/2D hydrodynamic model covers a longer reach of the Thames, 58km from upstream of Sandford lock to Reading Bridge. It has been developed using the Flood Modeller and TUFLOW software, which is consistent with the CH2M modelling for the testing the OFAS scenario. It includes 10 lock and weir locations, has flow inputs from three tributaries, The rivers Ock, Thame and Pang, and seven other intervening inputs. The overall number of cross sections was not provided but these were taken from a combination of earlier modelling studies. It was not stated how these compared with the sections used in the initial technical note, but it is likely they were the same. The reporting discusses the careful updating of the necessary 1D model components to work correctly in a 1D-2D modelling environment. The model conversion and update exercise as described in the report follows the expected process of replacing extended cross-sections in the original 1D model with 1D components, covering just the main channels and hydraulic structures, and 2D model components covering floodplain areas. The use of LiDAR data for the general floodplain model components follows standard practice. LiDAR was also used for the levels of linear features such as the river banks. LiDAR data can be problematic in such situations due to the filtering out of trees etc. and a general tendency to underestimate the levels of features which are small compared to the LiDAR grid resolution. However, the general discussion in the report indicates an awareness of the issues involved and the alternative seems likely to have been extensive ground survey.

The 1D/2D hydrodynamic modelling study is accompanied with a model manual (document 19). It provides details of the model construction, the software and version used, the files from both the modelling software and from other input data such as GIS layers. The purpose of the document is for future simulations of the hydrodynamic models as this may be a task undertaken by different consultants at the request of the Environment Agency.

3.4 Initial Downstream Modelling Results

Results of the modelling were presented in terms of the levels at the locations given on the previous page. It is not clear why the results were presented for Reading as this is downstream of Mapledurham and all descriptions of the model have given Mapledurham as the furthest downstream extent. The results also show the difference between the pre and post WCC simulations and for the 16 locations for the majority of scenarios the increase in water level is either very small, less than 1cm, or there is actually a reduction in water levels. The only scenario where the increase in levels is greater than 1 cm is for the 2007 event. The maximum increase is shown to be 0.017m (1.7cm) at Sutton Courtenay. The increase for the 2007 event is attributed to the fact that it was a summer events over a relatively short time-span where the peak flows from the Thames and the Ock were almost coincident, whereas most flood events occur in winter over a longer period with the peak in the Ock occurring sooner than the peak on the Thames.

The technical note stated that part of the final scheme design will consider how the small increases in water level can be eliminated or demonstrated as acceptable. One way to address this would be to implement a full 1D/2D model as carried out for the flood alleviation scheme itself, in order to help reduce the risk of unanticipated consequences. Also since the greatest increase in flood levels was from the 2007 scenario where the timing of flood peaks in the Thames and its tributaries was different from what would normally be expected with flood events, the sensitivity of the proposals to different hydrograph shapes and different relative event severities between the various inflows might usefully be considered as part of the scheme validation.

With the increase in water level as given in the technical note, although numerically small, it is not made clear whether property or infrastructure would be affected by any such increases in flood levels. Nothing in the technical note on the impact of these water levels, for example if they are within or above the river banks or a description of the level relative to local ground levels. As part of the demonstration of the mapped flood outlines, particular attention was paid to the areas where an increase in the flood extent was shown to occur with the OFAS scenario when compared to baseline conditions. The slight increases in flood level in the order of 0.01m only led to a very minor increase one area where a larger area was shown to flood was near Sutton Courtenay (Figure 3-1) where according to the CH2M modeller, the slight increase in water level caused the flood water to rise over a threshold into an area of lower altitude land. An examination of the OS base maps found that the flooded area was actually a gravel pit, so the increase in flood extent posed no hazard to any residential areas. in the flooded area in the order of just one or two additional pixels at the 2D model resolution. It should also be noted that the EA has been known to block flood mitigation projects leading to any increases in downstream flood levels, even when it is demonstrable that no property would be affected. Mapping the flood extent at those locations where an increase in water levels has been predicted, either through the application of 1D/2D models or the use of 1D model output and surface interpolation techniques in GIS would be able to demonstrate the potential impact.

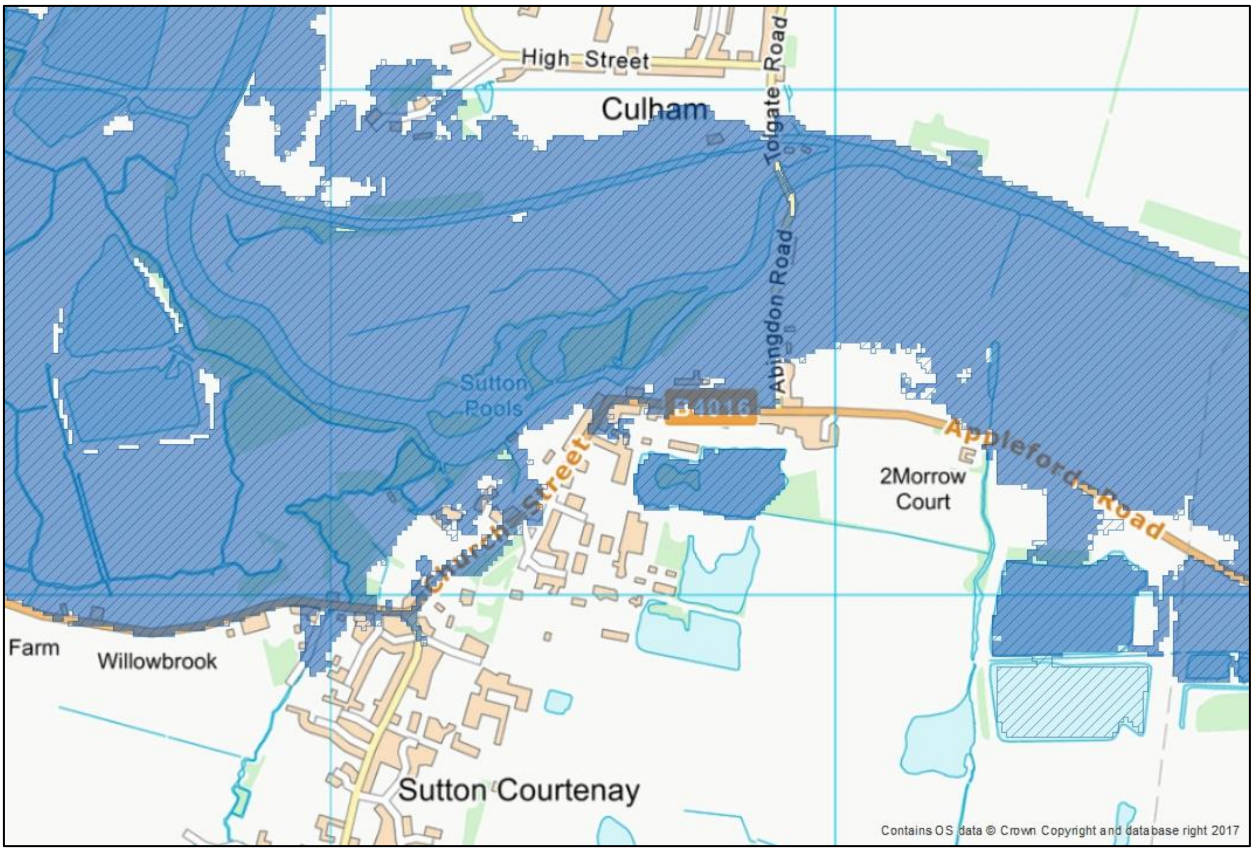

Figure 1. The extent of flooding for the baseline (dark blue) and OFAS scenario (cross-hatched)

3.5 1D/2D Downstream Modelling Results

The 1D/2D modelling report (document 18) provides considerable detail on the calibration of the model and simulations of the various return period flood events, including tabulated values of observed and modelled water levels at the head (upstream) and tail (downstream) sections at each weir. Further plots of model output are given in the appendices showing the comparison of predicted and observed water levels over time. There is overall a very good agreement for the calibration events with the levels at the weirs being within 0.15m of observed levels for 78 out of 88 records. Maps of a comparison of the observed and modelled flood events for 2003 and 2007 are presented in the appendices. Visually there is a good comparison between the data although the report states that the model gives wider areas of flooding downstream of Wallingford. However, there is no measurement of the actual flooded area to quantify the model performance.

In terms of the impact of the OFAS there is no confirmation that any of the return period flood events actually used the outflow from the preferred OFAS option or if they were just using the flows with the current network of channels. It is assumed that this part of the modelling exercise has yet to be undertaken.

3.6 Peer Review of Downstream Modelling

There was no formal peer review of the modelling reported in the technical note (document 17) but the 1D/2D downstream modelling underwent a peer review of behalf of the EA, which was undertaken by JBA Consulting. The output of the review (Documents 21 and 22) are completed proformas rather than proper written documents. The review actions used the same colour coding as the peer review of the OFAS modelling (green – negligible impact, amber – potential impact and red – high impact). The review raised 5 negligible, 7 potential and 1 high impact issue. All of these were addressed by CH2M and subsequently approved by JBA Consulting.

3.7 Downstream Modelling Conclusions

The WRA review of the downstream modelling studies associated with the OFAS has the following conclusions:

The CH2M technical note is lacking in detail and is clearly an interim output. The document states that further work will be undertaken to take account of the results of this modelling and to assess means to mitigate and potential increase in water levels downstream.

The modelling approach undertaken, although less detailed that that used for the flood alleviation scheme itself is a standard flood modelling approach, and the fact that it is based on existing flood forecasting models does demonstrate that the model is of suitable quality.

Details on the resolution of the hydrodynamic model are missing from the report although some additional information has been provided through correspondence with the modelling team a proper schematic of the hydrodynamic model would be of benefit.

One question arises in relation to the model extent which is described in the text as being from Sandford to Mapledurham. However, model results are also given for Reading/Caversham which is downstream of Mapledurham. The correct extent of the model needs to be confirmed.

Input hydrographs for the model simulations are presented showing the pre-and post WCC hydrographs at Sandford. These are shown to be very similar although it would be useful to have a table showing the numerical differences.

The results show either a decrease or very slight increase in water levels of less than 0.01m for the majority of the modelled scenarios. The simulations of the 2007 flood event show the highest increase in water levels between the pre-and post WCC of 0.017m at Sutton Courtenay.

There is no reason to doubt these results given the similarity of the input hydrographs and the quality of the modelling. The technical note also gives reasons to account for the differences between pre-and post WCC levels for the 2007 event.

Further simulations using different hydrograph shapes and different relative event severities between the various inflows would be useful as a sensitivity test.

The documentation of the downstream modelling study does not attempt to map the flood extents. A separate demonstration of the modelled flood extents has shown very little difference in the flooded extents between the baseline and OFAS scenarios. Where a larger area of inundation was identified in Sutton Courtenay, this was found to be in an existing gravel pit and not a hazard to residential areas.

The subsequent reports of the more detailed hydrological and 1D/2D/ hydrodynamic modelling present results of a very thorough investigation and have used the most appropriate tools and methodology throughout.

However, the outcomes of these reports do not contribute to the VOWH requirements to determine whether or not the OFAS will have any significant adverse impacts upon flooding downstream of Sandford.

The impacts have subsequently been identified by WRA following examination of the modelled flood outlines provided by the EA.

Overall this WRA review is in the same opinion as the EA that the downstream impacts of the OFAS in terms of an increased flood hazard will be very minimal.