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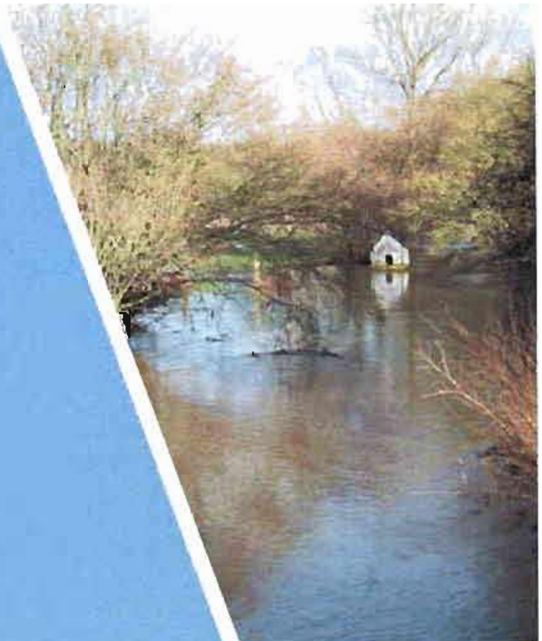
ENVIRONMENT AGENCY

BRISTOL FROME FLOOD MANAGEMENT STUDY

PROJECT REFERENCE: IMG 1628

Strategic Review Report (including Environmental Overview)

Issue 2 - **FINAL**



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EXECUTIVE SUMMARY

The Environment Agency, South West Region, has commissioned a flood management study, to examine current and future flood management risks within the Bristol Frome catchment and to specifically address the impacts of future development and climate change. The Environment Agency have also asked for an assessment of current operating practice with regard to the operation of penstocks and radial gates at Eastville and Tubbs bottom respectively.

This report confirms that the Bristol Frome culvert system (including the Northern Stormwater Interceptor sewer (NSWI)) has the capacity to convey flows in excess of the 100 year flood both today and in 50 years time (assuming current climate change predictions) based on the current model assessment. This assumes that the system is maintained in a good and sound condition, and that there is no asset deterioration over the fifty year time horizon. It further assumes that the operational control follows defined procedures.

As an output to this study a Preliminary Strategic Review report was issued in June 2004, setting out what was required to take the management study forward and to report on the current status of flood defence assets, their condition and the current standard of flood protection they afforded.

This review identified that failure of the Bristol Frome culvert system would result in extensive severe flooding of large areas of central Bristol. But, in terms of their general condition the visual inspection undertaken suggests that there is no immediate risk of large scale failure of any section of the culvert. However, structurally significant deterioration was identified at a number of locations which, if left un-attended, could result in partial failure of the culvert roof or walls. Such a failure could result in a blockage to flows within the culvert which could cause flooding upstream of the culvert. Culvert monitoring and structural analysis, put in place as a consequence of this PSR Report (2004) is being commissioned separately by the Environment Agency

The results obtained from the hydraulic modelling undertaken of the Bristol Frome culvert system confirm its dependence on the NSWI to provide flood relief during high flow events. The combined capacity of the culvert and the NSWI has a lower bound estimate of 104m^3/s (assuming the NSWI will convey 45m^3/sec of which it is believed to be capable), which is well in excess of the 100-year flood. Taking current allowances for climate change into account the combined intakes at Eastville may still cope with a 100-year flood in 50 years time. Furthermore, the study confirmed the flood risk to localised hot-spots along the river, such as The Dingle in Winterbourne Down, Nightingale Bridge at Frampton Cotterell and St Johns Way in Chipping Sodbury.

The river corridor is of high local value for both biodiversity and recreation. Several protected species are present and the river has a rich archaeological heritage.

To conclude, the most sustainable way that flood risk can be managed at present in the case of the Bristol Frome is to continue with the existing actions to manage flood risk (but accepting that flood risk will increase over time from this baseline). However, it may be considered prudent at some subsequent review to consider taking further action to maintain the status quo position to reflect development and climate change impacts during the intervening period.

The key recommendations arising are: associated with improving confidence in the modelling and hydrology – flow and rainfall gauging in the catchment, specifically at flows at Wade Street and rainfall at Eastville; and linked to development control, where the current policy of attenuating on the left bank and discharging on the right bank is maintained.

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FROME CATCHMENT – PERSONAL NOTES

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CONTENTS

Appendices

Appendix A: Environmental Designations Map

Appendix B: Strategic Risk Assessments

List of Tables

List of Figures

1. Introduction

1.1. Background

1.1.1 This is the concluding report produced under the broad heading 'Bristol Frome Flood Management strategy study'. The full list of titles of reports produced under this heading are:

- ① Culvert Inspection Report. April 2004. 5025049_rt001i1.doc
- ② Culvert Property Survey Report. April 2004. 5025049_rt02i1.doc
- ③ Preliminary Strategic Review. August 2004. 5025049_rt06I2.doc
- ④ Catchment Hydrology and Baseline Modelling Report. February 2005. 5025049_rt07ai2.doc and 5025049_rt07bi2.doc
- ⑤ Assessment of Economic Benefits. December 2004. 5025049_rt08i2 Final.doc

1.1.2 The Preliminary Review Report was the essential first step in the strategic consideration of appropriate flood risk areas related to the Bristol Frome catchment. It identified the 'where are we now' position and defined those current flood risk management challenges but without providing an assessment of opportunities to minimise future flood risk.

1.1.3 This final report is intended to summarise the existing (and future) flood risk across the catchment and to identify where operating policies and procedures either need to be put in place or strengthened to minimise flood risk in the future.

1.2. Description of Strategy Study

1.2.1 The Study has required a detailed understanding of the hydraulic system in order to determine the magnitude and scale of any future viable and necessary flood management actions. This has required modelling of the catchment to be undertaken. Accurate hydraulic modelling of the network, including the culverted sections under the centre of Bristol has been essential in determining the current capacity of the drainage system.

1.2.2 The development of The Frome extends from its source near Tetbury in Gloucestershire, through the towns and villages of Yate, Frampton Cotterell and Winterbourne, to the heart of Bristol and the Floating Harbour (see Figure 1 in Appendix A). The steep slopes in the headwaters and the high proportion of urban land use within the Bristol Frome promote a rapid response to precipitation. The time to peak discharge within this sub-catchment is greater than at any other location within the overall Bristol Avon catchment (based on work undertaken by Halcrow). At times of high flow, the Northern Storm Water Interceptor sewer (NSWI) is operated by the Agency to convey excess flood water from the Frome at Eastville under the city to the disused Blackrocks Pumping Station and a tidal outfall. Since the Bristol Frome provides the primary source of water to the Bristol Floating Harbour (BFH) operation of the NSWI in this manner has the potential to affect water levels in the BFH (but only if NSWI is open and the Frome culverts are shut).

1.2.3 Historically there have been a number of flooding incidents in Bristol, generally resulting from prolonged precipitation either due to one frontal system or back to back frontal systems in the catchment of the River Frome. However since the construction of the Northern Storm Water Sewer coupled with the adoption of appropriate operating procedures in the 1970's there has been no significant flooding reported in Bristol itself. Elsewhere in the Frome catchment flooding has been recorded at a number of locations. This study has looked at these locations and using the output from the modelling analysis has produced maps covering the extent of flooding from a 100 year event These maps are found in ref ④ above.

1.2.4 Long term issues in particular have centred upon the adequacy of the Bristol Frome culverts both in terms of their carrying capacity or conveyance and residual asset life. These have been exacerbated by rapid and extensive development in the catchment and the likely impact of climate change. This study has addressed these issues and has been able to provide answers to hitherto unquantifiable concerns.

1.3. Strategic Aims and Objectives

1.3.1 The strategic requirements were to quantify the flood risks to Bristol and across the Frome catchment, both now and in the future; and to identify the short, medium and long term flood risk management policies that could mitigate against potential impacts. Such impacts could include: an increase in run off into watercourse due to urban expansion; reduced or accelerated soil erosion (or compaction) and subsequent changes in run off due to agricultural practices; and more extreme weather conditions as a result of climate change with the possibility of increased storminess and higher precipitation. The consequences of which could lead to increased runoff and/or a reduction in channel conveyance.

1.3.2 Strategic issues were established jointly through consultation with Agency consultees and expressed in suitable terms which addressed the identified problems without pre-supposing any specific solution. These included:

- determining appropriate geographical boundaries for rural, semi-rural and urban catchments in order to estimate flood flows in the River Frome and tributaries;
- reviewing condition and plight of Frome culvert system together with the identification of appropriate structural works;
- consideration of the impact of urbanisation within the catchment in terms of run off and flood risk, specifically with respect to the current development control strategy;
- testing of the Frome culvert system to determine realistic estimates of carrying capacity;
- modelling the River Frome and its tributaries to refine anticipated flood levels and by definition the flood map for a range of conditions;
- development of the way forward by determining appropriate flood risk policies and measures and recommending changes in current operation procedures, if appropriate;
- developing an understanding of environmental issues pertinent to the catchment and possible flood management opportunities.

1.3.3 The Preliminary Strategic Review identified strategic opportunities that needed to be considered in order to meet the likely objectives of a future Catchment Flood Management Plan covering the Avon & Frome catchments This Strategic Review report discusses those opportunities and considers their appropriateness; these include:-

- development of the way forward by determining appropriate flood risk policies and measures and recommending changes in current operation procedures;
- increased Storage at Tubbs Bottom;
- provide storage upstream of Yate;
- provision of local flood risk management measures;
- provide Storage on Ladden Brook;
- Bristol Frome culvert improvement or refurbishment;
- extension / expansion of the Bristol Frome culvert system.

1.3.4 The appraisal period (for the economic assessment) should reflect the physical life (with maintenance) of the longest lived asset under consideration for a scheme. The presumption, based on Defra advice, is that a 100-year timeframe should be appropriate for new construction. In all other respects, the strategy period for this study covers 50-years, subject to regular and periodic reviews.

1.4. Project Team

1.4.1 **Environment Agency:**

▪ Project Executive	John Taberham
▪ Project Manager	Megan Thomas
▪ NEAS Officer	Deborah Dunsford
▪ Area Client Representative	Kevin Woodley

1.4.2 **Atkins:**

▪ Project Manager	Mike Vaughan
▪ Strategy Development	Philip Marsden
▪ Hydrology and Modelling	Suzie Gore
▪ Environmental Assessment	Karen Hills

2. Background

2.1. Description of the Study Area

2.1.1 A Catchment Overview has already been provided in the Atkins PSR (June 2004).

2.1.2 In terms of definition and extent the River Frome is a tributary of the River Avon and flows from the Cotswold Hills, through South Gloucestershire and then southwest to the centre of Bristol. The river rises in Doddington (near Tormarton) and flows down through Chipping Sodbury, Yate, Frampton Cotterell, Hambrook, Frenchay, Stapleton and Eastville Park. At Eastville it takes a different character as most of the river is culverted from this point until it discharges either into the Floating Harbour in central Bristol or into the River Avon at Blackrocks. See Figure 2-1.

2.1.3 In total the River Frome is approximately 20 miles (32 km) long. However, a number of tributaries discharge into the upper reaches and so the overall catchment is relatively large, spanning a total area of approximately 177 km². The main tributaries of the Frome include, Bradley Brook, Ladden Brook, Rodford Brook, Frampton End (also known as Tubbs Bottom) and Folly Brook. See Appendix A for a detailed catchment plan.

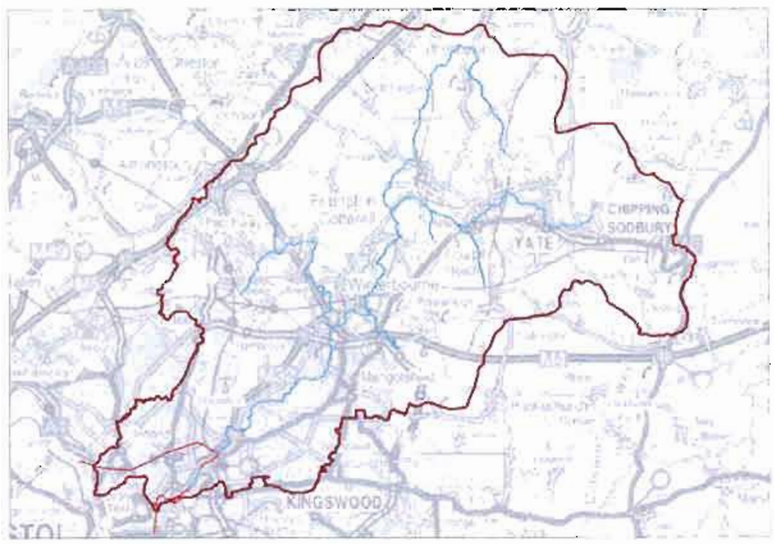

Figure 2-1: Frome catchment plan

2.1.4 The River Frome is already substantially urbanised, embracing not only North East Bristol and its individual communities but also the towns of Yate and Chipping Sodbury to the East, Frampton Cotterell and Winterbourne in the centre of the catchments and the recent Bradley Stoke development. These areas have grown rapidly during the past 30 years and they are predicted to grow as quickly in the future Whilst development in the short term will be focussed on completing previous allocations (eg Emersons Green Area C) there is likely to be further demand for housing land north of the M4, particularly north Yate and the Badminton Road corridor

2.1.5 An agricultural (land drainage) pumping station at Ladden Bows was operational until the 1980s and used to lift surface water over a geological feature on the Ladden Brook. This is now abandoned as it ceased to be viable.

2.1.6 A land use planning investigation study was undertaken by Halcrow as part of the River Frome (Bristol) catchment Study in 1991. This indicated that 21.6% of the catchment above the Eastville intakes was estimated to have been developed by 1990. This growth in development was potentially envisaged to increase to 26.5% by the addition of committed developments and Local Plan allocations. Work undertaken as part of this study (and previously reported in the PSR) now estimates that the current urbanisation of the catchment is 26% However, despite this increase in residential development, there has been no report of significant flooding problems in recent years.

2.2. Bristol Frome Culvert System (including Northern Stormwater Interceptor sewer)

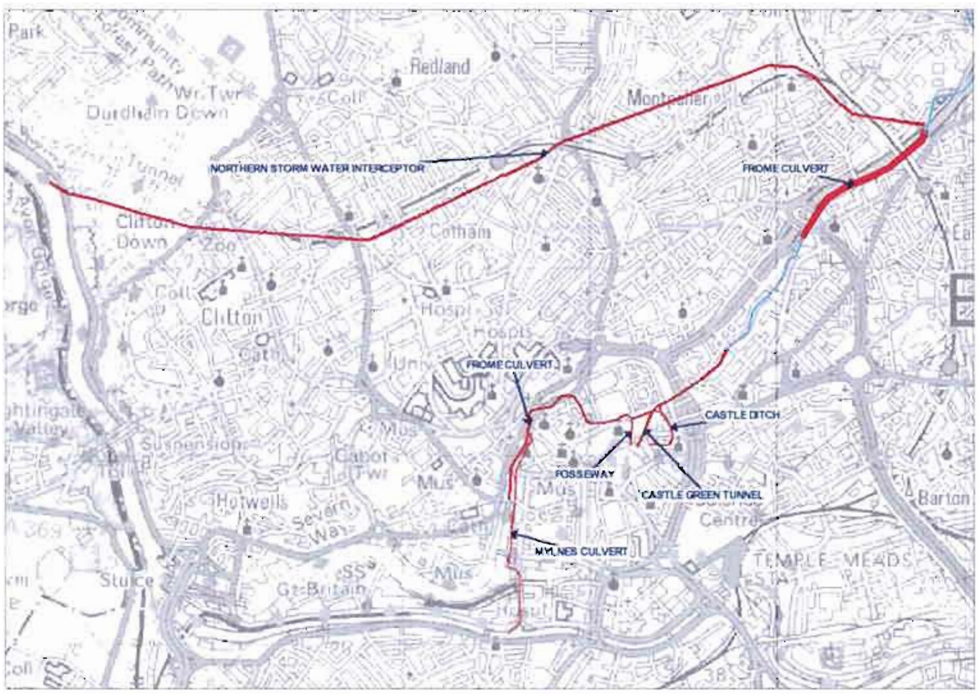

Figure 2-2: Culvert layout plan

2.2.1 The River Frome Culvert carries the River Frome under the centre of Bristol from the Eastville intake to its outlet into the Floating Harbour at Neptune's statue, St Augustine's Parade. There are three smaller culverts, Castle Ditch, Fosseway and Castle Green Tunnel, branching from the main culverts which also discharge into the Floating Harbour. The Mylnes Culvert begins at Stonegates chamber located at the northern end of St Augustine's Parade and outfalls to the River Avon just downstream of Bathurst Basin – the culvert conveys low flows from the River Frome Culvert to the River Avon. The outfall of the Mylnes culvert is flapped, and hence tide locks, although the efficiency of the flap is unknown.

2.2 2 Much of the length of the main culvert lies beneath highways or open space; however, there are significant lengths, notably between Fairfax Street and Nelson Street, and Nelson Street and Bridewell Lane, which are beneath buildings.

2.2.3 In times of flood, excess waters are passed over a side weir into a relief culvert at Eastville, known as the Northern Stormwater Interceptor sewer (NSWI).

2.3. Current Development Control Strategy

2.3.1 Residential build is increasing across the catchment and there are extensions of urban area. These are currently:

- Northfield – (Filton)
- extension of Emersons Green
- extension of Yate and Chipping Sodbury

2.3.2 These developments will all contribute to flooding especially through Bristol despite the fact that they are not necessarily located within the floodplain.

2.3.3 The Agency manages the catchment in such a manner that the general policy from a flood risk management perspective is to attenuate flow on the left bank of the Frome and to let the flow go on the right bank of the Frome wherever practicable.

2.3.4 In terms of planning and development control the policy adopted by the Agency may be summarised very briefly as working with planning authorities to advise that development takes place away from the flood plain and to encourage the use of sustainable drainage systems (SUDs). Current Environment-Agency-South-West Regional policy is to limit run-off from development to that equivalent to greenfield run-off depending on return period.

2.3.5 SUDs is a central policy for the Planning Authorities. In the case of South Gloucestershire on-site devices are required in respect of areas exceeding 1 ha. There are areas of soakaways but the majority of the Frome Catchment is clay. Hence in reality sustainable drainage systems here mean predominantly ponds (and swales).

2.3.6 The Wessex Water Policy is that run-off following development should be limited to a 1 in 2 year "green field site level" or "as existing" in the case of land use changes for developed sites. SUDs, Swales and Ponds are currently not adopted by Wessex (2004).

2.4. Current Operational Strategy (Excluding Flood Warning)

2.4.1 Operating Procedures are set out in the Environment Agency - SW Region: North Wessex Area Flood Procedures (dated September 2003) for the Frome culvert gates and the NSWI penstock, and Tubbs Bottom Radial Gates.

2.4.2 There are also fixed weirs located within the Frome culvert system designed to prevent flow spilling back into the Frome Culvert from the Floating Harbour.

Floating Harbour

2.4.3 Bristol City Council endeavour to regulate the BFH level within a small fixed range (6.1m to 6.2m. However, high flows in the Frome, and Avon, can trigger a significant rise in level in the harbour (as discussed in Section 5).

Eastville

2.4.4 The purpose of the site is to control the flow from the Bristol Frome into the Frome culvert and the Northern Stormwater Interceptor sewer (NSWI) and to prevent debris entering the culvert or the NSWI. Whilst debris is intercepted at this location there is no mechanism for preventing debris entering the culvert at Wade Street which is located downstream of Eastville after a section of open channel. In normal flow conditions, the Bristol Frome flows into the Frome culvert only. During periods of high river flow, the excess is diverted into the NSWI, although the amount taken off is finite.

2.4.5 Whilst the procedures require the penstocks to be operated to retain a water level of approximately 0.8m at Eastville until fully opened, the study and model work undertaken suggests that day to day operations to achieve this are variable and inconsistent with regard to water level control. It is apparent that the procedure is to fully open two of the NSWI vertical gates/penstocks once the level on the gauge at Eastville reaches a defined level (and delineated by a line marked on the chamber wall at 8.34m AOD) and to fully open the remaining two if that alarm level is subsequently exceeded. Evidence also suggests that these penstocks have been left open post high river events.

Tubbs Bottom

2.4.6 The Tubbs Bottom Reservoir was constructed in the early 1980's and was designed to contain the 1 in 65 year flood without spilling. The original design for the operation of this dam envisaged that the pass forward flow from the dam would be controlled by twin radial gates with a maximum opening achievable of 1.5m. In reality the Agency operate these gates in a permanent position with the gates set to a minimum opening of 400 mm. Under normal everyday operating conditions the gates remain in this fixed position. The only time the gate position is altered is for either maintenance or inspection.

2.4 7 Hydrological analysis suggests that the dam is overtopped at the 1 in 35 year event in this configuration, a much more frequent occurrence than it was designed for.

2.5. Strategic Issues Identified

- flood risk management at Eastville is not carried out in conjunction with the operating management of the floating harbour.
- reliance on Ponds/Swales for alleviating storm water run-off from new development assumes they operate as designed (and receive regular maintenance, desilting etc)
- run-off arising from storm events in excess of design event likely to overwhelm storage ponds and pass straight into receiving water courses (with consequential downstream impacts).
- long term need for further flood storage areas within Frome catchment if development continues at current pace.
- anticipated changes to climate and the likely response to development over the next 50 years or so.

2.6. Data Collected

2.6 1 A review of available reports and documents provided by the Environment Agency has been undertaken to inform the production of all the reports produced as part of this study. A full description of this review is provided in Appendix E of the PSR.

2.6.2 A limited number of site specific walkovers have been undertaken as part of this process, both at the start of the strategy project and during the work undertaken.

3. Flood Risk

3.1. Modelling Approach

3.1.1 The Section 105 (S105) ISIS model of the River Frome was reviewed during Phase 1 of the Bristol Frome Flood Management Strategy (scoping study). As part of Phase 2, the model was enhanced and improved to allow confident use of its predictions in the development of the flood management strategy. These are detailed further in the Catchment Hydrology and Baseline Modelling Report

3.1.2 The model contains approximately 52km of river and includes the 2003 Tidal Risk model of the River Avon and the Bristol Floating Harbour.

Hydrology

3.1.3 The hydrology in the catchment is significantly affected by the floodwater control mechanism at Tubbs Bottom, where a washland and attenuation structure dominates the downstream flow. Further control of flows in the Bristol Frome area is made at Eastville, where the NSWI provides a flood bypass tunnel for the centre of Bristol.

3.1.4 The rural hydrology was assessed using the two approaches defined in the Flood Estimation Handbook.

3.1.5 The urban catchments were assessed separately from the rural areas, using methods specific to urban drainage. A surface water sewer model was built using InfoWorks CS software and the WaPUG Type-1 skeletal planning specification. The model was simulated with observed and design rainfall to provide inflows to the ISIS model.

3.1.6 The River Avon and BFH were included in the Bristol Frome model for ease of consideration of the downstream boundary.

InfoWorks Culvert Model

3.1.7 An InfoWorks culvert model was built to represent the culvert system beneath Bristol City Centre. The extents of the Bristol Frome culvert model were defined to include all surface water sewers which drain to the Frome Culvert, the Mylnes Culvert, Castle Ditch, Fosseway Culvert, and Castle Green Tunnel.

Calibration of the Models

3.1.8 The models were verified by comparison against four recent flood events. The four events were:

- 24 December 1999;
- 30 October 2000;
- 11 February 2002; and
- 2 January 2003

3.1.9 The ISIS model proved to be suitable for determination of flood stage and flows in the river system although was not good at predicting the recession of the flood hydrographs. Calibration of the InfoWorks culvert model was undertaken at two locations, Stonegates and Fossegates, and for two events, February 2002 and January 2003. However, the results were inconclusive and highlighted the uncertainty in the raw data.

3.2. Modelling Outcomes

3.2.1 The calibrated models were used to simulate design storms of different return periods and duration – assuming a consistent storm type over the whole Frome catchment. The critical duration was found to vary between 12-hours and 48-hours, with the upper reaches having a faster response time, and reaches 'in the shadow of' Tubbs Bottom (Algars Manor to Winterbourne) being most sensitive to longer storms.

3.2.2 The baseline modelling concluded that:

- the design flows derived from the ISIS river model determined a 100-year flood of $80m^3/s$ at Eastville;
- the ISIS river model indicated that Tubbs Bottom would be overtopped at a return period of 35-years, and that at the critical 100-year event, a flow of $10m^3/s$ will pass over the dam;
- the accepted capacity of the Frome culvert system is $104m^3/s$ which includes the $45m^3/s$ that the NSWI can convey (the NSWI conveys less flow during tidelock periods although a positive discharge can be maintained if sufficient flow passes into it);
- the 200-year flow of $91m^3/s$ arriving at Eastville can be conveyed through the culvert system (including NSWI) with no surface flooding;
- there is some capacity within the culvert system to accept more flow or provide a factor of safety;
- the Frome culvert system may be capable of taking between the 150-200-year flood in 50 years time at which time Tubbs Bottom would be overtopped by a 15-year event;
- the anticipated effects of predicted climate change will progressively lower the standard of service provided by both Tubbs Bottom and the Frome Culvert system; and
- more comprehensive site records are required to improve future model calibration

3.3. Frome Culverts

3.3.1 The ability to convey flood flows through the Frome Culverts is determined by two factors, condition and conveyance capacity (dictated by size and hydraulic gradient).

3.3.2 The observations noted in the Culvert Inspection Report (visual condition survey - reference ①) indicate that there is no immediate risk of large scale failure of any section of the culvert. However, structurally significant deterioration was reported at a number of locations, which if left unattended, could result in partial failure of the culvert roof or walls. In addition to the risks to public health and safety, partial failure could result in a blockage to flows within the culvert which could cause substantial flooding both upstream of the Frome Culvert and in the centre of Bristol. Also, significant deposits of silt were observed in the lower parts of the River Frome culvert, which have reduced the capacity of the culvert system to convey flow. Culvert monitoring and structural analysis, put in place as a consequence of this earlier Atkins report (2004) is being commissioned separately by the Environment Agency

3.3.3 There is also a risk of flooding occurring as a consequence of material deposited by fly tipping, or other means, in the open section of the river becoming trapped/lodged within the culvert system and leading to a partial or total blockage of the system downstream of Wade Street Currently there is no trash screen at the culvert entry at Wade Street to prevent such debris to be conveyed into the culvert system.

3.3.4 Flood risk management at Eastville, the upstream end of the Frome culvert system, depends wholly on the satisfactory operation of the vertical intake gates to the NSWI. In normal flow conditions, the Bristol Frome flows into the Frome culvert only. During periods of high river flow, the excess is diverted into the NSWI. Flow can be stopped from entering the Frome culvert by closing two intake vertical gates and two penstocks.

3.3.5 Historical evidence indicates that the flooding in Eastville in 1968 may have been caused or exacerbated by the closure of the Frome culverts during a high river flow event. Operating procedures now provide for the NSWI gates to be opened during high river flow to provide flood relief to the Frome culverts. The operating procedures currently in place and described at S2.4.2 appear to have ensured that the NSWI gates have been opened at the appropriate times. However, the system relies on manual intervention both to open and shut the gates and there appear to have been inconsistencies in the manner these gates have been opened and closed between successive high flow events, albeit without detriment. It is our conclusion that the operating procedures need to be re-visited and re-written to reflect current circumstances in order to ensure a consistent manner is adopted in addressing future flood risk. Automated control (but with a manual override) would largely obviate the need for manual intervention to be relied upon to control upstream water levels and would represent a significant improvement over the current arrangement both in terms of timeliness, effectiveness and in ensuring the appropriate split of flows between the NSWI and the Bristol Frome culverts. A feasibility study is recommended to consider this issue in more detail.

3.3.6 In terms of conveyance the design simulations undertaken using the ISIS model indicate a 100-year flow arriving at Eastville of $80m^3/s$ The output of the specialist culvert model that was developed for the Frome culverts suggests a culvert capacity of $59m^3/s$ These results confirm the dependence on the NSWI to provide flood relief during high flow events The combined capacity of the culvert and the NSWI has a lower bound estimate of $104m^3/s$ (assuming the NSWI will convey $45m^3$/sec of which it is believed to be capable (at full ~4.9m diameter bore, with no surcharge, or tide), which is well in excess of the 100-year flood. In practice modelling indicates that surcharge of the NSWI can take peak flows upward of $54m^3/s$ during low tide, which reduces to $38m^3/s$ during tidal submergence of the outfall.

3.3.7 Taking current allowances for climate change into account (see 3.7) the combined intakes at Eastville may still cope with a 100-year flood in 50 years time based on the current extent of urbanisation.

3.4. Tubbs Bottom Detention Reservoir

3.4 1 The model simulations indicate that Tubbs Bottom Reservoir has a lower standard of service than originally thought, (65 years) and is likely to overtop more frequently (35 years). Overtopping of the structure leads to a rapid increase in downstream flows, rising by $10m^3$/sec in under five hours It follows in such overtopping situations that it may be anticipated there will be an increased risk to people and property immediately downstream of the reservoir. This finding is of particular importance as the dam would have been designed under the Reservoirs Act to behave in a certain way at its original standard. This finding should be brought to the attention of the Panel Engineers who will be able to determine the impact of it.

3.5. Other Flooding Hot Spots

3.5.1 Sites at risk from flooding within the Frome catchment have been previously identified in the Environment Agency Flood Procedures for the Bristol Frome.

3.5.2 As part of this study a re-assessment has been undertaken of the properties currently considered to be at risk based on the output from the hydraulic model. The information presented in the following table has been abstracted from the flood risk mapping exercise undertaken following completion of the modelling. It identifies the flooding hotspots to reflect the risks as you move down the catchment. As can be readily seen there are some properties included in the table which suffer from flooding but not from the River Frome itself.

Area	No. of Properties
St Johns Way - B4060, Chipping Sodbury	**24**
Brook Street, Chipping Sodbury	1
Bennetts Court to Tree Leaze, Yate	22
Canterbury Avenue to Tyndale Avenue, Yate	8
Celestine Road, Yate	**14**
Nibley	3
Algars Manor, Tubbs Bottom	1
Parsonage Bridge, Frampton Cotterell	**4**
The Dingle, Winterbourne Down	**5**
Moorend Road, South of Whiteshill	3
Pye Corner, North of Whiteshill	1
Whiteshill	2
Hambrook	7
Cleeve Mill, Frenchay	1
Frenchay	**8**
Broom Hill	8
Eastville	**38**
Eastville Intake	**34**
Bristol City Centre	**2743**
Total	**2927**

= flooding from the River Frome
= flooding from the Bradley Brook
= flooding from unnamed tributary

Table 3-1: Properties within the 100-yr floodplain and assuming culvert failure

3.5.3 In the case of the Winterbourne Down area the Halcrow draft CFMP Inception Report for the Bristol Avon (and Frome) quotes 17 properties and identifies this as the principle area of concem within the Frome catchment outside of Bristol. Halcrow have indicated that all the properties mentioned as at risk of flooding were based on historical records of flooding taken from press cuttings, local knowledge etc. The figures differ from those identified as part of this study. This may be explained by Halcrow looking at a slightly different/larger area at Winterbourne Down, for instance the Halcrow report makes no mention of flooding in other locations such as Yate or Chipping Sodbury. At the scale of modelling undertaken as part of this study it should be assumed that the summary information contained in the table above reflects the most up to date analysis.

3.6. Post Development Risk

3.6.1 The Preliminary Strategic Review explored the nature of urban growth within the catchment and how this was predicted to increase in the future. The following growth rates were predicted to be:

	2004	2029	2054	2104
Predicted Urbanisation	26%	34%	47%	60%

Table 3-2: Predicted urbanisation

3.6.2 Modelling was undertaken to determine what effect this increase in development would have on river levels and flows within the catchment. The predicted urban area in km^2 for each year was calculated, and subsequently the URBEXT and Tp(0) values were adjusted.

3.6.3 The modelling results indicated that this increased urbanisation would have a small effect on water levels and flows within the system. Water levels and flows increased along the River Frome from Chipping Sodbury to Hambrook at the Bradley Brook confluence, with the largest increases (+88mm / +3m^3/s) observed at the Frampton Cotterell gauge.

3.6.4 However, downstream of Hambrook and on the Bradley Brook itself, water levels were seen to decrease. In the year 2104, water levels were predicted to decrease by 51mm and flow by nearly 2m^3/s at Pye Corner, whilst at Frenchay the scenario gave a decrease in peak flow of 1m^3/s.

3.6.5 Increasing the urbanisation leads to a decrease in the critical storm duration for each sub-catchment and hence they respond less critically to a given storm: this could be an attributable factor to the decrease in water levels and flows. Quite how this changes the critical response of the Frome has not been tested, although given the discrete durations tested was not thought to affect the above results. Furthermore, the effect of urbanisation is seen through separation of the convoluted hydrograph, with a rise in the rapid urban runoff and a reduction in the slower rural response.

3.7. Climate Change

3.7.1 In order to consider the potential impact of climate change it is important to recognise that there are some general limitations which constrain the approach and accuracy of any predictions made. First, there are ranges of predicted climate change scenarios associated with the consequences of global warming and second for any scenario, different existing climate change models predict different values. It may be therefore concluded that there is no commonly agreed single set of results that can be applied

3.7.2 For the purpose of this study an assessment has been made assuming a 20% increase in flood flow. The value of 20% is broadly in line with the scenarios of increase in winter precipitation by the 2080's for the current UKCIP (UK Climate Impacts Programme) studies and appears as an illustrative assessment scenario in PPG 25 on development and flood risk.

3.7.3 The following table calculates the effect of climate change at Eastville in both 50 and 100 years time. In the case of 50 years time, 20% has been added to the present flows and in 100 years time, 40% has been added. The increased flow in 2055 generates a 700mm increased in peak levels at Eastville.

Return Period years	2005 Flow at Eastville in cumecs	2055 Flow at Eastville in cumecs	2105 Flow at Eastville in cumecs
20	60	72	84
50	69	83	97
75	76	91	106
100	80	96	112
150	85	102	119
200	91	109	127

Table 3-3: Effects of increased rainfall (flow)

3.7.4 The results of the baseline modelling suggest that a 200-year design flow can be conveyed through the culvert system today. in 2055 the system could convey between a 150 to 200-year flood. However in 100 years time the system may only be able to take the 50-year flood in its present configuration.

3.7.5 The effect of sea level rise (296mm over the next 50 years) on its own is less than 100mm at Eastville (280mm in the Avon at Black Rocks), with the rise in sea level affecting the conveyance ability of NSWI (in the form of extended tide lock periods and surcharge). However, the effect of sea level rise on the discharge capacity of the NSWI is nominal, reducing discharges by only $1m^3/s$. Sea levels also affect the Mylnes Culvert and the BFH (due to tidelock increasing period of gate closure; and direct inflows over the gates and surrounding land) and hence the Frome Culverts.

3.7.6 Taking both increased flow (rainfall) and sea level rise into consideration produces a rise in water level of greater than 800mm at Eastville.

3.7.7 At Tubbs Bottom, the effects of climate change are to reduce the standard of service provided by the storage from approximately 35 years to 15 years (in the year 2055).

3.8. Susceptibility to Rainfall

3.8.1 The hydraulic and hydrological modelling undertaken as part of this study has been based on single storm events. There remains the need to consider other types of storm events.

3.8.2 The susceptibility of the Frome catchment to rainfall relates the ability of the catchment to generate flood risk to rainfall. This is normally related to the catchment topography and morphology, along with precipitative patterns.

3.8.3 The Frome catchment provides a mixture of features that act antagonistically in terms of rainfall susceptibility. The large urban areas and steep mid catchment seek to convert rainfall into river flow in a short time; whilst the rural upland catchment, online Tubbs Bottom and modern urban drainage attenuation features seek to delay the response from other parts of the catchment. The tidal influences at the Bristol Floating Harbour and NSWI also seek to increase the susceptibility in the lower catchment.

3.8.4 Tests undertaken with the Bristol Frome hydraulic model have indicated that double fronted storms could fill the natural and man-made storage within the catchment and generate increased flows at Frenchay and Eastville. For example, two 10-year storm events occurring within 24 hours of each other were found to produce some 10% more flow at Frenchay (and hence Eastville) on the second event, whilst at Tubbs Bottom, the peak stage rises by over 600mm and becomes equivalent to the 1 in 50 year water level.

3.8.5 The 1992 Bristol Frome Catchment Study considered catchment wide, conveyor belt and moving storms. The study found that smaller storms centred over the Bradley Stoke area generated the highest flood flows at Frenchay, as did the frontal rain moving east to west.

3.8.6 More recent research by Collier and Fox (2003) has examined means of assessing the flooding susceptibility of river catchments to extreme rainfall, and proposed a decision support scoring system for use prior to the onset of rain. Based on their approach, the Frome catchment would appear to be "mildly susceptible" to flooding, with low soil moisture deficit and high SPR contributing towards this.

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4. Flood Risk Management

4.1. Flood Risk Management Policies

4.1.1 Catchment Flood Management plans (CFMPs) will improve the Agency's understanding of what factors influence floods and flood risks at the catchment scale. They will identify the size and location of various influences that can make a difference to flood risks in the catchment. Such influences may, for example include:

- land Use;
- changes in rural landscape;
- loss of wildlife habitats or biodiversity;
- measures to reduce the effects of floods on communities; and
- climate change.

4.1.2 CFMPs will not provide detailed management solutions for flooding issues in a catchment rather they will provide broad policies that will guide and enable solutions to be developed that will make sense in the context of the whole catchment and for the long term.

4.1.3 The Frome catchment will form part of the wider Bristol Avon CFMP. Whilst it is too early to anticipate the broad policies that will evolve from the development of such a plan, key influences already identified as part of this study will include land use, climate change and the culvert systems through Bristol. Based on the modelling output from this study, which confirms that the culvert systems have the capacity to provide an acceptable level of flood risk for the next fifty years, the most sustainable way that flood risk can be managed at present in the case of the Bristol Frome is to continue with the existing actions to manage flood risk (but accepting that flood risk will increase over time from this baseline). However, it may be considered prudent at some subsequent review to consider taking further action to sustain the current scale of flood risk into the future based on development and climate change impacts during the intervening period.

The most sustainable way in which flood risk can be managed at present in the case of the Bristol Frome is to continue with the existing management actions

4.2. Flood Management Opportunities

4.2.1 Investigations were undertaken to determine the effects of implementing a number of flood management opportunities within the catchment.

Storage on the Ladden Brook

4.2.2 Cog Mill, on the Ladden Brook, was identified as a possible location to construct a flood retention dam. A 1.5m diameter culvert was tested to control forward flow. Water levels on the River Frome, downstream of its confluence with the Ladden Brook, were reduced with reductions of up to 418mm predicted at Cog Mill. Although the decreases at Frenchay and Eastville were not as great, the reductions in water level were in the region of 40mm and 150mm respectively. Flows at Frenchay and Eastville were reduced by 2.9m^3/s and 2.1m^3/s respectively. This option would flood land as far upstream as the railway line south-east of Tytherington.

4.2.3 Further options were identified, such as that of catchment transfer, but these were ultimately dismissed. In order to test the potential of catchment transfer of the Ladden Brook into the Little Avon catchment to the north, all flow from the Ladden Brook was removed from the ISIS model, representing the best possible scenario that could be achieved (equivalent to simulating infinite storage). This produced similar trends to storage, but the changes were more dramatic. Downstream of the Ladden Brook / River Frome confluence, water levels reduced by up to 767mm, whilst at Frenchay and Eastville they reduced by 167mm and 533mm respectively. Flows were reduced by 23.m^3/s at Cog Mill 11m^3/s at Frenchay and Eastville. However, these results should be read with the emphasis that implementation of the complete transfer would not be realistic, let alone possible.

Storage on the Bradley Brook

4.2.4 This option would require a retention dam near Sturden Court and was tested with a 1.8m diameter culvert as the flow control structure, regulating forward flow. This could potentially flood Beacon Lane (the B4057) which is a busy commuter route. The effect of storing flow on the Bradley Brook was predicted to have a dramatic effect on water levels and flow in the River Frome at Hambrook. At Frenchay and Eastville, water levels were reduced by 181mm and 533mm respectively. Flow was reduced at these locations by 11m^3/s.

Raising of Localised Defences

4.2.5 Within the catchment there are a number of flooding hotspots. The hotspots include: Chipping Sodbury; Celestine Road, Yate; Parsonage Bridge, Frampton Cotterell; The Dingle, Winterbourne Down; and Frenchay.

4.2.6 Simple modelling analysis was undertaken to determine the effects of raising defences at these flooding hotspots, both individually and together. Banks were raised by over 2m in some locations to contain the flood levels. However, additional overbank survey would be required to enhance this work and generate confidence in the results.

4.2.7 The model predictions at the 100-year event were.

- raising banks to prevent overtopping at Celestine Road (Yate) increases water levels up to 93mm in the immediate vicinity. The effects of this bank raising influences water levels up to 290m upstream,
- raising defences at Frenchay affects water levels along 815m of river (maximum increase 158mm);
- raising defences at Parsonage Bridge (Frampton Cotterell) increases water levels in the immediate vicinity by 656mm; and
- if banks are raised along the 500m stretch of the River Frome immediately downstream of Damson Bridge (Winterbourne), the effect on water levels is dramatic. Water levels increase in the immediate vicinity by up to 713mm but the effect on water levels is evident for approximately another 2.5km upstream of Damson Bridge. Immediately upstream of Damson Bridge water levels are increased by 500mm, decreasing upstream to Watley's End.

4.2.8 If banks were raised in all of the flooding hotspots simultaneously, the combined effect would be increased water levels experienced throughout much of the system upstream of Frenchay. The localised effect of the combined defences was predicted to be not too dissimilar to that when considered as a stand-alone scheme –eg the 713mm increase at Damson Bridge is no higher when incorporating all the local defences as it is for defences in this area alone. However, raised flood levels would redistribute flood water and could cause flooding of further properties. Confirmation of this cannot be made without further modelling and survey of the floodplain in the urban areas (possibly addressed by individual site prefeasibility studies)

Alteration to the Operation of Tubbs Bottom Retention Dam

4.2.9 The Preliminary Strategic Review identified that 'there is no evidence to indicate that Tubbs Bottom is operated in such a way as to optimise its storage potential'. Therefore, a number of options have been modelled to test the effects of altering the way that Tubbs Bottom is operated to reduce flows downstream of Tubbs Bottom on the River Frome (particularly at Eastville). At present, both sluice gates are left open at a constant 400mm throughout the duration of an event.

4.2.10 Tests were under taken to analyse the effects of: opening the sluice gates further raising the height of the dam; closing the sluice gates from their 400mm position during an event; closing the sluice gates during an event to maintain a forward flow of 12m^3/s; and combinations of the aforementioned scenarios.

4.2.11 The results indicated that the one solution for the gate would be to:

- raise the crest of the dam by 1m;
- continue leaving the sluice gates open at 400mm during the first part of an event;
- close the gates to 200mm near to the peak of the event, and then
- leave the gates open at 200mm for the remainder of the event

4.2.12 At Algars Manor, this option would reduce water levels by 672mm, whilst at Frenchay and Eastville water levels would reduce by 56mm and 170mm respectively. Flows at Frenchay and Eastville would reduce by 3-4m^3/s. The results indicated that operation of the sluice gates in this way would have to be accompanied with an increase in the crest level of the dam in order to prevent overtopping as the storage area fills. Should the dam crest level not be raised, water levels at Algars Manor and The Dingle would increase by 135mmm and 121mm respectively.

4.2.13 Although it is clear from the results that it would be beneficial to lower the gates before the peak of an event, it should be borne in mind that further analysis should be undertaken to determine the optimal gates operation and that in practice this would require gate automation and improved telemetry systems. Furthermore, Tubbs Bottom could be better managed to increase nature conservation and provide environmental enhancement.

Alteration to the Operation of the Northern Storm Water Interceptor Intake Gates

4.2.14 The Preliminary Strategic Review identified that during the 1968 flood, the operation of the structures at the Eastville Intake (NSWI gates and M32 culvert gates) contributed to the flooding experienced in the Eastville vicinity. The report commented that 'In 2004 the operational control of the gates to the Northern Storm Water Interceptor still does not appear to be undertaken in a consistent manner'. It was therefore considered appropriate to test some new scenarios for the NSWI intake, to determine whether the operation of the gates could be optimised. Discussions with the emergency workforce identified that the operation of the NSWI gates was carried out in such a way as to maintain a water level of 8.34mAOD in the River Frome channel during times of high flow. Scenarios were modelled to establish whether this operational procedure made best use of the available capacity in the NSWI during high flows.

4.2.15 The results indicate that at present the NSWI gates are likely to be operating as effectively as they could be (providing the gates are operated as reported by the Emergency Workforce team). The scenario that was believed would offer the greatest relief for the Frome culvert (permanently open all NSWI gates to 2.8m and reduce the height of the Frome side weir by 500mm), reduced flow within the Frome culvert, but not to the extent expected. At Wade Street peak flow was reduced by 21l/s. Flow into the NSWI itself increased by 43l/s.

4.2.16 One further opportunity is a reduction in risk of flooding from the BFH. It is evident that the diversion of above normal flows down the NSWI would provide relief to the BFH, and reduce the rise, or rate of rise, of water levels in this pound.

Removal of the Restriction at Mill Tail in the Frome Culvert

4.2.17 Whilst undertaking modelling work it was noted that the section of the Frome Culvert known as Mill Tail was significantly smaller than the remainder of the system. This narrowing causes a restriction to flow. To determine the effect of removing this restriction, widening of the Frome Culvert in this area was modelled, using the InfoWorks culvert model. The model identified that this option would reduce water levels at Wade Street by 6mm. This option would have no effect at Eastville.

Removal of Silt from the Frome Culvert

4.2.18 At present there is a large amount of silt within the Frome Culvert. A scenario was modelled whereby the silt was removed from the culvert system to determine what effect this had on flows. Throughout the Frome Culvert, flow increased by between 1-2m^3/s. Flows also increased in Castle Ditch, Castle Green Tunnel and Fosseway Culvert (by a maximum of 1m^3/s, 0.3m^3/s and 0.6m^3/s respectively) and water levels increased throughout the culvert system. Whilst the source of the silt remains unknown, the effect of removing it is not large.

Reduction in Height of the Fixed Spill Weirs to Castle Ditch, Castle Green Tunnel, Fosseway Culvert and Frome Culvert

4.2.19 The InfoWorks culvert model was used to model the effect of decreasing the height of the fixed weirs in the culvert system at the upstream ends of Castle Ditch, Castle Green Tunnel, Fosseway culvert and Stonegates. The fixed weirs were reduced from 6.35mAOD to 6.25mAOD. The results identified that this option would reduce water levels at Wade Street by 41mm.

Addition of a Second Castle Green Tunnel

4.2.20 Within the InfoWorks culvert model a second Castle Green Tunnel was tested. The new tunnel was a replica of the original, using the same invert levels and pipe dimensions (2.6m diameter and 4.45m AOD falling to 3.8m AOD invert). A fixed weir was added at the upstream end of the tunnel, identical to the one at the upstream end of the original Castle Green Tunnel. This option reduced water levels at Wade Street by 752mm.

Increasing the Capacity of the Mylnes Culvert

4.2.21 This option involved increasing the size of the Mylnes culvert from a 1.52m × 1.37m sprung arch culvert to a 1.8m diameter circular culvert, whilst keeping the original invert levels. This option had little effect on water levels at Wade Street, reducing water levels by only 17mm.

Upsizing of the Frome Culvert and Castle Green Tunnel

4.2.22 The InfoWorks culvert model identified that the shallow gradients of Castle Green Tunnel and part of the Frome Culvert (between Castle Ditch and Castle Green Tunnel) were reducing the capacity of the system in these locations. This option involved upsizing this 40m length of the Frome Culvert and the Castle Green Tunnel to a box culvert, 6.5m x 3.7m. This option had minimal effects on water levels within the culvert system, reducing water levels at Wade Street by 6mm.

4.3. Summary of Opportunities

4.3.1 The modelling has shown that the current river system is capable of dealing with in excess of the 100-year flood.

4.3.2 Consideration of possible options to alleviate what risks there are suggest that flood storage (Bradley Brook foremost, Ladden Brook and at Tubbs Bottom) could be used to reduce flows and stage, particularly in the immediate downstream reaches of the attenuating structure. The use of Tubbs Bottom is particularly important for Frampton Cotterell.

4.3.3 Once within Bristol City, only the addition of an extra relief culvert was shown to alleviate water levels in the culvert system and at Wade Street. However, the effects of this on the Bristol Floating Harbour need to be considered.

4.4. System Control (Tubbs Bottom, Eastville, Floating Harbour)

Floating Harbour

4.4.1 Previous work undertaken by Halcrow (Bristol City Tidal Risk Strategy, Final report, 2004) identified that flood flows in the River Frome, in conjunction with extreme tide levels, could result in potential flooding problems. Tests undertaken with the Bristol Frome hydraulic model have indicated a rise in level within the BFH of 800mm when modelling a 100-year flood discharging against a peak tide (a MHWS tide was used). The opportunity exists to reduce flood risk around the BFH by diverting normal flows through the NSWI and use the Frome culverts as a relief system (albeit for aesthetic flows required to maintain the culverts).

Culvert System

4.4.2 The assessment of flood risk has confirmed that the ability to convey flood flows through the Frome Culverts is determined by two factors, conveyance capacity (dictated by size and gradient) and condition. There is a risk that these culverts could become blocked by waterborne debris or suffer failure leading to collapse and thereby triggering a blockage. Appropriate action is being taken by the Agency to monitor structural condition as previously identified. However, there is no facility or measure in place to prevent debris from being carried into the Frome culverts downstream of Eastville.

Investigate the feasibility of constructing coarse grid at entrance to Wade Street culvert.

4.4.3 Flood risk management at Eastville, at the upstream end of the Frome culvert system, depends wholly on the satisfactory operation of the vertical intake gates to the NSWI. This operation also impacts on the level in the Bristol Floating Harbour. More importantly a considerable number of properties rely on timely and appropriate action from the Environment Agency for flood protection. The current operating procedures could be further improved to minimize the risk of flooding.

Formalise the control operations of the main structures (such as gates), and examine the feasibility of automating control and to optimise where practicable.

Tubbs Bottom

4.4.4 The operation of Tubbs Bottom has largely evolved as a consequence of experience in the field and has resulted in the gates being kept in a fixed/permanent open position with a 400mm aperture. Modelling tests suggest that a reduction in flow during flood events can be secured at Frenchay and Eastville by varying the aperture opening. This may be achieved by varying discharge (by maximising flow throughput during the rising hydrograph) with a consequential reduction in peak flow and level at Frenchay.

Formalise the control operations of the radial gates and determine the practicality and effectiveness of automated variable control to optimise discharge.

4.5. Other Opportunities including Flood Warning

Flood Warning

4.5.1 There is one Flood Warning Area covering the entire Bristol Frome between Chipping Sodbury and the Bristol Floating Harbour. Whilst the Environment Agency operate up to a four stage flood warning system across much of England and Wales covering Flood Watch: Flood Warning: Severe Flood Warning: & All Clear, they only operate a three stage warning on the Bristol Frome. In the case of the Frome they do not issue a severe flood warning. These warnings are based on trigger levels (or stage levels) reached at Frenchay river level gauge; these appear to have been last reviewed in 1997 based on the information collected. There may be some scope for the development of a flood forecasting model given the flood travel times at Frenchay of between 7 and 10 hours, but given that the flooded areas for the Frome are small, so a small number of properties are identified at risk outside of Bristol, this may not prove to be a viable opportunity.

4.5.2 The model simulations also indicate that Tubbs Bottom Reservoir has a lower standard of service than originally thought; it is likely to overtop more frequently. In such overtopping situations it may be anticipated that there will be an increased risk to people and property immediately downstream of the reservoir (which has implications under the Reservoirs Act) In such circumstances is the issue of a severe flood warning as distinct from a flood warning appropriate to this location (and based on a Tubbs Bottom Level)?

Review Flood Warning Procedures and Trigger Levels for the Catchment

4.5.3 There are in excess of 2,000 properties currently at risk in the centre of Bristol and whilst the risk of flooding may not be high, if everything is operated correctly at Eastville, there is nevertheless a risk of failure due to human error, power failure and unforeseen circumstances. Whilst it may not be possible or indeed necessary to extend the current three stage warning to a four stage one the impact of such a failure should one occur is extremely high. In such circumstances consideration should be given to the updating of the current Major Incident Plan.

Give consideration with others to the updating of the Major Incident Plan for the centre of Bristol (this could be extended to cover the Bristol Floating Harbour if other operating authorities were interested in participating)

Possible opportunities to further reduce current level of flood risk

4.5.4 A number of various opportunities for flood risk management have been tested, of which a couple or so may be worthwhile pursuing in the long term (outside the 50-year life of this assessment), these include:

- provision of flood storage on the Bradley Brook, and
- provision of an additional relief culvert along the Bristol Frome Culvert system or upsizing parts of the existing system.

4.5.5 The provision of flood storage on the Ladden Brook has been found to have little effect on levels at Frenchay and may therefore be discounted for the future.

4.6. Development Control Considerations

4.6.1 For the future, there is widespread agreement that surface water drainage systems perform a wider range of functions, to make human activity more sustainable - socially, economically, and environmentally.

4.6.2 It has been strongly argued that the approach taken with Sustainable Drainage Systems (SUDs) supports this suggested aim, by slowing down the flow of water and by reproducing a pre-development pattern of discharge. This attenuation of the run-off water, allowing infiltration or delayed onward transmission of flows, theoretically decreases the risk of downstream flooding, improves water quality and has potential benefits for water supplies and wildlife The SUDs approach involves a wide variety of techniques from soakaways and rainwater harvesting to ponds and wetlands. In some cases, watercourses confined to concreted channels have been returned to a more natural state as part of the SUDS approach, with the creation of open, meandering channels.

4.6.3 The Government is committed to ensuring that land use policy aims to reduce, and certainly not add to, the overall level of flood risk. In the Defra document 'Making Space for Water' the Government proposes that solutions for flood management that work with natural processes to make more space for water should be identified and pursued where possible.

4.6.4 However SUDs are based on fixed design considerations, such as storage must be made available for a 100 year event, but what happens to the catchment when such events are exceeded?

4.6.5 The current development control strategy adopted by the Agency in relation to managing flow, of retention on one part of the catchment (left bank) and positive drainage over the remainder, has been proven in part by this study.

4.6.6 Tubbs Bottom Reservoir has strategic importance in effecting a significant reduction in flows arriving at Frenchay and this study has identified that flows through Frenchay could be over 20m^3/s larger should the Tubbs Bottom washland and control be removed, with stage at Frampton Cotterell and Winterbourne Down rising over 600mm. However further increases in storage capacity at this location do not confer any further benefit in the form of reduced peak flows at Frenchay.

4.6.7 In particular the modelling undertaken has shown that the provision of attenuation and retention on the Ladden Brook has little effect on peak flows at Frenchay, despite significantly reducing flows through Frampton Cotterell and Winterbourne Down (-13m^3/s flow and -200mm stage). In fact, the best case scenario, albeit an unrealistic one, of complete catchment transfer/full storage of the Ladden Brook runoff reduces flows at Frenchay by 11m^3/s, whereas this produces a 23m^3/s reduction in Frampton Cotterell, equivalent to over a 600mm decrease in peak stage. Such a proposition would be beneficial for Eastville, although wholly unachievable, but demonstrates the best attainable using transfer/storage techniques on the Ladden Brook.

4.6.8 Perhaps the key finding is the importance of the Bradley Brook discharge on the development of the flood hydrograph at Frenchay. For a 24-hour storm, discharge from the Folly Brook peaks first, followed quickly by that from the Bradley Brook (which Is 3 times larger than the Folly Brook). The peak flow from Tubbs Bottom arrives some 5 hours later, with the Ladden Brook flow plug arriving a further 2 hours later At the time of the peak flow at Frenchay, the Folly Brook is in recession, the Bradley Brook peaks, whilst discharges from Tubbs Bottom and the Ladden Brook are still rising.

4.6.9 It can be inferred that increased attenuation on the Folly Brook would seek to delay the peak discharge to meet that arriving from the dominant Bradley Brook catchment. Should the reduction in peak attenuated flows not be significant, then detriment may be caused downstream of Frenchay. The development study for Emersons Green Area C is investigating drainage proposals and the effects on discharges into the Folly Brook and it follows that use of the enhanced Frome model should be made to test the effect of the Area C development on the Frome

4.6.10 Development of the flood hydrograph at Frenchay has also identified the following issues:

- the superposition of hydrographs shows a double peaked response downstream of the Folly Brook, although this is somewhat smoothed by the magnitude of the Bradley Brook response;
- urbanisation within the Ladden Brook catchment could speed up the discharge response and enhance the flood peak at Frenchay;
- the overtopping-surge downstream of Tubbs Bottom has a notable effect on the overall flood hydrograph, adding a 'shoulder';
- raising the radial gates at Tubbs Bottom would increase the rising limb flows and thus increase them at Frenchay;
- lowering the radial gates at Tubbs Bottom would bring forward the time of crest overtopping and hence increase flows at Frenchay; and
- optimisation of the radial gates at Tubbs Bottom could be used to delay the rising limb flow until the peak flow from the Bradley Brook has entered the Frome, subsequent opening of the gates will increase downstream flows but the superposition of these with the receding Bradley Brook could be beneficial

4.6.11 Figure 4-1 below illustrates these observations with the 24-hour storm hydrograph for the 100-year flood.

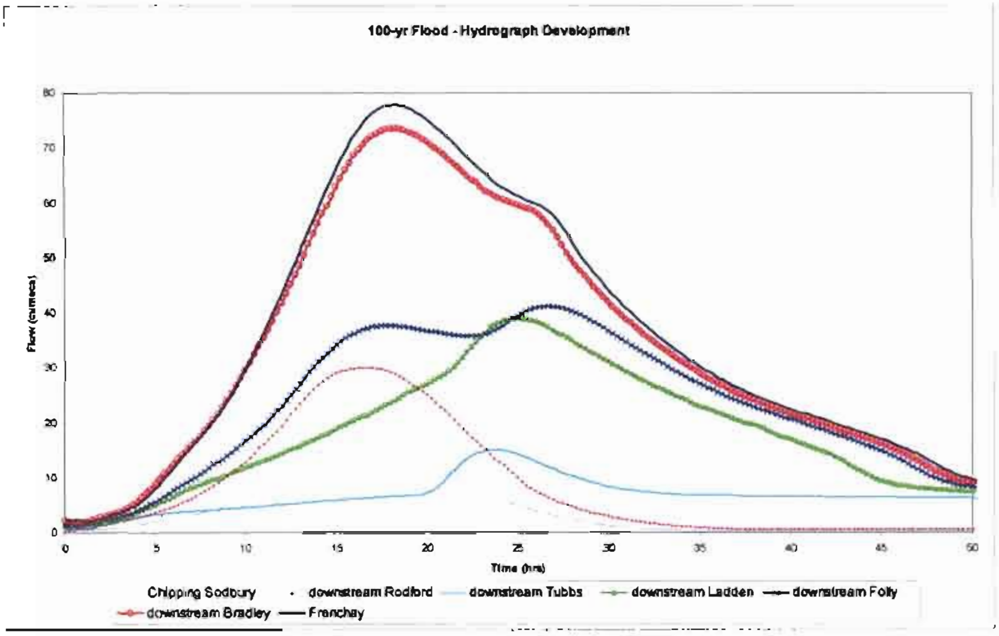

Figure 4-1: Development of flood hydrograph

4.6.12 It would appear from the testing that strategic storage on the Bradley Brook provides betterment to the Frome, reducing flood levels and flows. It can be inferred that site storage, beyond that to greenfield runoff varying with return period, will have a similar effect. Thus the current development control policy could be amended to accept on-site storage within the Bradley Brook. However, attenuation of flows into the Bradley Brook will seek to reduce the peak discharge into the Frome, yet also delay the timing of the peak flow, forcing it back in time towards the arrival of the peak flow from the Frome itself (say from 18hrs in the figure above, towards 27hrs). This strategic approach will thus require regular monitoring by updating the urban drainage and FEH models at an appropriate level of detail, followed by simulation of the new inflows within the ISIS model

4.6.13 The window of opportunity for storage is finite, and any increase in flow of the recession hydrograph discharging from the Bradley Brook will compound the second, currently lower, peak of the Frome. Hence, storage will work, but only to a point, after which the Frome becomes the source of the major flow peak.

4.6.14 To this effect, any application proposing storage must be considered in the context of the whole Bradley Brook catchment, its relative timing and effect on the Frome.

4.7. Implementation / Delivery Risk

4.7.1 As in any strategic study, a number of risks can be identified relating to assumptions about priorities, costs, resources, and other factors (e g. the underlying datasets). The output matrices from the strategic risk assessment workshop held as part of this study are included in the appendices to this report. They identify all known risks associated with the flood risk management opportunities highlighted. Very high strategic risks relating to the delivery of an acceptable level of service in terms of flood risk assessment have been identified under the broad heading of 'Performance and Response'. This covers the risks associated with the performance of the existing infrastructure and the impacts of events larger than the modelled design event.

4.8. Residual Risk

4.8.1 In general terms the following key threats to asset performance and response have been identified as falling into two categories during the risk assessment considerations, these are:

- residual life of asset; and
- human intervention.

4.8 2 These threats could be exacerbated by the impact of events greater than the modelled design event.

4.8.3 The assessment undertaken indicates that a Bristol Frome Culvert failure is the single largest risk of flooding within the Frome catchment, followed by one involving human error in operating the gates at Eastville. This likelihood of failure will increase over time due to increasing flood flows consequent upon climate change, and deterioration of the assets.

4.8.4 Furthermore an increased frequency of peak flood and rapid water level drawdown conditions will become more likely as a consequence of higher run-off due to further development and climate change: both conditions having unstabilising effects on the fabric of the culvert system

5. Socio-Economics

5.1. Riparian Ownership

5.1.1 Much Bristol Frome culvert (notably between Fairfax Street and Nelson Street, and Nelson Street and Bridewell Lane) lie beneath buildings, including the Galleries Shopping precinct and Avon Ambulance Service. As part of the BFFMS Study, a database of property and interests along the route of the culverts has been prepared. This has been assembled on the basis of the identification and cataloguing of the occupiers and tenants of properties and land lying within ten metres of the culverts. The outcome of which is the identification of 331 separate property interests.

5.1.2 In law, the riparian owner will own the land over the culvert and the fabric of the culvert and the various rights and duties of the riparian owner will continue to apply in relation to the culvert, including maintenance thereof. Additional legal complications can arise where ownership has changed since the original provision of a culvert, and where a property search on purchase of the property has failed to identify potential legal liabilities of the purchaser. A further problem arises when an old culvert needs replacing, in such circumstances it can prove difficult to ascertain the extent of a riparian owner's liability in respect of the new culvert. Currently the Environment Agency's role in relation to these culverts is largely a supervisory one given its duty to exercise a general supervision over all matters relating to flood defence, although permissive powers to do work exist.

5.2. Economic Assessment

5.2.1 An assessment of the economic benefits has been undertaken to identify the assets at risk of flooding and the severity of flood risk to these assets as part of the study commission. The information presented below has been abstracted from the 'Assessment of Economic Benefits report'.

Property at Risk

5.2.2 The table below summarises the assets within the 100 year return period flood outline, although this includes those properties with thresholds that are above the flood level.

Assets	Quantity	Description
Residential Properties	1,706	Estimated number of properties within the 100 year return period flood envelope.
Commercial Properties	1,198	Estimated number of properties within the 100 year return period flood envelope
Motorways	M32 and M4	Motorways within the 100 year return period flood envelope.
A Roads	4	Minor A road within the 100 year return period flood envelope.
B Roads	10	Minor B roads within the 100 year return period flood envelope.
Areas of Environmental Significance	0	Hectares of environmentally designated areas within the 100 year return period flood map.
Agricultural Land	696	Hectares of agricultural land within the 100 year return period flood map.
Ancient Woodland	1	Hectares of ancient woodland within the 100 year return period flood map.

Table 5-1: Assets within the 100 year return period floodplain

5.2.3 There is a minor difference between the number of properties quoted in the economic evaluation and those quoted in the table at Section 4.3. A floodplain outline for the River Frome and its tributaries had been drawn by Atkins as part of this study. This selected 2904 properties, on which the economic analysis was based. However when looking at the flooding hotspots to identify numbers of properties in each location using the simple boundary select function identifies all properties (represented by a solitary point) within the boundary but will not select a property should the point representing it fall outside of the floodplain boundary. This scenario may lead to properties not being selected, even though they may experience property flooding. This exercise identified a further 23 that were experiencing flooding but that were not included in the economic analysis

5.2.4 In particular the property numbers for the economic analysis were obtained from address point data for the catchment from the Agency based on floodplain boundary in MapInfo These properties included all of those within the floodplain extent, along the Frome and all of its tributaries. Whereas looking at the flooding hotspots in Section 4.3 we only looked at those particular areas listed in the table.

The 'Do Nothing' or 'Walk Away' option.

5.2.5 In order to evaluate the worthwhileness of doing something it is necessary to provide a common baseline against which alternative options may be assessed. The 'Do Nothing' option is often quoted as the baseline case but in this case this is not technically correct. It is the 'walk-away' option which requires evaluation. This is where there is currently significant investment in drainage infrastructure (the culvert systems) and the option is to walk away and abandon all maintenance, repair and operation of the existing structure, allowing nature to take its course. Simply continuing with maintenance and repair of the existing culvert system is then one of the 'do something' options.

5 2.6 Two management approaches have been considered within the study for the purpose of evaluation:

- **Scenario 1: Do Something – Existing Conditions** – Current maintenance regimes are continued and flood risk to assets remains broadly the same as today;
- **Scenario 2: Walk Away** – Under this scenario it is assumed that all maintenance is abandoned, which will result in the collapse of the Frome Culvert within 15 years. This in turn will result in a collapse of the Northern Storm Water Interceptor (NSWI) within 75 years, which will lead to the mass write-off of properties in the centre of Bristol.

Write Off Values

5.2.7 Write off in this context means that properties are abandoned (or permanently vacated) reflecting the fact that the likely flood risk denies future progress and prosperity (and with it all hopes and ambitions). This study has taken the approach of valuing risk in terms of expected losses (present value damages (PVd)) resulting from flood damages across a range of flood events and discounted over a hundred year time horizon. The Table below presents the results of these valuations.

Scenario	PVd (£'000)	Properties Written Off	Properties Flooding			Total Properties Affected
			Residential Properties	Commercial Properties	Total Properties	
Existing Conditions	4,023	3	368	52	420	423
Walk Away	80,134	1604	584	99	683	2287

Table 5-2: Present Value Flood Damage Results over a 100 year time horizon

5.2.8 The results shown above require some explanation. In the 'existing conditions' scenario it has been assumed that the culvert systems provide a deteriorating level of service due to climate change and sea level rise but that no catastrophic failure occurs during the appraisal period. It is anticipated that towards the end of the 100 year appraisal period that three properties in Hambrook would become uninhabitable. In the 'walk away' scenario it has been assumed that there would be a collapse of the Frome Culvert at Year 15 and that there would be a further collapse of the NSWI at Year 75.

5.2.9 A number of critical and vulnerable assets are predicted to flood under the Do Nothing scenario, including the United Bristol Health Trust Ambulance Station, Avon and Somerset Constabulary Headquarters, Cabot Primary School and St James and Agnes Nursery School. No care homes, hospitals, electrical sub stations, or other significant infrastructural elements are predicted to flood under the Do Nothing scenario.

5.2.10 Limitations in the National Property Database prevent an accurate estimation of the numbers of highly vulnerable residential properties at risk, such as bungalows. Given the highly urban nature of the flood risk area, bungalow numbers are likely to be very low, whereas the number of basement and first floor flats are likely to be significant.

5.2.11 These results indicate that in excess of 1600 properties could be written off in the event of the public bodies responsible for arterial drainage were to 'walk away' and abandon all maintenance and repair. A major part of the current heart of Bristol City Centre could be abandoned, and those adjacent remaining city centre properties could be blighted for ever. The 'economic' well being of Bristol would be devastated by such an occurrence and the impacts would be felt far beyond the perimeter of the city centre.

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6. Environmental Overview

6.1. Existing Environment

6.1.1 The purpose of this section if to collate and document the environmental work, carried out for this study, for future reference, with the intention of providing a clear and concise overview of the key issues.

6.1.2 A brief review of the existing environmental characteristics of the catchment was undertaken. It should be noted that a full scoping study was not undertaken; instead data was gather via a review of existing information held by the Agency and available over the internet, and from consultation with a number of Environment Agency area staff. Should the study be progressed further a more thorough review of the environmental issues pertinent to the proposals being pursued should be undertaken.

6.1.3 An Environmental Designations Map (Appendix A - Figure 1) is contained within the appendices and reference to individual designations is contained within the text in the remainder of this section.

6.1.4 The river corridor is of high local value for both biodiversity and recreation. Several protected species are present in the catchment and the river itself has a rich archaeological heritage (mills, BFH etc).

6.2. Land Use Planning

6.2.1 Land use and transport planning decisions within the Bristol Frome catchment are governed by the Joint Replacement Structure Plan (JRSP) for the former Avon County Council area. The plan was adopted in September 2002 and was prepared jointly by Bristol City Council, Bath and North East Somerset Council, North Somerset Council and South Gloucestershire Council. The JRSP is also complimented by the Local Plans for each of the councils, two of which are relevant to the Bristol Frome catchment:

- Bristol Local Plan - adopted in December 1997; and
- Draft South Gloucestershire Local Plan - planned to be adopted in late 2005.

6.2.2 Both of the above Local Plans provide detailed development and planning guidance within a local context to the Bristol Frome area.

6.3. Human Beings

Settlement

6.3.1 The Frome catchment is dominated by urban areas, which are interspaced by areas of agriculture in the north and areas of open, common land throughout The majority of the southern part of the catchment falls over the city centre of Bristol, which like any city centre is highly developed with a mixture of commercial, retail and residential properties. Other urban conurbations, which not only form the outskirts of Bristol but also fall within the Frome catchment include; Yate, Chipping Sodbury, Winterbourne and Patchway.

Recreation and Tourism

6.3.2 The Frome catchment as a whole is important for recreation and tourism because of the number of people that live within or near to it. The River Frome and associated valley are an important recreational resource.

6.3.3 The Frome Valley Walkway runs along almost the entire length of the River Frome. The route is a total of 29kms (18 miles) long and encourages a number of different activities including; walking, dog walking, running and cycling It is an important recreational route that helps to connect communities and open spaces. At various places along its length it creates important links to other public rights of way/trails, these can be seen on Figure 6-1.

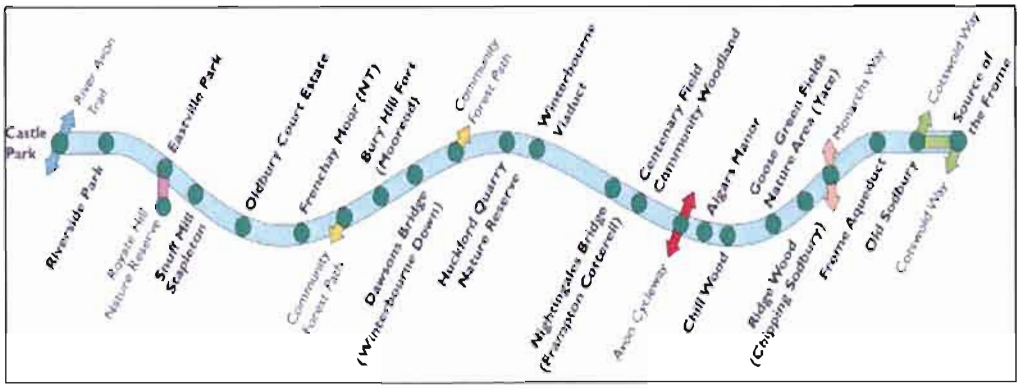

Figure 6-1: The Frome Valley Walkway

6.3.4 The above diagram also shows that the walkway links up with nature reserves along its route, for example the Royate Hill Nature Reserve.

6.3.5 The River Frome flows through a number of different public parks, three of which are major public parks near to Bristol city centre: Oldbury Court Estate, Snuff Mills Park and Eastville Park. These more central parks offer important rural retreats in an otherwise urban environment and together with others in the catchment have a high recreational/amenity value within the area.

6.3.6 Canoeing and angling are also popular. There are a great number of angling clubs along the river but most angling activity takes place in the centre of the catchment around Frampton Cotterell. The EA are keen to promote angling especially close to urban areas. There are a number of official and unofficial put-ins and take-outs for canoeists along the river.

6.4. Biodiversity, Flora and Fauna

6.4.1 There are no Sites of Scientific Interest (SSSI), Natura 2000 sites or other nationally or internationally designated sites within the Frome catchment that directly relate to the River Frome environment. The SSSIs that are present in the catchment are shown in Appendix A and include both geological and nature conservation sites Avon Gorge SSSI in the south west extremity of the catchment (NGR ST560743) is also designated as a Special Area of Conservation (SAC). The most relevant designation to the catchment is that the whole of the River Frome is designated as a Site of Nature Conservation Importance (SNCI), indicating the river is of local conservation interest.

6.4.2 There are also a number of local nature reserves and County Wildlife Sites (for example Royate Hill Nature Reserve and Huckford Quarry Nature Reserve) and community forest areas within the catchment and these further add to the conservation value.

6.5. Protected and Notable Species

6.5.1 The Frome valley is an important feature for wildlife as it provides a green corridor of freshwater habitats, woodlands, parks and open spaces cutting through the densely built up areas in Bristol and the towns and farmlands of South Gloucestershire. There are a number of important species (some that are protected under UK law and/or UK Biodiversity Action Plan (BAP) priority species) which can be found within Frome catchment.

Bats

6.5.2 The Frome Valley with its combination of lakes, pools, the River Frome itself, broadleaved woodlands and parkland is a haven for several bat species. Bats are protected nationally by the Wildlife and Countryside Act 1981 and under Schedule 2 of the Conservation (Natural Habitats, etc) Regulations, 1994 and all species are also included in the EC Habitats and Species Directive 1992. Three species are frequently observed within the Frome catchment.

6.5.3 The most common bats on the Frome are Pipistrelles, hunting for their favoured prey, small flies and moths, over ponds and in and amongst broadleaved trees In the summer Pipistrelles will roost in trees and in the roofs of houses. Winter hibernation sites are almost exclusively in buildings.

6.5.4 *Daubentons bats* are most likely to be seen flying low over the water in Eastville Park, trawling for mayflies as they emerge from the surface of the water. In summer Daubentons bats roost in a wide variety of sites including trees, tunnels, bridges and stone buildings. During the winter they hibernate in caves and other underground sites.

6.5.5 *Noctules*, amongst Britain's largest bats with a wing-span of 45cm, can often be seen flying high over Eastville and Oldbury Parks enroute to their feeding areas - broadleaved woodland, parkland, permanent pasture and water. They feed principally on flies, moths, cockchafer and dor beetles. Hollows in trees provide summer roosts and during the winter they will squeeze into rock fissures and hollows and bat boxes.

Crayfish

6.5.6 Recent surveys along the River Frome and its tributaries have found populations of the nationally rare and native white-clawed crayfish. This large crustacean is protected under Schedule 5 of the Wildlife and Countryside Act 1981 and has suffered a massive decline due to the introduction of the American signal crayfish, which carries crayfish plague. Crayfish like clear, well oxygenated water and locations without too much fine sediment The populations on the Frome are regionally important.

Water voles

6.5.7 At one time it was thought that there were no water voles within the Frome catchment, however, they have recently been found around Chipping Sodbury. In addition, the Ladden Brook is thought to have suitable water vole habitat, although none have been found. A more detailed survey of the catchment is required prior to any work being undertaken, especially as they have legal protection under Schedule 5 section 9 (parts 4a and 4b) of the Wildlife and Countryside Act 1981 (as amended) and, Section 81 of The Conservation and Rights of Way Act 2000. This makes it illegal to intentionally damage, destroy or obstruct access to any structure or place that water voles use for shelter or protection, or intentional disturbance of water voles whilst in occupation of these places.

Otters

6.5.8 Otters are also thought to inhabit reaches of the Frome catchment. They require bank-side vegetation cover, an abundant food supply, clean water and undisturbed areas of dense scrub for breeding. Otters are protected under Section 5 of the Wildlife and Countryside Act 1981 (as amended), Section 81 of The Conservation and Rights of Way Act 2000, as well as Schedule 2 of The Conservation (Natural Habitats &c.) Regulation 1994.

Birds

6.5.9 Bird communities provide a measure of habitat quality. All birds are protected during the breeding season and it is illegal under the Wildlife & Countryside Act 1981 (as amended) to damage or destroy bird nests and their eggs. Some particularly vulnerable species are given additional measures for protection. Birds found within the Frome catchment that are particularly notable are described below.

6.5.10 Kingfishers are protected under Section 1 of the Wildlife and Countryside Act 1981(as amended), which is particularly relevant within the Frome catchment where it is estimated that perhaps only 10 pairs are nesting in the Bristol area. The overhanging branches and riverside trees typical along the river, especially between Eastville and Winterbourne are considered to provide ideal kingfisher habitat.

6.5.11 Grey Wagtails are quite common within the Frome Valley, with several pairs breeding annually. However, the Grey Wagtail is an uncommon breeding species in the region largely because of the limited number of suitable breeding sites and so the Frome wagtails are considered an important local population.

6.5.12 Records of Dippers in the Frome Valley go back for over a hundred years although now it is likely that only a couple of pairs breed regularly. The dipper is a valuable addition to the birdlife of the Frome because it is an indicator of high water quality and it is scarce in many other areas locally.

6.5.13 A significant colony of House Martins breeds in Colston School, Stapleton close to the top of the western side of the valley. The Frome is important to the continued success of the colony because the birds use the river mud to build their nests and find an abundant variety of insects for food near to the water. These birds have also been seen near to Snuff Mills a little further up the valley.

6.6. Fisheries

6.6.1 Key fish species found within the Frome catchment include migratory trout, coarse fish and eels. There is no evidence to indicate that salmon are present. However, fish passage is an issue throughout the river system as many of the weir structures in the upper catchment are privately owned making it difficult to ensure fish passes are incorporated into any repair works undertaken. In the lower sections, there are a number of large weirs and culverts, which also act as barriers to fish. Fish populations also suffer due to poor water quality.

6.6.2 Past habitat improvements within the catchment have been proven to benefit fish. A post project survey was carried out following habitat improvement works carried out between Chipping Sodbury and Tubbs Bottom. The survey showed improvements in fish populations in this reach.

6.7. Landscape and Visual Amenity

6.7.1 The landscape and character of the Frome catchment is very varied and has been subject to man's influence throughout the ages.

6.7.2 The north of the catchment (from Frampton Cotterell up to Tytherington and its surrounding area) is relatively agricultural and is drained by the Ladden Brook and associated tributaries. The settlement pattern is very rural, dominated by small villages, isolated farmsteads and houses scattered along the sparse network of roads. The landscape is very open, with few hedgerow trees and intricate field patterns. According to a study commissioned by the NRA in 1994 the Ladden sub-catchment was subject to an agricultural drainage scheme in the 1960s and consequently the majority of the tributaries are now dry and the Ladden itself has uniform steep and high banks and has been straightened in places. As a result of the scheme and regular dredging and clearance of riparian vegetation the ecological value of the river and its adjacent corridor were described as low.

6.7.3 As a result of urban development, the south of the Frome catchment has become increasingly urbanised and impermeable, resulting in the increased risk of flash, scouring floods. The lowest section of the Frome is particularly affected by this urban growth. From Stapleton bridge (where the M32 crosses the river) to its confluence with the Avon, the Frome becomes fragmented by culverting and enclosed by adjacent development with only glimpsed views of the water possible. A study undertaken by Nicholas Pearson Associates in 1998 on behalf of the Environment Agency and Bristol City Council indicated that in those sections that remain open, the influence of the stormwater interceptor in the Lower Easton area was resulting in low water levels and slow flow rates, giving the river a very stagnant character.

6.7.4 The middle section of the catchment (between the areas of Stapleton and Frampton Cotterell) is still relatively urban and is being put under increasing pressure from development as Bristol city centre sprawls out into the suburbs. However, in this section the Frome itself is of particular interest as the river runs through a deep, narrow valley, the steep sides of which are mainly dominated by mature woodland. The area also portrays a number of natural rock outcrops and remnant quarries, which provide distinctive punctuation points along the valley.

6.7.5 Further to the east, the catchment is dominated by the urban conurbations of Yate and Chipping Sodbury. The land is more rolling and the outskirts of Chipping Sodbury give rise to views of the Cotswold scarp, which begins to dominate the landscape within these upper reaches of the River Frome. The most eastern extremities of this part of the catchment also fall within the important areas of the Cotswolds Area of Outstanding Natural Beauty (AONB) and Environmentally Sensitive Area (ESA).

6.7.6 Landscape and character descriptions of the Frome catchment can be obtained from English Nature's Natural Areas guidance and the Countryside Agency's Character Areas Assessments.

6.7.7 English Nature developed the Natural Areas classification system to sub-divide the country into individual 'biogeographic zones which reflect the geological foundation, the natural systems and processes and the wildlife in different parts of England, and provide a framework for setting objectives for nature conservation' (Biodiversity: The UK Steering Group Report, HMSO, 1995. Each Natural Area has a characteristic association of wildlife and natural features The Frome catchment crosses two Natural Areas: the Cotswolds; and the Bristol, Avon Valleys and Ridges, of which the latter is most relevant.

6.7.8 The Bristol, Avon Valleys and Ridges Natural Area is described as having a complex and varied landscape, characterised by alternating ridges and broad valleys with some steep wooded slopes and open rolling farmland. The large urban expanse of the city of Bristol, with its dramatic gorge of the River Avon, dominates the central part of the Natural Area. This Natural Area is underlain by Carboniferous and Jurassic Limestone and the geology interest of the area includes fossil-rich exposures, stratigraphic sites and karst features such as caves and a spectacular limestone gorge. The quarry exposures and the natural cliffs of the Avon Gorge, together with the screes, scrub, pockets of grassland and adjacent woodland, support an exceptional number of nationally rare and scarce plant species. Elsewhere the generally thin soils support woodlands, a number of parklands of conservation value, and limited areas of calcareous grasslands that are characteristically species-rich. There are also a number of significant water bodies features such as reservoirs, together with some wildlife-rich rivers and streams

6.7.9 The Countryside Agency has developed information and advice on the character of the English countryside. It includes systematic descriptions of the features and characteristics that make the landscape, by breaking England down into a number of Character Areas. The Frome catchment falls within the Bristol, Avon Valleys and Ridges Character Area. Key characteristics of the areas include:

- a landscape of very mixed landform, geology and settlement pattern, strongly influenced by the Avon Valley, Bristol at its centre and by its industrial history;
- low-lying, shallow valleys which contrast with limestone ridges and scarps;
- frequent large villages, small towns and major conurbations but also undisturbed rural areas;
- wooded scarps - with ancient woodland - and high, open, downland ridges;
- legacy of coal industry evident in tips, settlement patterns and reclaimed areas;
- waterside mills and other features of former rural industries;
- frequent parks, mansions and manor houses.

6.7.10 The many buildings, cottages, walls and bridges in and around the Frome Valley are also important to creating the character and landscape of the area. This is because a great number of them are constructed of Pennant Sandstone, which is a local, natural resource in the area.

6.8. Water Quality/Resources

6.8.1 A good water quality is vital for a healthy water environment and so the Environment Agency monitors and sets water quality targets in all rivers. These targets are known as River Quality Objectives (RQOs) and are used for planning the maintenance and improvement of river quality. RQOs establish a defined level of protection for aquatic life, whilst also helping to sustain the use of rivers for recreation, fisheries and local wildlife and protect the interests of abstractors. The water quality classification scheme used to set RQO planning targets is known as the River Ecosystem scheme

6.8.2 The River Ecosystem scheme provides a nationally consistent basis for setting RQOs. The scheme comprises five classes that reflect the chemical quality requirements of communities of plants and animals in rivers.

6.8.3 With regard to the Frome catchment water quality varies slightly throughout its entirety but overall is of a fairly good quality meeting an RQO rating of RE2. This class is described as: water of good quality suitable for all fish species However, areas of poor water quality do exist and examples of possible causes of poor water quality and in some cases RQO failures within the Frome catchment are outlined below:

- urbanisation - runoff from roads and car parks carries pollutants with it such as oil residues and litter. Urban runoff contributed to an RQO failure in the Frome near Yate Trading estate in 1997.
- sewage infrastructure problems - for example combined sewer outflows and wrong connections between sewer pipes and surface water drains.
- agriculture - for example soil erosion due to agricultural practice may be giving rise to heavy silt loading in some areas of the Frome.
- low flows - as associated with the culverted section of the Frome under the M32, can result in reduced levels of dissolved oxygen, which adversely impacts on the river ecology.

6.8.4 Climate change and the implications for dryer summers and more intense rainfall events could affect water quality and resource in the future, possibly exacerbating the effects of pollution in some instances.

6.9. Archaeology and Cultural Heritage

6.9.1 The heritage and history of the Frome catchment extends back many years. The name Frome is derived from Anglo-Saxon 'Frum" meaning rapid or vigorous and the path of the river passes a number of medieval churches, old quarries, mines and mills. The River Frome also played a very important role in the development of Bristol.

6.9.2 Bristol, which means 'Bridge Town' or 'Place of the Bridge', first existed on high ground on the Gloucester side of the River Avon. By 1000AD it had become an important trading centre. As the town grew it took over the rival settlement of Redcliffe and later spread up the slopes of Kingsdown, therefore incorporating the River Frome as an important transport artery. The marshes along the Avon and the Frome were then drained and reclaimed and in the 13th Century (1240 - 48) the Frome was straightened out from St John's Gate to a new junction with the Avon. When this massive Mediaeval engineering feat was completed Bristol had a new harbour which replaced the Avon wharves as the centre of the city's port trade. While the new 'trench' was still tidal its bottom was soft mud and so at low-tide ships could rest into it without breaking as was sometimes the case on the Avon's stony bed.

6.9.3 During the period that followed (1248-1809) Bristol became a prosperous City based on two rivers the Avon and the Frome. However, as the city grew, and industries expanded to supply goods for the colonial and slave trades the ships grew larger and required deeper waters. This lead to a decline on the wharfs of the Frome and eventually in 1892-3 resulted in the stretch of the Frome from Rupert Street to St Augustine's Bridge (opposite the end of Baldwin St) to be covered. In 1938-9 the further stretch from St Augustine's Bridge to where the Neptune statue now stands was also covered.

6.9.4 Further upstream, on what was then the outskirts of Bristol, the River Frome continued to play an important role in Bristol's industrial and leisure activities. As well as being a source of water power for a whole series of mill operated industries the Frome also provided opportunities for the local population to enjoy themselves. Fishing, drinking and feasting days at Earls Mead (Pennywell Road today) were popular and during Victorian times places still popular today like Eastville Park and Frenchay were also hives of activity, attracting Bristolians for boating, fishing and relaxing in tea gardens.

6.9.5 The Frome catchment was also an important mining and quarrying area. The Frome Valley was particularly rich in Pennant Sandstone, which has been quarried there since the 17th Century and was extensively used to assist the rapid development of housing and industry during the Victorian era.

6.9.6 Today, many of the important heritage sites and structures of the Frome catchment have been lost (for example, Baptist Mills) to development and urban growth but some still remain and can be seen in the form of Pennant Sandstone buildings, mills and bridges, for example:

- Snuff Mill at Stapleton has been partly renovated by Bristol City Council and the working water mill can still be seen. Despite its name the Mill was mostly used for grinding corn in the 17th and 18th Century although later on it also powered a large saw for cutting blocks of Pennant Sandstone from the adjacent quarry.
- Nightingale's Bridge crossing the Frome in Frampton Cotterell. Once used by pack-horses it is now the only remaining arched bridge over the river out of three that used to exist along this section of the river.
- the historic town of Chipping Sodbury and its pretty High Street is strongly influenced by the wide range of Pennant Sandstone buildings that characterise the town centre.

6.10. Geology

6.10.1 The geology of the catchment is relatively complex. The east and centre of the catchment are dominated by sandstones of the Coal Measures and Mercia Mudstone. The geology to the west of the catchment is less permeable, dominated by Mercia Mudstone and Liassic clays. Superficial deposits largely comprise meltwater gravels and terraces, mainly located in the west of the catchment.

6.10.2 A number of mini gorges have been created where the River Frome cuts through the Pennant Sandstone ridges, particularly between Winterbourne and Eastville. This grey or sometimes red stone is widely found in east Bristol and South Gloucestershire and exposures are often visible along the banks of the River Frome and at nearby local quarries.

6.10.3 There are five geological Sites of Special Scientific Interest (SSSI) within the catchment (see Appendix A): Quarry Steps Durdham Down SSSI (NGR ST573746), Barnhill Quarry SSSI (NGR ST725827), Tytherington Quarry SSSI (NGR ST662888), Avon Gorge SSSI (NGR ST560743) and Winterbourne Railway Cutting SSSI (NGR ST651799). These have all been given notification due to the unique geological exposures that occur at each location.

6.11. Interaction of the Rivers Frome and Avon

6.11.1 The River Avon exerts little effect on the Frome except for tide locking (Mylnes and NSWI culverts). The BFH is fed by the Avon at Netham Lock and in times of high Avon flow, water can spill into the BFH from other locations. High water levels in the BFH can discharge into the Frome over the fixed weirs within the Frome culvert system. No other water based interaction occurs. Failure of the current flapped outfalls (such as that believed at the Mylnes culvert) could allow Avon water into the From system.

6.12. Areas for Potential Environmental Improvement In relation to Future Work

6.12.1 The following list provides areas that could be used to provide environmental enhancement should works be undertaken in the Frome catchment.

- Tubbs Bottom washland for nature conservation
- Fish passes on key structures for migratory fish
- Buffer strips / highway and car park polishing for improved water quality
- Public awareness for dealing with litter and illegal dumping / disposal
- Sewage and sewerage improvements for raising water quality
- Ladden Brook for natural geomorphology
- Operating regimes and channel morphology for avoiding the deleterious effects of low flows

6.13. Preliminary Environmental Assessment

6.13.1 A number of possible opportunities have been identified by the study for possible future flood risk management. These are summarised below along with appropriate environmental considerations that might require further assessment, should they be pursued:

- continue with the existing management actions. This approach is likely to involve proactive and reactive maintenance measures. Continuing with the existing management is unlikely to result in significant environmental impacts (4.1.3);
- investigate the feasibility of constructing a coarse grid at entrance to Wade Street culvert. There are likely to be environmental impacts associated with construction works. The structure itself could have an impact on the local landscape depending upon its size, but no significant long-term operational impacts would be anticipated, as long as regular maintenance and clearance of the grid was undertaken (4.4.2);
- formalise the control operations of the main structures (such as gates), and examine the feasibility of automating control and to optimise where practicable. There would be no environmental considerations associated with this option as long as the management regime were not significantly altered. Significant changes could affect water levels and might have secondary impacts on biodiversity and landscape (paragraph 4.4.3);
- review Flood Warning Procedures and Trigger Levels for the catchment. There are no environmental considerations associated with this element of work (4.5.2);
- give consideration with others to the updating of the Major Incident Plan for the centre of Bristol (this could be extended to cover the Bristol Floating Harbour if other operating authorities were interested in participating). There would be no environmental impacts associated with this element of work (paragraph 4.5.3); and
- further assessment of culvert condition and possible remedial work. If remedial works are to be undertaken then a number of environmental issues would need to be taken into account. Undertaking work inside the culvert would give rise to the risk of water pollution, not only from the materials being used to undertake the works, but also from the potential to mobilise silt (possibly contaminated) and consequently increase the suspended sediment load within the Frome. Internal work is also likely to disturb any fauna that use the culvert, in particular protected species such as nesting birds and roosting bats. Fish populations are also likely to be disturbed if any dewatering is required (paragraph 3.3.2).

6.13.2 Should a full PAG2 strategy be developed from the study, and an SEA required in the future then a more rigorous environmental assessment process will need to be followed and additional work required. This will involve external consultation with relevant stakeholders in order to gather further environmental information on the study area and help to define the scope of the SEA. Strategic environmental objectives, targets and indicators will need to be drafted, which will be used in the consultation process and in the environmental appraisal of the flood defence options identified within the strategy. The environmental appraisal should identify the key positive and negative impacts associated with each of the strategy options, assess the options against the environmental objectives and ultimately identify the most environmentally appropriate strategy option or options. The SEA process would need to be documented with an Environmental Report.

6.13.3 If any of the individual elements of work were to be pursed in the future then a Environmental Impact Assessment of the scheme is likely to be required. This would require consultation with relevant external stakeholders, identification of local planning policies and plans, setting clear objectives with targets, and the undertaking of additional surveys, including ecology. A Scoping Report detailing the environmental issues associated with each of the scheme alternatives would be required. Once a preferred option were selected, the process would be summarized in an Environmental Report or Statement, which would identify the key environmental impacts of the preferred option and the associated mitigation measures.

7. Consultation

7.1.1 Consultation with professional bodies has formed an integral part of the study. A Quality of Life Capital Workshop was held in April 2003 to identify the environmental features considered to contribute to quality of life within the catchment. Limited discussions of draft targets and indicators for the strategy were also held. Participants in the Quality of Life Capital Workshop are summarised below in Table 1. Consultation with the public has not been undertaken.

External Organisations	
David Evans	South Gloucestershire Council, archaeologist
Jim Phillips	Bristol Frome Development Project
Sophia Price	Bristol City Council, nature conservation
Dave Villis	South Gloucestershire Council, ecologist
Bob Jones	Bristol City Council, archaeologist
Environment Agency/Atkins	
Vicky Ellis	Environmental Impact Assessment Co-ordinator Wales
Kevin Woodley	Flood Defence Improvements
Ken Tatem	Flood Defence Strategic planning
Roger Lewis	Project Manager (previous)
Pete Hart	Environmental Management Team Leader
Gerard Stewart	Environmental Developments Advisor
Jo Treweek	Environmental Impact Assessment Consultancy support to EA
Steve Barge	Atkins Consultants Limited
Karen Hills	Atkins – Consultants Limited

Table 7-1: Quality of Life Capital Workshop Participants

7.1.2 The key features and issues identified as a result of the Quality of Life Capital workshop should be used as the basis for aspirational objectives of any future strategies and schemes – these include:

- Frome Valley walkway which maintains access corridors along the river, particularly in urban areas is considered important.
- It is important to maximise the opportunities for biodiversity associated with the river corridor and the connections of the river corridor out into the wider countryside
- It is important to maintain public access to and along the river and in the future make more of the riverside accessible for horse riders and cyclists
- It is important to maintain access links to the river and further extend existing and future (i.e. aspirational) circular routes.
- It is important to preserve and enhance the features of the Frome Valley SNCI
- It is important to maintain and enhance the landscape character associated with the individual river reaches
- It is important to ensure that facilities are made safe for river users in a way which does not detract from the appearance of the river and its setting
- It is important to respect the integrity of historic features associated with the river
- It is important to provide a framework that enables the Agency to request that future developments make provision to meet the needs of the river and its users in a sustainable way
- It is important to provide for the management of flood risk in such a way that the litter problems of the river are minimised and dealt with in a sustainable manner.

7.1.3 A brief internal consultation exercise (user requirements) was undertaken with Environment Agency staff as part of Phase 1 of the study. Groups of staff from Flood Defence (operations, warning, improvements and workforce); Development Control; Strategic Planning; and Fisheries, Recreation and Biodiversity were consulted:

Environment Agency Consultation	
Megan Thomas	NCPMS
Richard Horrocks	Regional Flood Defence Manager
Ken Tatem*	Flood Defence Strategic Planning
Iain Sturdy*	Flood Defence Operations
John Philip & Dave Crowson	Development Control
Kevin Woodley, Paul Knight, Catherine Eales, Dave Sutton & Jim Barlow	Flood Defence
Martin Weiler & Samantha Dawe	Corporate Affairs
Keith Nursey, Ray Smith, Olivia Burtchaell	GIS / Data Management
Melissa Clarkson, Steve Thomas, David Lloyd & Simon Smythe	Environment
Chris Bown, Jack Mason*	Lewin, Fryer & Partners
Jacob Franklin*	Capita Symonds

Table 7-2: Phase 1 consultation

7.1.4 Key issues included:

- the current strategy is piecemeal and operationally based;
- the EA do not feel that they have a good understanding of the hydrology of the sub-catchments (timings and interactions);
- the lower hydraulic model needs calibrating;
- there is a need for an urban hydrology study
- the Eastville Intake is the prime control on the catchment because it has limited forward capacity;
- during tide lock there are no suitable discharge points;
- it is unknown whether Tubbs Bottom is being operated to its maximum potential;
- there are problems with tress and debris blocking bridges and culverts,
- there may be partnering and sharing of assets between the EA, Wessex Water and Bristol City Council in the future;
- the current flood warning system covers only 6% of the catchment. Drastic changes are needed to meet the required 77% coverage:
- there is no official agreement between the EA and Bristol City Council regarding the operation of the Floating Harbour;
- fish passage and the need to incorporate fish passes into new and existing structures along the Frome and its tributaries;
- there is a need for a cycleway along the Bristol Frome;
- the creation of car parks could help to promote angling throughout the catchment;
- recreation, especially canoeing must be considered when altering existing structures or designing new ones; and
- there is potential to create fast flowing rapids at Snuff Mills for rodeo canoeing.

7.1.5 Bristol City Council, South Gloucester local authority and Wessex Water were identified as key stakeholders and consulted on commencement of the study. Meetings were held with these organisations to disseminate and gather information.

External Consultation	
Bristol City Council	
Chris Barrow	Engineering Manager, (Engineering Services)
South Gloucestershire	
Nigel Hale	Senior Project Manager (Technical Services)
David Buckland	Principal Engineer (Technical Services)
Wessex Water	
Peter Weston	Senior Engineer
Mike McMahon	Senior Engineer
Andy Purvey	Developer Liaison (Strategic Planning)

Table 7-3: External Consultation

7.1.6 In August 2004, a options workshop was undertaken with the Environment Agency and Atkins project teams (see below) to identify possible short, medium and long term options for flood defence within the catchment. A wide range of options were considered and included measures such as upstream storage, flow diversion and altered land use management. Many of these options have however been discounted on the grounds that they are not effective in significantly reducing flood levels, are too costly or could not be easily achieved by the Environment Agency.

August 2004 Workshop Participants	
Environment Agency	
Megan Thomas	NCPMS Project Manager
Kevin Woodley	Flood Defence Improvements / Area Representative
Ken Tatem	Flood Defence Strategic planning
Iain Sturdy	Flood Defence Operations
Melissa Clarkson	Fisheries, Recreation and Biodiversity
John Philip	Development Control
Sam Dawe	
John Wilkins	
Floyd Blake	
Matt Jones	NEAS
Atkins	
Phil Marsden	BFFMS Coordinator
Mike Vaughan	BFFMS Project Manager
Karen Hills	WS Atkins – contractors to EA
Suzie Gore	Modelling
Viviana Levy	Economic Appraisal

Table 7-4: Participants at the Options Workshop

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8. Summary

8.1. Key Achievements of the Study

a) urban hydrology and urban drainage modelling has been included in the catchment hydrology;
b) the rural hydrology and catchment contributions have been updated
c) general updates and enhancements of have been made to the ISIS model, resulting in improved run times and inclusion of Bristol Floating Harbour, River Avon and Mylnes culvert;
d) the ISIS model has been corrected at Eastville to more realistically represent the NSWI and its operation, this included a survey of the Eastville intake structure;
e) floodplain mapping was provided for urban areas and the flood risk quantified;
f) a partial visual condition survey of Frome culvert system was completed and delivered with an associated report.
g) a property survey of riparian occupants/owners along Frome culvert routes was completed which could be used to secure external funding for culvert works
h) an assessment of flood damage costs over a possible scheme life was provided, giving do nothing scenarios considered and modelled, the write off values and sum of benefits derived
i) the model was used to test various possible opportunities for Flood Risk Management along the Frome
j) a culvert model developed outside of ISIS using specialist software.
k) the primary concerns of the key stakeholders were gathered

8.2. Key Findings of the Study

a) the culvert survey highlighted the requirement for urgent works to the soffit of the Frome culvert in several locations;
b) based on current assessment the Frome culverts have a capacity of $59m^3/s$,
c) the 100 year flow arriving at Eastville is $80m^3/s$;
d) the Frome Culvert and NSWI may cope with approximately $100m^3/s$ or flows in excess of the 100 year flood
e) the ISIS model design simulations indicated that Tubbs Bottom has a lower standard of service than originally thought;
f) flood storage on the Bradley Brook is technically feasible and will reduce flows passing through Frenchay and Eastville;
g) flood storage on the Ladden Brook has no effect on flows at Frenchay
h) Tubbs Bottom has a strategic importance in reducing flows arriving at Frenchay and Eastville but increasing its storage capacity further has little or no effect at Frenchay either now or in the future.
i) based on the current climate change predictions, Eastville intakes may still cope with a 100 year flood in 50 years time

8.3. Key Issues from the Study

a) the Preliminary Strategic Review of current issues identified that there is a lack of telemetry data available in the catchment (for appropriate calibration of the hydraulic model and general monitoring) and that there are no set procedures for recording the operation of the control gates at Eastville
b) culvert monitoring and structural analysis ha put in place as a direct consequence of the earlier Atkins (2004) report has being undertaken as a separate commission arranged by the Agency

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9. Recommendations

9.1. Policies

9.1.1 The operation of the NSWI and Bristol Frome culverts seems vulnerable and imprecise given the dependence the centre of Bristol has on these systems for flood conveyance (and avoidance of flooding) Apart from clearly and succinctly setting out the operating procedures the Environment Agency should ensure that a full record of operational activities is maintained and also ensure new telemetry is working fully.

9.1.2 The effect of raised flood defences in the Chipping Sodbury, Yate, Frampton Cotterell and Winterbourne Down areas should be fully investigated, making use of floodplain survey in these locations and the current ISIS model. It would appear that such measures have little effect on the flows downstream of Frenchay and could be used to address the short term requirements for flood risk management in the catchment.

9.1.3 The convolution of the flood hydrograph is the key to understanding flood management in the Bristol Frome catchment. The strategy study has identified that the Bradley Brook provides the dominant input into the Frome and peaks at Frenchay before the input arriving from the upper Frome. As such, works to attenuate flow peaks in the upper catchment have little effect at Frenchay: to provide improvements, the lower and rising limb of the upstream hydrograph needs to be attenuated. Nevertheless, a reduction in the flood peak discharging from the Bradley Brook would have a direct effect on flow in the Frome at Frenchay and Eastville. As such, the technical potential for flood storage within the Bradley Brook catchment is one of importance and the pasture and river valley along the Bradley Brook between Matford Bridge and the railway viaduct could be allocated for future impoundment should the need arise. Storage on the Bradley Brook was the single most effective solution tested in alleviating flow arriving at Eastville.

9.2. Tasks

9.2.1 The following list of recommendations have been drawn for the whole Bristol Frome Flood Management Strategy study (all reports prepared)

9.2.2 **Operational**

a) report Tubbs Bottom findings to the Reservoirs Act' Supervising Engineer;
b) review existing operating procedures for the opening and closure of the gates to the NSWI culvert at Eastville and update. This also needs to be extended to cover the issue of recording the current status of the gate aperture openings
c) review performance of telemetry at Eastville
d) review trashing arrangements to the entrance to the NSWI culvert at Eastville to cater for mechanical failure.
e) preparation of a Major (Catastrophic) Incident Plan to cover reach of river downstream of Tubbs Bottom detention reservoir in the event of dam failure or major overtopping.
f) determine the optimal use of Tubbs Bottom to evaluate whether prefilling would provide sufficient lag in the upper catchment to mitigate flows at Frenchay
g) flow diversion arrangements at Eastville should be reviewed with the intention of maintaining dry weather flows in the main Frome culverts and diverting medium flows through the NSWI, using the remaining Frome culvert capacity to take flood flows.
h) continue with the existing management actions (4.1.3)
i) investigate the structural condition of culvert and undertake repair where necessary
j) remove the debris and in-channel items from the culvert system – this could include the silt (where possible) and various supports (once repaired)
k) investigate origin of silt in the culvert system to see if linked to the damaged flap on the Mylnes culvert. This would help to determine whether silt removal is a sustainable option.
l) undertake a condition survey of the NSWI to check its medium and long term ability to discharge flows from the Frome;
m) review all attenuation measures installed as a condition of recent development and future approved development, to assess their effectiveness long term / maintenance requirements
n) consider updating the MIP for the centre of Bristol

o) amend the Development Control strategy to accept storage for new development on the Bradley Brook subject to strategic control;
p) work with South Gloucestershire Council to safeguard the rural land adjacent to the Bradley Brook, downstream of Matford Bridge, in future local plans;
q) any changes in operational procedures should be assessed against the environmental baseline and appropriate action taken.

9.2.3 Capital

a) installation of a coarse trash screen at Wade Street to alleviate the risk of culvert blockage cause by deposition along the open channel between here and the M32 culvert;
b) installation of a centrally located in-catchment rain gauge will improve post flood event analysis and to facilitate improvements to the flood warning service;
c) installation of a flow gauging site at Eastville to record the division of flows through the Frome culverts and NSWI will improve post flood event analysis and facilitate improvements to the flood warning service;
d) future calibration of the ISIS model will be needed once a significant amount of data has been collected (gauges above), followed by a review of the strategic direction taken;
e) Further modelling should be undertaken at a prefeasibility level to establish the effect of local raised defences – this will require the procurement of additional survey data or the use of LiDAR to extend model cross sections.
f) if benefit-cost analyses are undertaken for specific flood defence schemes, property threshold values should be refined and the benefit from traffic disruption and agricultural land should be included;
g) undertake further sensitivity analysis to determine optimal gate operation at Tubbs Bottom (paragraph 4.2.13), and investigate automated variable control of the radial gates at Tubbs Bottom (paragraph 4.4.4) whilst formalising the control;
h) any changes in implementation of construction work should be assessed against the environmental baseline and appropriate action taken;
i) upstream storage on the Bradley Brook provides the best opportunity for reducing future flows at Frenchay. The land downstream of Matford Bridge is recommended as the most appropriate location for implementing such opportunity; and
j) the provision of a further branch on the Frome culverts provides the best opportunity for alleviating future flooding from the Frome in Bristol: the land at Castle Green is recommended as the most appropriate location for implementing such opportunity

Appendices

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Appendix A:
Maps

Figure 1: Environmental Designation and Constraints map

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Appendix B: Strategic Risk Assessments

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