URS

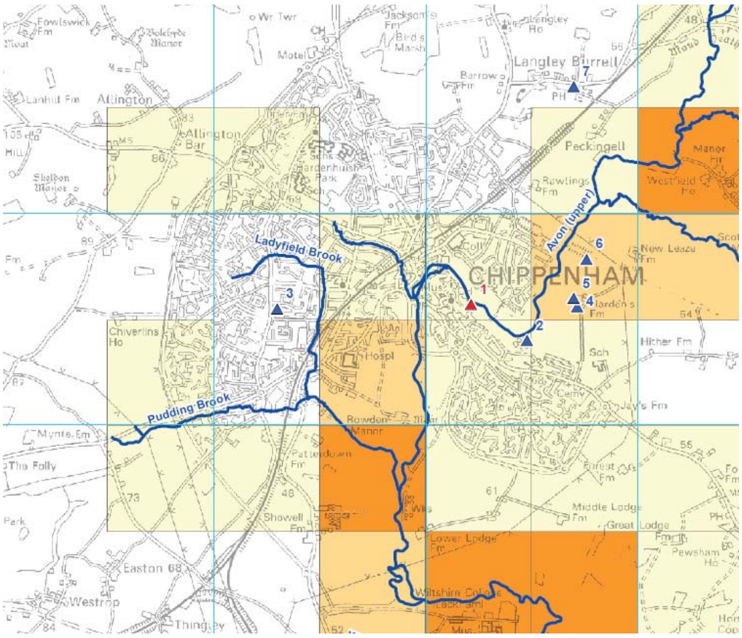
Scott Wilson

Chippenham Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 1 & 2

November 2011



Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility
November 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	26/01/2011	Draft	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
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Abbreviations

ACRONYM	DEFINITION
AStGWF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
RBMP	River Basement Management Plan
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Interfluve	A ridge or area of land dividing two river valleys.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, under capacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the ‘infiltration’ category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

Groundwater flooding occurs as a result of water rising up from the underlying aquifer or water flowing from groundwater springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by principal aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

Groundwater flooding tends to occur sporadically in both location and time, and tends to last longer than fluvial, pluvial or sewer flooding. Basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

The need to improve the management of groundwater flood risk in the UK was identified through DEFRA's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

Wiltshire Council has commissioned Scott Wilson to complete Phases 1 and 2 of their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Chippenham study area. From this analysis,

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

The Bristol Avon is the major river in the Chippenham area and rises in the Cotswolds to the north west. The river flows south through Chippenham, before flowing west towards Bath and then to its outlet on the Bristol Channel (Scott Wilson, 2007). The Bristol Avon and its tributaries in the area of Chippenham are shown on Figure 1.

Within the Chippenham area, ground levels range from around 50 maOD in the Bristol Avon's valley floodplain to around 120 maOD on the surrounding interfluve areas.

2.2 Geology

Figure 1 provides geological information for Chippenham and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series. Figure 2 provides a geological cross section, which has been used to improve the conceptual understanding of the area. 34 borehole logs were obtained from the BGS to provide local data and their locations are shown in Figure 1.

2.2.1 Bedrock Geology

Within the Chippenham study area, the bedrock geology of interest comprises the Combe Down Oolite, which in turn is overlain by the Forest Marble Formation, Cornbrash Formation, Kellaways Formation (Kellaways Sand Member overlying Kellaways Clay Member), and the Oxford Clay Formation. Additional details are provided in Table 1.

The Kellaways Formation and the Cornbrash Formation comprise the majority of the outcrop (surface) geology in the area of interest. In the north east of the Chippenham study area there is a significant outcrop of Kellaways Sand Member, which is found at the top of the Kellaways Formation.

The Forest Marble Formation outcrops at surface at a number of smaller localities in the centre and to the north west of the Chippenham study area, where the overlying Cornbrash Formation has been eroded away and superficial geology are absent.

There is geological faulting in the Chippenham area as shown by Figure 1. A laterally extensive fault runs from the north west (near to Kingstone St Michael) to the south east of Chippenham.

Table 1: Bedrock geology of significance to the study

Geological Units		Description	Thickness*
Ancholme Group	Oxford Clay Formation	Mudstone	Up to 150 m
	Kellaways Sand Member	Horizon at top of Kellaways Formation. Interbedded siltstone & sandstone	Up to 4 m
	Kellaways Clay Member	Mudstone	Up to 28 m
Great Oolite Group	Cornbrash Formation	Fine grained shelly limestone with thin clays and marls. Typically rubbly at the base but more sandy and better bedded in the upper part.	Up to 5 m
	Forest Marble Formation	Mudstone with impersistent band of shelly limestone. Acton Turville Beds (mainly limestone) at base.	Up to 35 m
	Combe Down Oolite	Limestone	Logs suggest 25 m
	Fullers Earth (grouped for simplicity)	Clay with chalky white limestone and Fullers Earth Rock beds	>28 m

*Thickness from The properties for secondary aquifers in England and Wales (Jones et al., 2000), Table 6.6 page 91.

2.2.2 Superficial Geology

The superficial geology of the area consists of Alluvium, Head, River Terrace Deposits, and Alluvial Fan Deposits.

In the majority of the study area, superficial geology is not present. However, in the valley of the Upper Bristol Avon River there are significant River Terrace Deposits (sand and gravel). The thickness of River Terrace Deposits to the south of Chippenham is indicated to be around 1 to 1.4 m thick by borehole logs ST97SW1, ST97SW9 and ST97SW156 (See Figure 1 for locations).

In the Upper Bristol Avon's floodplain and some of its tributaries there are deposits of Alluvium (clay, silt, sand & gravel), which in places overlie the River Terrace Deposits. Borehole logs ST97SW156 & ST97SW59 indicate that to the south of Chippenham near to the Upper Bristol Avon River the Alluvium deposits are around 1.2 to 4 m thick. The logs suggest that in this area the Alluvium has a high clay content mixed with sand and gravel.

To the east and west of the Chippenham study area there are small deposits of Head. These comprise a mixture of clay, silt, sand & gravel.

To the south of Chippenham, away from developed areas, there exist Alluvial Fan Deposits on the Kellaways and Oxford Clay Formations. The Alluvial Fan Deposits are expected to consist of a mixture of clay, silt, sand & gravel, but there are no logs to confirm their thickness or lithology.

2.3 Hydrogeology

The hydrogeological significance of the various geological units within the study area is provided in Table 2. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 2 and is shown in Figure 3.

Table 2: Geological Units in the study area and their hydrogeological significance

Geological Units		Expected Permeability Based on geological data	Hydrogeological Significance
Superficial Geology	River Terrace Deposits (Sand & Gravel)	High	Secondary A aquifer
	Head Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
	Alluvium	Low to Moderate	Variable but classified as secondary aquifer
	Alluvial Fan Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
Bedrock Geology	Oxford Clay Formation	Low	Aquiclude
	Kellaways Sand Member	Moderate to High	Secondary A aquifer
	Kellaways Clay Member	Low	Aquiclude
	Cornbrash Formation	Moderate to High	Secondary A aquifer
	Forest Marble Formation	Low to Moderate (mudstone) Moderate to High (limestone)	Aquiclude, although a lower limestone unit is expected to behave as an aquifer.
	Combe Down Oolite	High	Principal aquifer
	Fullers Earth (grouped for simplicity)	Low to Moderate	Variable but classified as Secondary aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale (EA website, 2010).
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers (EA website, 2010).

2.3.1 Bedrock Geology

The Oxford Clay Formation and the Kellaways Clay Member are aquicludes and do not permit groundwater flow. They are classified as unproductive strata.

The Kellaways Sand Member, found at the top of the Kellaways Formation is considered to have a high permeability due to its sand content. There is potential for localised perched water tables in this horizon due to the outcrop at surface and the underlying impermeable Kellaways Clay Member. Therefore the Kellaways Sand Member is of interest to the current study.

The Forest Marble Formation generally has a low permeability in the middle and upper horizons due to a high clay content, although the basal horizon is mostly limestone facies, which are water bearing (also referred to as Acton Turville Beds).

The Cornbrash Formation is classified as a secondary A aquifer (water bearing) and rests above the Forest Marble Formation. The thin aquifer is typically hydraulically separated from the Combe Down Oolite aquifer (Table 2) by the clays in the Forest Marble Formation. This scenario is expected to lead to the development of a perched water table in the Cornbrash Formation. Therefore, the Cornbrash Formation is of interest to this study because it outcrops at surface over much of the study area.

The Combe Down Oolite underlies the Forest Marble Formation and is classified as a principal aquifer. The Forest Marble Formation confines the Combe Down Oolite aquifer in the Chippenham area and therefore the Combe Down Oolite aquifer is not pertinent to the current study.

2.3.2 Superficial Geology

The hydrogeological significance of the Alluvium in the river valleys is expected to be variable, although locally it may behave as an aquifer where the sand and gravel content is high.

Head and Alluvial Fan Deposits are expected to behave as an aquitard, although sand horizons may locally form a secondary aquifer depending on their lateral extent and thickness.

The gravely River Terrace Deposits are expected to behave as a secondary A aquifer and are of interest to the current study.

2.3.3 Bedrock Groundwater Levels

Cornbrash Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Cornbrash Formation. However, Table 3 presents water level data from three BGS borehole logs. Whilst it is important to note that the data is not recent and does not show seasonal fluctuations, it does indicate that a perched water table exists within the thin Formation and is close to ground level in places. The locations of the boreholes identified within Table 3 are shown on Figure 1.

Table 3: Water levels in the Cornbrash Formation obtained from BGS logs

Borehole Reference	Approximate Location	Water Level (mbgl)	Date of record	Base of Cornbrash below GL (m)
ST97SW37	Central Chippenham	1.85	5/02/1988	4
ST97SW204	NW of Chippenham	1.6	1/09/1993	2.7
ST97SW13	SW of Chippenham	0.84	1937	4.5

'mbgl' – meters below ground level.
'GL' – Ground Level; 'NW' – north west; 'SW' - southwest

The Ladyfield Brook and Pudding Brook probably receive groundwater inflow (baseflow) from the Cornbrash Formation. However, there are no available data to confirm groundwater / surface water interactions.

Forest Marble Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Forest Marble Formation. Whilst the lower Forest Marble Formation is water bearing, development of groundwater resources appears to have targeted the deeper and more permeable Combe Down Oolite. However, certain boreholes have been constructed to receive water from both horizons. There may be a degree of hydraulic continuity between the lower Forest Marble Formation and the Combe Down Oolite. BGS borehole log ST97SW13 indicates that in 1937 the water level was at 14.71 m below ground level to the south west of Chippenham.

Combe Down Oolite

Groundwater level data associated with five boreholes has been obtained from the Environmental Agency for the Chippenham area. The borehole locations are shown in Figure 4 and the water levels are presented in Appendix 1. The borehole water level records show that:

- Season fluctuations in the Combe Down Oolite range between 5 to 15 metres as shown by the hydrograph for Arlington Number 1 and Number 2, located to the north west of Chippenham and away from groundwater abstractions.
- The piezometric water level in the Combe Down Oolite can be at or close to ground level during the peak period of winter recharge (December to April). This is evident at Arlington during the particularly wet years of 1994/95 and 2000/01.
- Piezometric water levels in the Combe Down Oolite to the south of Chippenham, close to the Upper Bristol Avon River can be close to or above ground level (artesian) as shown by the hydrograph for Lacock number 2.

Despite piezometric levels within the Combe Down Oolite being at or close to ground level, the overlying clay horizons prevent groundwater flooding from this aquifer.

2.3.4 Superficial Geology Groundwater Levels

The Environment Agency does not monitor groundwater levels in the superficial geology. However, two of the BGS borehole logs (Table 4) indicate a water level of around 3.1 to 3.3 m below ground level in the Chippenham area. Whilst there are no recent water levels it would appear that the River Terrace Deposits form a perched aquifer over the Kellaways Clay Member.

Table 4: Water levels in the River Terrace Deposits obtained from BGS logs

Borehole Name	Approximate Location	Water Level (mbgl)	Date of record	Overlain by Alluvium
ST97SW59	Central Chippenham	3.3	23/06/1994	Yes
ST97SW24	Central Chippenham	3.1	14/07/1986	Yes

'mbgl' – meters below ground level

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

River flow and stage data were requested from the Environment Agency. The Stanley station monitors both the river stage and flow of the River Marden to the east of Chippenham (Figure 4). However, the data are not relevant to the current study as the River Marden, upstream of the gauging station, is not in hydraulic continuity with the aquifers in the study area.

In the Chippenham area, bedrock geology groundwater / surface water interactions along the Upper Bristol Avon River will be limited due to the underlying Kellaways Clay Member. However, tributaries such as the Ladyfield Brook, Pudding Brook and Chissell Brook are expected to receive groundwater from the Cornbrash Formation and Kellaway Sands Member.

With regards to superficial geology groundwater / surface water interactions, it is likely that there is some hydraulic continuity between the perched aquifer within the River Terrace Deposits and the Upper Bristol Avon River.

Unfortunately there are no continuous or recent groundwater level data for the aquifers of interest, or stage data for the surface water courses in Chippenham, and therefore it is not possible to gain a more informed understanding of groundwater / surface water interactions.

2.3.6 Abstractions and Discharges

The location of groundwater and surface water abstractions and discharge permits were requested from the Environment Agency (Figure 4). The larger abstractions (e.g. public water supply) are not shown for confidentiality reasons.

Within the Chippenham area there are many small groundwater abstraction licences (<20 m^3/day) and only three of significant volume. There are two agricultural abstractions located around 2 km north east and 2 km south of the town centre, licensed to abstract 27375 m^3/year and 5000 m^3/year, respectively. It is not clear which geological formation the boreholes abstract from.

The third licence is located approximately 4-5 km to the south of Chippenham, allowing 3320000 m^3/year to be abstracted. Again, it is not clear which formation this abstraction occurs from, but it is likely to be the Combe Down Oolite.

Figure 4 identifies many discharge permits within the Chippenham study area. Whilst it is not identified whether these are to ground or surface water, the plotted locations infer that the majority are to surface water courses.

2.3.7 Artificial Groundwater Recharge

Water mains leakage data for the Chippenham area were not provided for this study. It should be noted that additional recharge to perched groundwater tables by leaking mains could result in a local rise in groundwater levels. This rise might not prove significant under dry conditions, but could exacerbate the risk of groundwater flooding following periods of heavy rainfall.

The drainage/sewer network can act as a further source of artificial recharge. When pipes are installed within principal or secondary aquifers, the groundwater and drainage network may be in partial hydraulic connection. When pipes are empty, groundwater may leak into the drainage network with water flowing in through cracks and porous walls, draining the aquifer and reducing groundwater levels. During periods of heavy rainfall when pipes are full, leaking pipes can act as recharge points, artificially recharging the groundwater table and subsequently increasing groundwater levels with potential impacts on groundwater quality.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the Chippenham study area. The key groundwater flooding mechanisms that may exist are:

- **Cornbrash Formation outcrop area in central and west Chippenham:** The available datasets indicate that a perched groundwater table exists within the Cornbrash Formation. Due to the permeable but thin nature of this Formation, basements / cellars and other underground structures may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of infiltration SUDs and / or artificial recharge from leaking pipes.
- **Kellaways Sand Member outcrop area in north east Chippenham:** There is potential for a perched groundwater table to exist within the Kellaways Sand Member. Due to the permeable but thin nature of this aquifer, basements / cellars and other underground structures may be at risk from prolonged groundwater flooding from periods of prolonged rainfall, increased utilisation of SUDs and / or artificial recharge from leaking pipes.
- **Superficial geology aquifers in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding may be associated with the substantial sand and gravel River Terrace Deposits, or to a lesser degree Alluvium, where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain “in-bank”, and this can trigger a rise in groundwater levels in the associated superficial geology. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial geology.
- **Superficial aquifers not in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding is also associated with substantial River Terrace Deposits (gravel and sand), Alluvial Fan Deposits and Head deposits, but occurs where they are not in immediate hydraulically connection with surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.
- **Impermeable (silt and clay) areas downslope of aquifer outcrop (various locations):** Groundwater flooding may occur where groundwater springs / seepages form minor flows and ponding over impermeable strata where there is poor drainage. This mechanism may occur as a result of natural (e.g. rainfall) or artificial (e.g. water main leakage) recharge.
- **Uncapped boreholes drilled into the Combe Down Oolite:** The piezometric levels within the Combe Down Oolite are at or close to ground level following sustained wet periods, although overlying clay horizons prevent groundwater flooding from this aquifer. However, uncapped boreholes would provide an artificial pathway for groundwater to flow to surface and cause groundwater flooding.

3.2 Evidence of Groundwater Flooding

Figures 1, 3, 4 and 5 show the location of one historic groundwater flooding incident that was identified by the Environment Agency. The Figures also show the locations of another six flooding incidents that may have been influenced by groundwater conditions, but have been identified as either fluvial or pluvial flooding. These flooding incidents have also been considered by this study, as it is often difficult to identify the cause of a flooding incident. Details of the reported incidents are shown in Table 5, including the local geology and the date of the reported incident.

Table 5: Selected flooding incidents

Geological Units*	Grid Reference	No**	Reported Incident	Date
Cornbrash Formation / River Terrace Deposits	ST 92428 73140	1	Groundwater flooding – no other comment	30/10/2000
Cornbrash Formation / River Terrace Deposits	ST 92960 72800	2	Fluvial flooding – no other comment	12/04/1960
Cornbrash Formation	ST 90605 73101	3	Fluvial flooding – no other comment	12/01/1979
Kellaways Clay Member / River Terrace Deposits	ST 93430 73120	4	Surface Water flooding – no other comment	12/04/1960
	ST 93400 73200	5	Surface Water flooding – no other comment	03/06/1978
	ST 93520 73570	6	Surface Water flooding – no other comment	12/04/1960
Kellaways Sand Member	ST 93400 75200	7	Surface Water flooding – no other comment	03/06/1978

Note: * Geology of incident based on plotted location on Figures 1 & 4.

** Reference number as shown on Figures 1, 3, 4 & 5.

Based on Figure 1, the hydrogeological situation of incidents 1, 2, 4, 5 and 6 are similar, although only incident 1 is listed as a groundwater flooding incident. These locations are shown to be on a shallow aquifer (Cornbrash Formation / River Terrace Deposits) where groundwater levels are likely to be influenced by the Upper Bristol Avon River but also rainfall runoff from the impermeable Kellaways Clay Member on higher ground.

Figure 1 shows that locations 3 and 7 are both located on shallow aquifers but do not appear to be close to any surface water courses. It is plausible that these two flooding incidents were influenced by groundwater conditions.

It is important to note that the listed flooding incidents in Table 5 are not contemporary; there are no available data beyond the end of October 2000. In addition, until recent years there have been few drivers in place to ensure the systematic recording of flood incidents and their likely cause.

3.3 Areas Susceptible to Groundwater Flooding

The Environment Agency has produced a data set referred to as 'Areas Susceptible to Groundwater Flooding (AStGWF)', on a 1 km grid (Figure 5). This utilises the BGS 1:50,000 Groundwater Flood Susceptibility data set for consolidated aquifers (bedrock) and superficial geology.

The Environment Agency data set shows the percentage of each 1 km square that falls within the high to very high BGS groundwater flooding susceptibility categories. It does not show the

probability / risk of groundwater flooding occurring; this can only be determined following site specific investigation works and desk studies. It also does not take into account groundwater level rebound following cessation of abstraction.

An absence of values for any grid square means that no part of that square is identified as being susceptible to groundwater emergence (Environment Agency AStGWF Guidance Document).

The areas that are identified as being most susceptible to groundwater flooding are located close to the Upper Bristol Avon and River Marden. By comparing the data set with Figure 1 (geological map) it is apparent that those grid squares identified as having an area greater than 50% with high to very high susceptibility to groundwater flooding are those where significant River Terrace Deposits are present.

Flooding incidents 4, 5 and 6 are located in grid squares within the >=25% <50% category, owing to the proximity of Alluvium and River Terrace Deposits adjacent to the Upper Bristol Avon River.

Incident numbers 3 and 7 located on the Cornbrash Formation and Kellaways Sand Member are shown to be in grid squares with no shading, which suggests no susceptibility to groundwater flooding. However, this could indicate that no water level data were available to the BGS when creating the original groundwater flood susceptibility Map. This notwithstanding, it is thought that the approximate areas identified by the Environment Agency as being susceptible to groundwater flooding are sensible.

3.4 Importance of Long Term Groundwater Level Monitoring

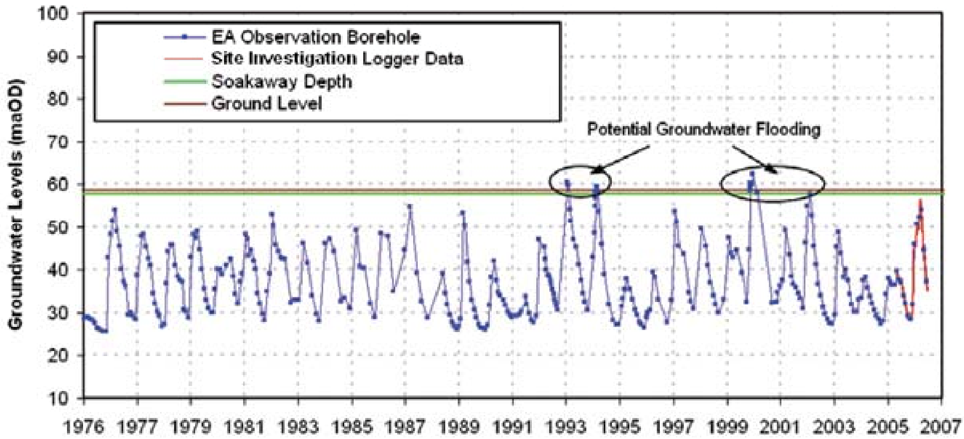
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers, Cornbrash Formation and Kellaways Sand Member are limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

It is not sufficient to rely on the work undertaken by developers through the planning application process, unless long term monitoring (several years) is one of the conditions when granting planning permission. Groundwater levels are often only measured once, or, at most, for a number of weeks. It would be advisable for the Council, in combination with the Environment Agency, to begin long term monitoring of the Cornbrash Formation, Kellaways Sand Member and superficial aquifer groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial flood defences.

It is also important to understand how changing policies relating to infiltration SUDS can impact upon groundwater levels. For example the introduction of infiltration SUDS (e.g. soakaways) may cause a rise in peak groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the Environment Agency owing to its responsibilities under the Water Framework Directive.

Long term groundwater level monitoring is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS.

Schematic demonstrating the importance of long term groundwater level monitoring



4 Water Framework Directive and Infiltration SUDS

The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Thames River Basin District is considered within the current study since infiltration Sustainable Drainage Systems (SUDS) have the potential to impact the water quality and water quantity status of aquifers and surface water courses.

4.1 Current Quantity and Quality Status

The current quantitative assessment for the area South of Malmesbury (Cornbrash Formation aquifer - GB40901G806000) is 'good' and the current quality assessment is 'good'. The quantitative and chemical quality in 2015 is also predicted to be good (Environment Agency, December 2009). The Cornbrash Formation is likely to be suitable for infiltration SUDS and it is important that use of these systems does not have an adverse impact on the status of the aquifer.

There is no equivalent assessment for the River Terrace Gravels or Kellaways Sand Member, which may also be suitable for infiltration SUDS.

4.2 Infiltration SUDS Suitability

Improper use of infiltration SUDS could lead to contamination of the superficial or bedrock geology aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

Environment Agency guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Wiltshire Council when approving or rejecting planning applications.

The areas that may be suitable for infiltration SUDS (e.g. soakaways, permeable paving) exist where there is a combination of higher ground (interfluves) and permeable geology (see Figure 3). However, consideration should be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at the down gradient location. This type of analysis is beyond the scope of the current report.

Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ), which are shown on Figure 3. Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance.

It is understood that the SPZs in the Chippenham area are associated with groundwater abstractions from the Forest Marble Formation and Combe Down Oolite, which are expected to be hydraulically isolated from the aquifers that outcrop in the Chippenham area. This notwithstanding, the developer should present a suitable risk assessment as part of any planning application.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

- The clays of the Forest Marble Formation are expected to hydraulically separate the underlying Combe Down Oolite principal aquifer from the surface aquifers. Therefore, the Combe Down Oolite is not of key interest to the groundwater flooding assessment.
- The key areas of interest are those underlain by Kellaways Sand Member, Cornbrash Formation or River Terrace Deposits (Figure 1). These geological units are expected to behave as aquifers and are likely to contain perched water tables i.e. they are a potential source of groundwater flooding.
- A number of potential groundwater flooding mechanisms have been identified. Key mechanisms are (i) rapid water level fluctuations in the River Terrace Deposits in response to river stage fluctuations (Upper Bristol Avon River), and (ii) response of perched groundwater levels within the Cornbrash Formation and Kallaways Sand Member to increased use of infiltration SUDS, leaking pipes and barriers to groundwater flow such as sheet piling. Properties at greatest risk of flooding are those with basements / cellars.
- Based on the available flood incident data and Environment Agency 'Areas Susceptible to Groundwater Flooding' data set, the areas most susceptible to groundwater flooding are those properties located on River Terrace Deposits, close to the Upper Bristol Avon River.
- The lack of reported groundwater flooding incidents on the Cornbrash Formation and Kellaways Sand Member suggests that whilst a perched aquifer may exist, groundwater levels are sufficiently low and/or there are a lack of receptors (e.g. basements), such that groundwater flooding has not been an issue. However, it is important to note that no groundwater flooding incident data post-2000 were available from the Environment Agency. In addition, increased discharges to these aquifers through infiltration SUDs may lead to future groundwater flooding issues. Therefore, use of infiltration SUDs should be carefully managed.
- The Environment Agency and Council do not currently monitor groundwater levels in the River Terrace Deposits, Kellaways Sand Member or Cornbrash Formation. Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

5.2 Recommendations

The following recommendations are made based on the findings of the current report:

- Data identifying properties with basements / cellars should be collected by Wiltshire Council;
- Site investigation reports for historic development sites could be reviewed to obtain additional groundwater level information, to improve the conceptual understanding of the area;
- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial, pluvial and sewer. An integrated understanding of flood risk will be gained through this exercise;
- Pluvial modelling often assumes that no infiltration of rainfall occurs (a worst case scenario). It is recommended that a sensitivity analysis is undertaken, whereby infiltration is modelled in those areas where permeable superficial geology are located;
- Monitoring boreholes should be installed in the River Terrace Deposits, Cornbrash Formation and the Kellaways Sand Member, fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on infiltration SUDS guidance provided.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered when approving planning applications;
- The impact of infiltration SUDS on groundwater levels (and therefore groundwater risk) should be considered further. This may require the construction of a local groundwater model following collection of groundwater level data.

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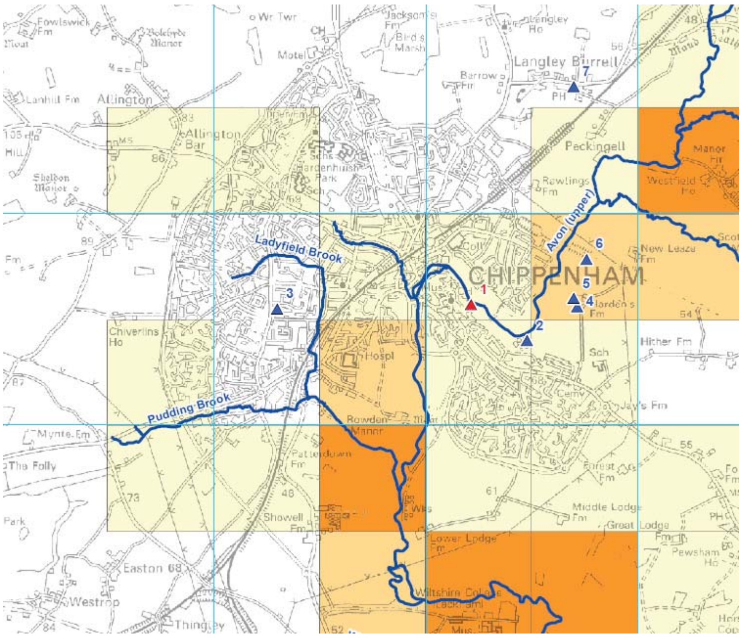
Chippenham Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 1 & 2

November 2011



Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility
November 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	26/01/2011	Draft	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
02	01/02/2011	Draft – for client comment only	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
03	November 2011	Final – No client comments following draft			

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Abbreviations

ACRONYM	DEFINITION
AStGWF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
RBMP	River Basement Management Plan
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Interfluve	A ridge or area of land dividing two river valleys.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, under capacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

Groundwater flooding occurs as a result of water rising up from the underlying aquifer or water flowing from groundwater springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by principal aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

Groundwater flooding tends to occur sporadically in both location and time, and tends to last longer than fluvial, pluvial or sewer flooding. Basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

The need to improve the management of groundwater flood risk in the UK was identified through DEFRA's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

Wiltshire Council has commissioned Scott Wilson to complete Phases 1 and 2 of their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Chippenham study area. From this analysis,

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

The Bristol Avon is the major river in the Chippenham area and rises in the Cotswolds to the north west. The river flows south through Chippenham, before flowing west towards Bath and then to its outlet on the Bristol Channel (Scott Wilson, 2007). The Bristol Avon and its tributaries in the area of Chippenham are shown on Figure 1.

Within the Chippenham area, ground levels range from around 50 maOD in the Bristol Avon's valley floodplain to around 120 maOD on the surrounding interfluve areas.

2.2 Geology

Figure 1 provides geological information for Chippenham and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series. Figure 2 provides a geological cross section, which has been used to improve the conceptual understanding of the area. 34 borehole logs were obtained from the BGS to provide local data and their locations are shown in Figure 1.

2.2.1 Bedrock Geology

Within the Chippenham study area, the bedrock geology of interest comprises the Combe Down Oolite, which in turn is overlain by the Forest Marble Formation, Cornbrash Formation, Kellaways Formation (Kellaways Sand Member overlying Kellaways Clay Member), and the Oxford Clay Formation. Additional details are provided in Table 1.

The Kellaways Formation and the Cornbrash Formation comprise the majority of the outcrop (surface) geology in the area of interest. In the north east of the Chippenham study area there is a significant outcrop of Kellaways Sand Member, which is found at the top of the Kellaways Formation.

The Forest Marble Formation outcrops at surface at a number of smaller localities in the centre and to the north west of the Chippenham study area, where the overlying Cornbrash Formation has been eroded away and superficial geology are absent.

There is geological faulting in the Chippenham area as shown by Figure 1. A laterally extensive fault runs from the north west (near to Kingstone St Michael) to the south east of Chippenham.

Table 1: Bedrock geology of significance to the study

Geological Units		Description	Thickness*
Ancholme Group	Oxford Clay Formation	Mudstone	Up to 150 m
	Kellaways Sand Member	Horizon at top of Kellaways Formation. Interbedded siltstone & sandstone	Up to 4 m
	Kellaways Clay Member	Mudstone	Up to 28 m
Great Oolite Group	Cornbrash Formation	Fine grained shelly limestone with thin clays and marls. Typically rubbly at the base but more sandy and better bedded in the upper part.	Up to 5 m
	Forest Marble Formation	Mudstone with impersistent band of shelly limestone. Acton Turville Beds (mainly limestone) at base.	Up to 35 m
	Combe Down Oolite	Limestone	Logs suggest 25 m
	Fullers Earth (grouped for simplicity)	Clay with chalky white limestone and Fullers Earth Rock beds	>28 m

*Thickness from The properties for secondary aquifers in England and Wales (Jones et al., 2000), Table 6.6 page 91.

2.2.2 Superficial Geology

The superficial geology of the area consists of Alluvium, Head, River Terrace Deposits, and Alluvial Fan Deposits.

In the majority of the study area, superficial geology is not present. However, in the valley of the Upper Bristol Avon River there are significant River Terrace Deposits (sand and gravel). The thickness of River Terrace Deposits to the south of Chippenham is indicated to be around 1 to 1.4 m thick by borehole logs ST97SW1, ST97SW9 and ST97SW156 (See Figure 1 for locations).

In the Upper Bristol Avon's floodplain and some of its tributaries there are deposits of Alluvium (clay, silt, sand & gravel), which in places overlie the River Terrace Deposits. Borehole logs ST97SW156 & ST97SW59 indicate that to the south of Chippenham near to the Upper Bristol Avon River the Alluvium deposits are around 1.2 to 4 m thick. The logs suggest that in this area the Alluvium has a high clay content mixed with sand and gravel.

To the east and west of the Chippenham study area there are small deposits of Head. These comprise a mixture of clay, silt, sand & gravel.

To the south of Chippenham, away from developed areas, there exist Alluvial Fan Deposits on the Kellaways and Oxford Clay Formations. The Alluvial Fan Deposits are expected to consist of a mixture of clay, silt, sand & gravel, but there are no logs to confirm their thickness or lithology.

2.3 Hydrogeology

The hydrogeological significance of the various geological units within the study area is provided in Table 2. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 2 and is shown in Figure 3.

Table 2: Geological Units in the study area and their hydrogeological significance

Geological Units		Expected Permeability Based on geological data	Hydrogeological Significance
Superficial Geology	River Terrace Deposits (Sand & Gravel)	High	Secondary A aquifer
	Head Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
	Alluvium	Low to Moderate	Variable but classified as secondary aquifer
	Alluvial Fan Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
Bedrock Geology	Oxford Clay Formation	Low	Aquiclude
	Kellaways Sand Member	Moderate to High	Secondary A aquifer
	Kellaways Clay Member	Low	Aquiclude
	Cornbrash Formation	Moderate to High	Secondary A aquifer
	Forest Marble Formation	Low to Moderate (mudstone) Moderate to High (limestone)	Aquiclude, although a lower limestone unit is expected to behave as an aquifer.
	Combe Down Oolite	High	Principal aquifer
	Fullers Earth (grouped for simplicity)	Low to Moderate	Variable but classified as Secondary aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale (EA website, 2010).
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers (EA website, 2010).

2.3.1 Bedrock Geology

The Oxford Clay Formation and the Kellaways Clay Member are aquicludes and do not permit groundwater flow. They are classified as unproductive strata.

The Kellaways Sand Member, found at the top of the Kellaways Formation is considered to have a high permeability due to its sand content. There is potential for localised perched water tables in this horizon due to the outcrop at surface and the underlying impermeable Kellaways Clay Member. Therefore the Kellaways Sand Member is of interest to the current study.

The Forest Marble Formation generally has a low permeability in the middle and upper horizons due to a high clay content, although the basal horizon is mostly limestone facies, which are water bearing (also referred to as Acton Turville Beds).

The Cornbrash Formation is classified as a secondary A aquifer (water bearing) and rests above the Forest Marble Formation. The thin aquifer is typically hydraulically separated from the Combe Down Oolite aquifer (Table 2) by the clays in the Forest Marble Formation. This scenario is expected to lead to the development of a perched water table in the Cornbrash Formation. Therefore, the Cornbrash Formation is of interest to this study because it outcrops at surface over much of the study area.

The Combe Down Oolite underlies the Forest Marble Formation and is classified as a principal aquifer. The Forest Marble Formation confines the Combe Down Oolite aquifer in the Chippenham area and therefore the Combe Down Oolite aquifer is not pertinent to the current study.

2.3.2 Superficial Geology

The hydrogeological significance of the Alluvium in the river valleys is expected to be variable, although locally it may behave as an aquifer where the sand and gravel content is high.

Head and Alluvial Fan Deposits are expected to behave as an aquitard, although sand horizons may locally form a secondary aquifer depending on their lateral extent and thickness.

The gravely River Terrace Deposits are expected to behave as a secondary A aquifer and are of interest to the current study.

2.3.3 Bedrock Groundwater Levels

Cornbrash Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Cornbrash Formation. However, Table 3 presents water level data from three BGS borehole logs. Whilst it is important to note that the data is not recent and does not show seasonal fluctuations, it does indicate that a perched water table exists within the thin Formation and is close to ground level in places. The locations of the boreholes identified within Table 3 are shown on Figure 1.

Table 3: Water levels in the Cornbrash Formation obtained from BGS logs

Borehole Reference	Approximate Location	Water Level (mbgl)	Date of record	Base of Cornbrash below GL (m)
ST97SW37	Central Chippenham	1.85	5/02/1988	4
ST97SW204	NW of Chippenham	1.6	1/09/1993	2.7
ST97SW13	SW of Chippenham	0.84	1937	4.5

'mbgl' – meters below ground level.
'GL' – Ground Level; 'NW' – north west; 'SW' - southwest

The Ladyfield Brook and Pudding Brook probably receive groundwater inflow (baseflow) from the Cornbrash Formation. However, there are no available data to confirm groundwater / surface water interactions.

Forest Marble Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Forest Marble Formation. Whilst the lower Forest Marble Formation is water bearing, development of groundwater resources appears to have targeted the deeper and more permeable Combe Down Oolite. However, certain boreholes have been constructed to receive water from both horizons. There may be a degree of hydraulic continuity between the lower Forest Marble Formation and the Combe Down Oolite. BGS borehole log ST97SW13 indicates that in 1937 the water level was at 14.71 m below ground level to the south west of Chippenham.

Combe Down Oolite

Groundwater level data associated with five boreholes has been obtained from the Environmental Agency for the Chippenham area. The borehole locations are shown in Figure 4 and the water levels are presented in Appendix 1. The borehole water level records show that:

- Season fluctuations in the Combe Down Oolite range between 5 to 15 metres as shown by the hydrograph for Arlington Number 1 and Number 2, located to the north west of Chippenham and away from groundwater abstractions.
- The piezometric water level in the Combe Down Oolite can be at or close to ground level during the peak period of winter recharge (December to April). This is evident at Arlington during the particularly wet years of 1994/95 and 2000/01.
- Piezometric water levels in the Combe Down Oolite to the south of Chippenham, close to the Upper Bristol Avon River can be close to or above ground level (artesian) as shown by the hydrograph for Lacock number 2.

Despite piezometric levels within the Combe Down Oolite being at or close to ground level, the overlying clay horizons prevent groundwater flooding from this aquifer.

2.3.4 Superficial Geology Groundwater Levels

The Environment Agency does not monitor groundwater levels in the superficial geology. However, two of the BGS borehole logs (Table 4) indicate a water level of around 3.1 to 3.3 m below ground level in the Chippenham area. Whilst there are no recent water levels it would appear that the River Terrace Deposits form a perched aquifer over the Kellaways Clay Member.

Table 4: Water levels in the River Terrace Deposits obtained from BGS logs

Borehole Name	Approximate Location	Water Level (mbgl)	Date of record	Overlain by Alluvium
ST97SW59	Central Chippenham	3.3	23/06/1994	Yes
ST97SW24	Central Chippenham	3.1	14/07/1986	Yes

'mbgl' – meters below ground level

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

River flow and stage data were requested from the Environment Agency. The Stanley station monitors both the river stage and flow of the River Marden to the east of Chippenham (Figure 4). However, the data are not relevant to the current study as the River Marden, upstream of the gauging station, is not in hydraulic continuity with the aquifers in the study area.

In the Chippenham area, bedrock geology groundwater / surface water interactions along the Upper Bristol Avon River will be limited due to the underlying Kellaways Clay Member. However, tributaries such as the Ladyfield Brook, Pudding Brook and Chissell Brook are expected to receive groundwater from the Cornbrash Formation and Kellaway Sands Member.

With regards to superficial geology groundwater / surface water interactions, it is likely that there is some hydraulic continuity between the perched aquifer within the River Terrace Deposits and the Upper Bristol Avon River.

Unfortunately there are no continuous or recent groundwater level data for the aquifers of interest, or stage data for the surface water courses in Chippenham, and therefore it is not possible to gain a more informed understanding of groundwater / surface water interactions.

2.3.6 Abstractions and Discharges

The location of groundwater and surface water abstractions and discharge permits were requested from the Environment Agency (Figure 4). The larger abstractions (e.g. public water supply) are not shown for confidentiality reasons.

Within the Chippenham area there are many small groundwater abstraction licences (<20 m^3/day) and only three of significant volume. There are two agricultural abstractions located around 2 km north east and 2 km south of the town centre, licensed to abstract 27375 m^3/year and 5000 m^3/year, respectively. It is not clear which geological formation the boreholes abstract from.

The third licence is located approximately 4-5 km to the south of Chippenham, allowing 3320000 m^3/year to be abstracted. Again, it is not clear which formation this abstraction occurs from, but it is likely to be the Combe Down Oolite.

Figure 4 identifies many discharge permits within the Chippenham study area. Whilst it is not identified whether these are to ground or surface water, the plotted locations infer that the majority are to surface water courses.

2.3.7 Artificial Groundwater Recharge

Water mains leakage data for the Chippenham area were not provided for this study. It should be noted that additional recharge to perched groundwater tables by leaking mains could result in a local rise in groundwater levels. This rise might not prove significant under dry conditions, but could exacerbate the risk of groundwater flooding following periods of heavy rainfall.

The drainage/sewer network can act as a further source of artificial recharge. When pipes are installed within principal or secondary aquifers, the groundwater and drainage network may be in partial hydraulic connection. When pipes are empty, groundwater may leak into the drainage network with water flowing in through cracks and porous walls, draining the aquifer and reducing groundwater levels. During periods of heavy rainfall when pipes are full, leaking pipes can act as recharge points, artificially recharging the groundwater table and subsequently increasing groundwater levels with potential impacts on groundwater quality.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the Chippenham study area. The key groundwater flooding mechanisms that may exist are:

- **Cornbrash Formation outcrop area in central and west Chippenham:** The available datasets indicate that a perched groundwater table exists within the Cornbrash Formation. Due to the permeable but thin nature of this Formation, basements / cellars and other underground structures may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of infiltration SUDs and / or artificial recharge from leaking pipes.
- **Kellaways Sand Member outcrop area in north east Chippenham:** There is potential for a perched groundwater table to exist within the Kellaways Sand Member. Due to the permeable but thin nature of this aquifer, basements / cellars and other underground structures may be at risk from prolonged groundwater flooding from periods of prolonged rainfall, increased utilisation of SUDs and / or artificial recharge from leaking pipes.
- **Superficial geology aquifers in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding may be associated with the substantial sand and gravel River Terrace Deposits, or to a lesser degree Alluvium, where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain "in-bank", and this can trigger a rise in groundwater levels in the associated superficial geology. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial geology.
- **Superficial aquifers not in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding is also associated with substantial River Terrace Deposits (gravel and sand), Alluvial Fan Deposits and Head deposits, but occurs where they are not in immediate hydraulically connection with surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.
- **Impermeable (silt and clay) areas downslope of aquifer outcrop (various locations):** Groundwater flooding may occur where groundwater springs / seepages form minor flows and ponding over impermeable strata where there is poor drainage. This mechanism may occur as a result of natural (e.g. rainfall) or artificial (e.g. water main leakage) recharge.
- **Uncapped boreholes drilled into the Combe Down Oolite:** The piezometric levels within the Combe Down Oolite are at or close to ground level following sustained wet periods, although overlying clay horizons prevent groundwater flooding from this aquifer. However, uncapped boreholes would provide an artificial pathway for groundwater to flow to surface and cause groundwater flooding.

3.2 Evidence of Groundwater Flooding

Figures 1, 3, 4 and 5 show the location of one historic groundwater flooding incident that was identified by the Environment Agency. The Figures also show the locations of another six flooding incidents that may have been influenced by groundwater conditions, but have been identified as either fluvial or pluvial flooding. These flooding incidents have also been considered by this study, as it is often difficult to identify the cause of a flooding incident. Details of the reported incidents are shown in Table 5, including the local geology and the date of the reported incident.

Table 5: Selected flooding incidents

Geological Units*	Grid Reference	No**	Reported Incident	Date
Cornbrash Formation / River Terrace Deposits	ST 92428 73140	1	Groundwater flooding – no other comment	30/10/2000
Cornbrash Formation / River Terrace Deposits	ST 92960 72800	2	Fluvial flooding – no other comment	12/04/1960
Cornbrash Formation	ST 90605 73101	3	Fluvial flooding – no other comment	12/01/1979
Kellaways Clay Member / River Terrace Deposits	ST 93430 73120	4	Surface Water flooding – no other comment	12/04/1960
	ST 93400 73200	5	Surface Water flooding – no other comment	03/06/1978
	ST 93520 73570	6	Surface Water flooding – no other comment	12/04/1960
Kellaways Sand Member	ST 93400 75200	7	Surface Water flooding – no other comment	03/06/1978

Note: * Geology of incident based on plotted location on Figures 1 & 4.

** Reference number as shown on Figures 1, 3, 4 & 5.

Based on Figure 1, the hydrogeological situation of incidents 1, 2, 4, 5 and 6 are similar, although only incident 1 is listed as a groundwater flooding incident. These locations are shown to be on a shallow aquifer (Cornbrash Formation / River Terrace Deposits) where groundwater levels are likely to be influenced by the Upper Bristol Avon River but also rainfall runoff from the impermeable Kellaways Clay Member on higher ground.

Figure 1 shows that locations 3 and 7 are both located on shallow aquifers but do not appear to be close to any surface water courses. It is plausible that these two flooding incidents were influenced by groundwater conditions.

It is important to note that the listed flooding incidents in Table 5 are not contemporary; there are no available data beyond the end of October 2000. In addition, until recent years there have been few drivers in place to ensure the systematic recording of flood incidents and their likely cause.

3.3 Areas Susceptible to Groundwater Flooding

The Environment Agency has produced a data set referred to as 'Areas Susceptible to Groundwater Flooding (AStGWF)', on a 1 km grid (Figure 5). This utilises the BGS 1:50,000 Groundwater Flood Susceptibility data set for consolidated aquifers (bedrock) and superficial geology.

The Environment Agency data set shows the percentage of each 1 km square that falls within the high to very high BGS groundwater flooding susceptibility categories. It does not show the

probability / risk of groundwater flooding occurring; this can only be determined following site specific investigation works and desk studies. It also does not take into account groundwater level rebound following cessation of abstraction.

An absence of values for any grid square means that no part of that square is identified as being susceptible to groundwater emergence (Environment Agency AStGWF Guidance Document).

The areas that are identified as being most susceptible to groundwater flooding are located close to the Upper Bristol Avon and River Marden. By comparing the data set with Figure 1 (geological map) it is apparent that those grid squares identified as having an area greater than 50% with high to very high susceptibility to groundwater flooding are those where significant River Terrace Deposits are present.

Flooding incidents 4, 5 and 6 are located in grid squares within the >=25% <50% category, owing to the proximity of Alluvium and River Terrace Deposits adjacent to the Upper Bristol Avon River.

Incident numbers 3 and 7 located on the Cornbrash Formation and Kellaways Sand Member are shown to be in grid squares with no shading, which suggests no susceptibility to groundwater flooding. However, this could indicate that no water level data were available to the BGS when creating the original groundwater flood susceptibility Map. This notwithstanding, it is thought that the approximate areas identified by the Environment Agency as being susceptible to groundwater flooding are sensible.

3.4 Importance of Long Term Groundwater Level Monitoring

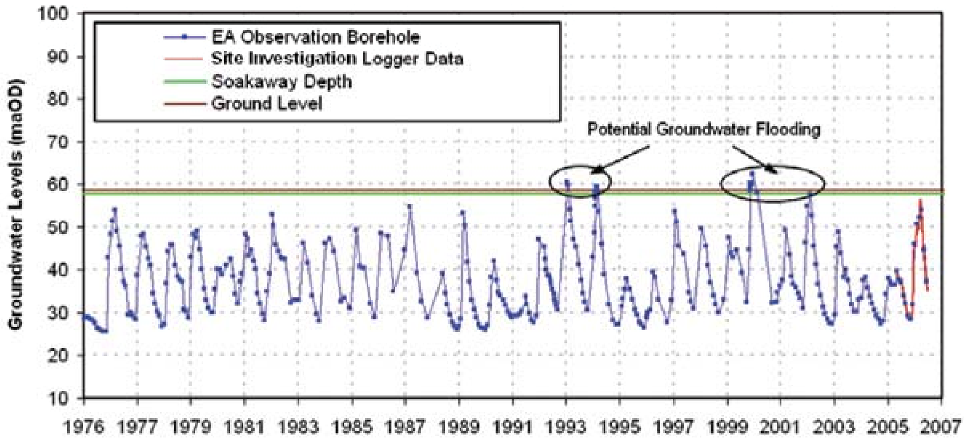
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers, Cornbrash Formation and Kellaways Sand Member are limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

It is not sufficient to rely on the work undertaken by developers through the planning application process, unless long term monitoring (several years) is one of the conditions when granting planning permission. Groundwater levels are often only measured once, or, at most, for a number of weeks. It would be advisable for the Council, in combination with the Environment Agency, to begin long term monitoring of the Cornbrash Formation, Kellaways Sand Member and superficial aquifer groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial flood defences.

It is also important to understand how changing policies relating to infiltration SUDS can impact upon groundwater levels. For example the introduction of infiltration SUDS (e.g. soakaways) may cause a rise in peak groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the Environment Agency owing to its responsibilities under the Water Framework Directive.

Long term groundwater level monitoring is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS.

Schematic demonstrating the importance of long term groundwater level monitoring



4 Water Framework Directive and Infiltration SUDS

The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Thames River Basin District is considered within the current study since infiltration Sustainable Drainage Systems (SUDS) have the potential to impact the water quality and water quantity status of aquifers and surface water courses.

4.1 Current Quantity and Quality Status

The current quantitative assessment for the area South of Malmesbury (Cornbrash Formation aquifer - GB40901G806000) is ‘good’ and the current quality assessment is ‘good’. The quantitative and chemical quality in 2015 is also predicted to be good (Environment Agency, December 2009). The Cornbrash Formation is likely to be suitable for infiltration SUDS and it is important that use of these systems does not have an adverse impact on the status of the aquifer.

There is no equivalent assessment for the River Terrace Gravels or Kellaways Sand Member, which may also be suitable for infiltration SUDS.

4.2 Infiltration SUDS Suitability

Improper use of infiltration SUDS could lead to contamination of the superficial or bedrock geology aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

Environment Agency guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Wiltshire Council when approving or rejecting planning applications.

The areas that may be suitable for infiltration SUDS (e.g. soakaways, permeable paving) exist where there is a combination of higher ground (interfluves) and permeable geology (see Figure 3). However, consideration should be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at the down gradient location. This type of analysis is beyond the scope of the current report.

Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ), which are shown on Figure 3. Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance.

It is understood that the SPZs in the Chippenham area are associated with groundwater abstractions from the Forest Marble Formation and Combe Down Oolite, which are expected to be hydraulically isolated from the aquifers that outcrop in the Chippenham area. This notwithstanding, the developer should present a suitable risk assessment as part of any planning application.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

- The clays of the Forest Marble Formation are expected to hydraulically separate the underlying Combe Down Oolite principal aquifer from the surface aquifers. Therefore, the Combe Down Oolite is not of key interest to the groundwater flooding assessment.
- The key areas of interest are those underlain by Kellaways Sand Member, Cornbrash Formation or River Terrace Deposits (Figure 1). These geological units are expected to behave as aquifers and are likely to contain perched water tables i.e. they are a potential source of groundwater flooding.
- A number of potential groundwater flooding mechanisms have been identified. Key mechanisms are (i) rapid water level fluctuations in the River Terrace Deposits in response to river stage fluctuations (Upper Bristol Avon River), and (ii) response of perched groundwater levels within the Cornbrash Formation and Kallaways Sand Member to increased use of infiltration SUDS, leaking pipes and barriers to groundwater flow such as sheet piling. Properties at greatest risk of flooding are those with basements / cellars.
- Based on the available flood incident data and Environment Agency 'Areas Susceptible to Groundwater Flooding' data set, the areas most susceptible to groundwater flooding are those properties located on River Terrace Deposits, close to the Upper Bristol Avon River.
- The lack of reported groundwater flooding incidents on the Cornbrash Formation and Kellaways Sand Member suggests that whilst a perched aquifer may exist, groundwater levels are sufficiently low and/or there are a lack of receptors (e.g. basements), such that groundwater flooding has not been an issue. However, it is important to note that no groundwater flooding incident data post-2000 were available from the Environment Agency. In addition, increased discharges to these aquifers through infiltration SUDs may lead to future groundwater flooding issues. Therefore, use of infiltration SUDs should be carefully managed.
- The Environment Agency and Council do not currently monitor groundwater levels in the River Terrace Deposits, Kellaways Sand Member or Cornbrash Formation. Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

5.2 Recommendations

The following recommendations are made based on the findings of the current report:

- Data identifying properties with basements / cellars should be collected by Wiltshire Council;
- Site investigation reports for historic development sites could be reviewed to obtain additional groundwater level information, to improve the conceptual understanding of the area;
- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial, pluvial and sewer. An integrated understanding of flood risk will be gained through this exercise;
- Pluvial modelling often assumes that no infiltration of rainfall occurs (a worst case scenario). It is recommended that a sensitivity analysis is undertaken, whereby infiltration is modelled in those areas where permeable superficial geology are located;
- Monitoring boreholes should be installed in the River Terrace Deposits, Cornbrash Formation and the Kellaways Sand Member, fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on infiltration SUDS guidance provided.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered when approving planning applications;
- The impact of infiltration SUDS on groundwater levels (and therefore groundwater risk) should be considered further. This may require the construction of a local groundwater model following collection of groundwater level data.

6 References

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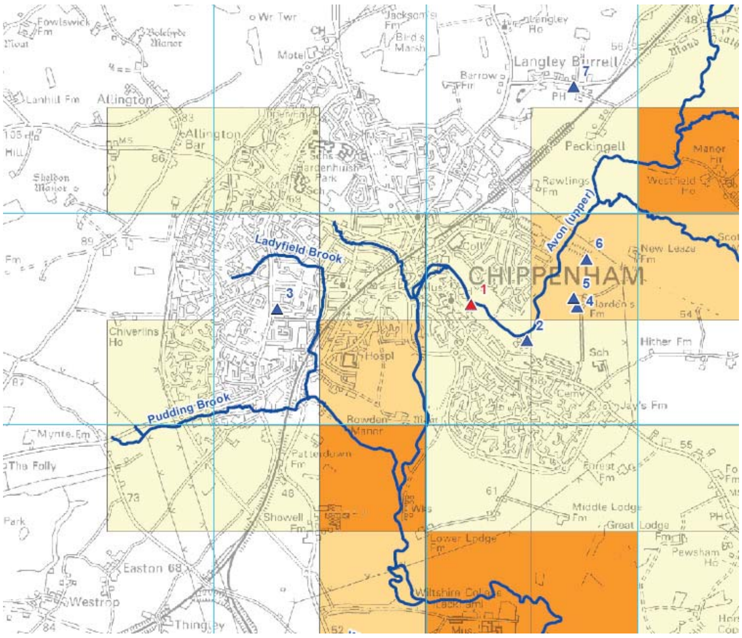
- Scott Wilson, October 2007. North Wiltshire District Council, Strategic Flood Risk Assessment Level 1 Report - Final Report.

Chippenham Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 1 & 2

November 2011



Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility
November 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	26/01/2011	Draft	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
02	01/02/2011	Draft – for client comment only	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
03	November 2011	Final – No client comments following draft			

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Abbreviations

ACRONYM	DEFINITION
AStGWF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
RBMP	River Basement Management Plan
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Interfluve	A ridge or area of land dividing two river valleys.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, under capacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

Groundwater flooding occurs as a result of water rising up from the underlying aquifer or water flowing from groundwater springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by principal aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

Groundwater flooding tends to occur sporadically in both location and time, and tends to last longer than fluvial, pluvial or sewer flooding. Basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

The need to improve the management of groundwater flood risk in the UK was identified through DEFRA's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

Wiltshire Council has commissioned Scott Wilson to complete Phases 1 and 2 of their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Chippenham study area. From this analysis,

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

The Bristol Avon is the major river in the Chippenham area and rises in the Cotswolds to the north west. The river flows south through Chippenham, before flowing west towards Bath and then to its outlet on the Bristol Channel (Scott Wilson, 2007). The Bristol Avon and its tributaries in the area of Chippenham are shown on Figure 1.

Within the Chippenham area, ground levels range from around 50 maOD in the Bristol Avon's valley floodplain to around 120 maOD on the surrounding interfluve areas.

2.2 Geology

Figure 1 provides geological information for Chippenham and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series. Figure 2 provides a geological cross section, which has been used to improve the conceptual understanding of the area. 34 borehole logs were obtained from the BGS to provide local data and their locations are shown in Figure 1.

2.2.1 Bedrock Geology

Within the Chippenham study area, the bedrock geology of interest comprises the Combe Down Oolite, which in turn is overlain by the Forest Marble Formation, Cornbrash Formation, Kellaways Formation (Kellaways Sand Member overlying Kellaways Clay Member), and the Oxford Clay Formation. Additional details are provided in Table 1.

The Kellaways Formation and the Cornbrash Formation comprise the majority of the outcrop (surface) geology in the area of interest. In the north east of the Chippenham study area there is a significant outcrop of Kellaways Sand Member, which is found at the top of the Kellaways Formation.

The Forest Marble Formation outcrops at surface at a number of smaller localities in the centre and to the north west of the Chippenham study area, where the overlying Cornbrash Formation has been eroded away and superficial geology are absent.

There is geological faulting in the Chippenham area as shown by Figure 1. A laterally extensive fault runs from the north west (near to Kingstone St Michael) to the south east of Chippenham.

Table 1: Bedrock geology of significance to the study

Geological Units		Description	Thickness*
Ancholme Group	Oxford Clay Formation	Mudstone	Up to 150 m
	Kellaways Sand Member	Horizon at top of Kellaways Formation. Interbedded siltstone & sandstone	Up to 4 m
	Kellaways Clay Member	Mudstone	Up to 28 m
Great Oolite Group	Cornbrash Formation	Fine grained shelly limestone with thin clays and marls. Typically rubbly at the base but more sandy and better bedded in the upper part.	Up to 5 m
	Forest Marble Formation	Mudstone with impersistent band of shelly limestone. Acton Turville Beds (mainly limestone) at base.	Up to 35 m
	Combe Down Oolite	Limestone	Logs suggest 25 m
	Fullers Earth (grouped for simplicity)	Clay with chalky white limestone and Fullers Earth Rock beds	>28 m

*Thickness from The properties for secondary aquifers in England and Wales (Jones et al., 2000), Table 6.6 page 91.

2.2.2 Superficial Geology

The superficial geology of the area consists of Alluvium, Head, River Terrace Deposits, and Alluvial Fan Deposits.

In the majority of the study area, superficial geology is not present. However, in the valley of the Upper Bristol Avon River there are significant River Terrace Deposits (sand and gravel). The thickness of River Terrace Deposits to the south of Chippenham is indicated to be around 1 to 1.4 m thick by borehole logs ST97SW1, ST97SW9 and ST97SW156 (See Figure 1 for locations).

In the Upper Bristol Avon's floodplain and some of its tributaries there are deposits of Alluvium (clay, silt, sand & gravel), which in places overlie the River Terrace Deposits. Borehole logs ST97SW156 & ST97SW59 indicate that to the south of Chippenham near to the Upper Bristol Avon River the Alluvium deposits are around 1.2 to 4 m thick. The logs suggest that in this area the Alluvium has a high clay content mixed with sand and gravel.

To the east and west of the Chippenham study area there are small deposits of Head. These comprise a mixture of clay, silt, sand & gravel.

To the south of Chippenham, away from developed areas, there exist Alluvial Fan Deposits on the Kellaways and Oxford Clay Formations. The Alluvial Fan Deposits are expected to consist of a mixture of clay, silt, sand & gravel, but there are no logs to confirm their thickness or lithology.

2.3 Hydrogeology

The hydrogeological significance of the various geological units within the study area is provided in Table 2. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 2 and is shown in Figure 3.

Table 2: Geological Units in the study area and their hydrogeological significance

Geological Units		Expected Permeability Based on geological data	Hydrogeological Significance
Superficial Geology	River Terrace Deposits (Sand & Gravel)	High	Secondary A aquifer
	Head Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
	Alluvium	Low to Moderate	Variable but classified as secondary aquifer
	Alluvial Fan Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
Bedrock Geology	Oxford Clay Formation	Low	Aquiclude
	Kellaways Sand Member	Moderate to High	Secondary A aquifer
	Kellaways Clay Member	Low	Aquiclude
	Cornbrash Formation	Moderate to High	Secondary A aquifer
	Forest Marble Formation	Low to Moderate (mudstone) Moderate to High (limestone)	Aquiclude, although a lower limestone unit is expected to behave as an aquifer.
	Combe Down Oolite	High	Principal aquifer
	Fullers Earth (grouped for simplicity)	Low to Moderate	Variable but classified as Secondary aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale (EA website, 2010).
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers (EA website, 2010).

2.3.1 Bedrock Geology

The Oxford Clay Formation and the Kellaways Clay Member are aquicludes and do not permit groundwater flow. They are classified as unproductive strata.

The Kellaways Sand Member, found at the top of the Kellaways Formation is considered to have a high permeability due to its sand content. There is potential for localised perched water tables in this horizon due to the outcrop at surface and the underlying impermeable Kellaways Clay Member. Therefore the Kellaways Sand Member is of interest to the current study.

The Forest Marble Formation generally has a low permeability in the middle and upper horizons due to a high clay content, although the basal horizon is mostly limestone facies, which are water bearing (also referred to as Acton Turville Beds).

The Cornbrash Formation is classified as a secondary A aquifer (water bearing) and rests above the Forest Marble Formation. The thin aquifer is typically hydraulically separated from the Combe Down Oolite aquifer (Table 2) by the clays in the Forest Marble Formation. This scenario is expected to lead to the development of a perched water table in the Cornbrash Formation. Therefore, the Cornbrash Formation is of interest to this study because it outcrops at surface over much of the study area.

The Combe Down Oolite underlies the Forest Marble Formation and is classified as a principal aquifer. The Forest Marble Formation confines the Combe Down Oolite aquifer in the Chippenham area and therefore the Combe Down Oolite aquifer is not pertinent to the current study.

2.3.2 Superficial Geology

The hydrogeological significance of the Alluvium in the river valleys is expected to be variable, although locally it may behave as an aquifer where the sand and gravel content is high.

Head and Alluvial Fan Deposits are expected to behave as an aquitard, although sand horizons may locally form a secondary aquifer depending on their lateral extent and thickness.

The gravely River Terrace Deposits are expected to behave as a secondary A aquifer and are of interest to the current study.

2.3.3 Bedrock Groundwater Levels

Cornbrash Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Cornbrash Formation. However, Table 3 presents water level data from three BGS borehole logs. Whilst it is important to note that the data is not recent and does not show seasonal fluctuations, it does indicate that a perched water table exists within the thin Formation and is close to ground level in places. The locations of the boreholes identified within Table 3 are shown on Figure 1.

Table 3: Water levels in the Cornbrash Formation obtained from BGS logs

Borehole Reference	Approximate Location	Water Level (mbgl)	Date of record	Base of Cornbrash below GL (m)
ST97SW37	Central Chippenham	1.85	5/02/1988	4
ST97SW204	NW of Chippenham	1.6	1/09/1993	2.7
ST97SW13	SW of Chippenham	0.84	1937	4.5

'mbgl' – meters below ground level.
'GL' – Ground Level; 'NW' – north west; 'SW' - southwest

The Ladyfield Brook and Pudding Brook probably receive groundwater inflow (baseflow) from the Cornbrash Formation. However, there are no available data to confirm groundwater / surface water interactions.

Forest Marble Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Forest Marble Formation. Whilst the lower Forest Marble Formation is water bearing, development of groundwater resources appears to have targeted the deeper and more permeable Combe Down Oolite. However, certain boreholes have been constructed to receive water from both horizons. There may be a degree of hydraulic continuity between the lower Forest Marble Formation and the Combe Down Oolite. BGS borehole log ST97SW13 indicates that in 1937 the water level was at 14.71 m below ground level to the south west of Chippenham.

Combe Down Oolite

Groundwater level data associated with five boreholes has been obtained from the Environmental Agency for the Chippenham area. The borehole locations are shown in Figure 4 and the water levels are presented in Appendix 1. The borehole water level records show that:

- Season fluctuations in the Combe Down Oolite range between 5 to 15 metres as shown by the hydrograph for Arlington Number 1 and Number 2, located to the north west of Chippenham and away from groundwater abstractions.
- The piezometric water level in the Combe Down Oolite can be at or close to ground level during the peak period of winter recharge (December to April). This is evident at Arlington during the particularly wet years of 1994/95 and 2000/01.
- Piezometric water levels in the Combe Down Oolite to the south of Chippenham, close to the Upper Bristol Avon River can be close to or above ground level (artesian) as shown by the hydrograph for Lacock number 2.

Despite piezometric levels within the Combe Down Oolite being at or close to ground level, the overlying clay horizons prevent groundwater flooding from this aquifer.

2.3.4 Superficial Geology Groundwater Levels

The Environment Agency does not monitor groundwater levels in the superficial geology. However, two of the BGS borehole logs (Table 4) indicate a water level of around 3.1 to 3.3 m below ground level in the Chippenham area. Whilst there are no recent water levels it would appear that the River Terrace Deposits form a perched aquifer over the Kellaways Clay Member.

Table 4: Water levels in the River Terrace Deposits obtained from BGS logs

Borehole Name	Approximate Location	Water Level (mbgl)	Date of record	Overlain by Alluvium
ST97SW59	Central Chippenham	3.3	23/06/1994	Yes
ST97SW24	Central Chippenham	3.1	14/07/1986	Yes

'mbgl' – meters below ground level

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

River flow and stage data were requested from the Environment Agency. The Stanley station monitors both the river stage and flow of the River Marden to the east of Chippenham (Figure 4). However, the data are not relevant to the current study as the River Marden, upstream of the gauging station, is not in hydraulic continuity with the aquifers in the study area.

In the Chippenham area, bedrock geology groundwater / surface water interactions along the Upper Bristol Avon River will be limited due to the underlying Kellaways Clay Member. However, tributaries such as the Ladyfield Brook, Pudding Brook and Chissell Brook are expected to receive groundwater from the Cornbrash Formation and Kellaway Sands Member.

With regards to superficial geology groundwater / surface water interactions, it is likely that there is some hydraulic continuity between the perched aquifer within the River Terrace Deposits and the Upper Bristol Avon River.

Unfortunately there are no continuous or recent groundwater level data for the aquifers of interest, or stage data for the surface water courses in Chippenham, and therefore it is not possible to gain a more informed understanding of groundwater / surface water interactions.

2.3.6 Abstractions and Discharges

The location of groundwater and surface water abstractions and discharge permits were requested from the Environment Agency (Figure 4). The larger abstractions (e.g. public water supply) are not shown for confidentiality reasons.

Within the Chippenham area there are many small groundwater abstraction licences (<20 m^3/day) and only three of significant volume. There are two agricultural abstractions located around 2 km north east and 2 km south of the town centre, licensed to abstract 27375 m^3/year and 5000 m^3/year, respectively. It is not clear which geological formation the boreholes abstract from.

The third licence is located approximately 4-5 km to the south of Chippenham, allowing 3320000 m^3/year to be abstracted. Again, it is not clear which formation this abstraction occurs from, but it is likely to be the Combe Down Oolite.

Figure 4 identifies many discharge permits within the Chippenham study area. Whilst it is not identified whether these are to ground or surface water, the plotted locations infer that the majority are to surface water courses.

2.3.7 Artificial Groundwater Recharge

Water mains leakage data for the Chippenham area were not provided for this study. It should be noted that additional recharge to perched groundwater tables by leaking mains could result in a local rise in groundwater levels. This rise might not prove significant under dry conditions, but could exacerbate the risk of groundwater flooding following periods of heavy rainfall.

The drainage/sewer network can act as a further source of artificial recharge. When pipes are installed within principal or secondary aquifers, the groundwater and drainage network may be in partial hydraulic connection. When pipes are empty, groundwater may leak into the drainage network with water flowing in through cracks and porous walls, draining the aquifer and reducing groundwater levels. During periods of heavy rainfall when pipes are full, leaking pipes can act as recharge points, artificially recharging the groundwater table and subsequently increasing groundwater levels with potential impacts on groundwater quality.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the Chippenham study area. The key groundwater flooding mechanisms that may exist are:

- **Cornbrash Formation outcrop area in central and west Chippenham:** The available datasets indicate that a perched groundwater table exists within the Cornbrash Formation. Due to the permeable but thin nature of this Formation, basements / cellars and other underground structures may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of infiltration SUDs and / or artificial recharge from leaking pipes.
- **Kellaways Sand Member outcrop area in north east Chippenham:** There is potential for a perched groundwater table to exist within the Kellaways Sand Member. Due to the permeable but thin nature of this aquifer, basements / cellars and other underground structures may be at risk from prolonged groundwater flooding from periods of prolonged rainfall, increased utilisation of SUDs and / or artificial recharge from leaking pipes.
- **Superficial geology aquifers in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding may be associated with the substantial sand and gravel River Terrace Deposits, or to a lesser degree Alluvium, where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain “in-bank”, and this can trigger a rise in groundwater levels in the associated superficial geology. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial geology.
- **Superficial aquifers not in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding is also associated with substantial River Terrace Deposits (gravel and sand), Alluvial Fan Deposits and Head deposits, but occurs where they are not in immediate hydraulically connection with surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.
- **Impermeable (silt and clay) areas downslope of aquifer outcrop (various locations):** Groundwater flooding may occur where groundwater springs / seepages form minor flows and ponding over impermeable strata where there is poor drainage. This mechanism may occur as a result of natural (e.g. rainfall) or artificial (e.g. water main leakage) recharge.
- **Uncapped boreholes drilled into the Combe Down Oolite:** The piezometric levels within the Combe Down Oolite are at or close to ground level following sustained wet periods, although overlying clay horizons prevent groundwater flooding from this aquifer. However, uncapped boreholes would provide an artificial pathway for groundwater to flow to surface and cause groundwater flooding.

3.2 Evidence of Groundwater Flooding

Figures 1, 3, 4 and 5 show the location of one historic groundwater flooding incident that was identified by the Environment Agency. The Figures also show the locations of another six flooding incidents that may have been influenced by groundwater conditions, but have been identified as either fluvial or pluvial flooding. These flooding incidents have also been considered by this study, as it is often difficult to identify the cause of a flooding incident. Details of the reported incidents are shown in Table 5, including the local geology and the date of the reported incident.

Table 5: Selected flooding incidents

Geological Units*	Grid Reference	No**	Reported Incident	Date
Cornbrash Formation / River Terrace Deposits	ST 92428 73140	1	Groundwater flooding – no other comment	30/10/2000
Cornbrash Formation / River Terrace Deposits	ST 92960 72800	2	Fluvial flooding – no other comment	12/04/1960
Cornbrash Formation	ST 90605 73101	3	Fluvial flooding – no other comment	12/01/1979
Kellaways Clay Member / River Terrace Deposits	ST 93430 73120	4	Surface Water flooding – no other comment	12/04/1960
	ST 93400 73200	5	Surface Water flooding – no other comment	03/06/1978
	ST 93520 73570	6	Surface Water flooding – no other comment	12/04/1960
Kellaways Sand Member	ST 93400 75200	7	Surface Water flooding – no other comment	03/06/1978

Note: * Geology of incident based on plotted location on Figures 1 & 4.

** Reference number as shown on Figures 1, 3, 4 & 5.

Based on Figure 1, the hydrogeological situation of incidents 1, 2, 4, 5 and 6 are similar, although only incident 1 is listed as a groundwater flooding incident. These locations are shown to be on a shallow aquifer (Cornbrash Formation / River Terrace Deposits) where groundwater levels are likely to be influenced by the Upper Bristol Avon River but also rainfall runoff from the impermeable Kellaways Clay Member on higher ground.

Figure 1 shows that locations 3 and 7 are both located on shallow aquifers but do not appear to be close to any surface water courses. It is plausible that these two flooding incidents were influenced by groundwater conditions.

It is important to note that the listed flooding incidents in Table 5 are not contemporary; there are no available data beyond the end of October 2000. In addition, until recent years there have been few drivers in place to ensure the systematic recording of flood incidents and their likely cause.

3.3 Areas Susceptible to Groundwater Flooding

The Environment Agency has produced a data set referred to as 'Areas Susceptible to Groundwater Flooding (AStGWF)', on a 1 km grid (Figure 5). This utilises the BGS 1:50,000 Groundwater Flood Susceptibility data set for consolidated aquifers (bedrock) and superficial geology.

The Environment Agency data set shows the percentage of each 1 km square that falls within the high to very high BGS groundwater flooding susceptibility categories. It does not show the

probability / risk of groundwater flooding occurring; this can only be determined following site specific investigation works and desk studies. It also does not take into account groundwater level rebound following cessation of abstraction.

An absence of values for any grid square means that no part of that square is identified as being susceptible to groundwater emergence (Environment Agency AStGWF Guidance Document).

The areas that are identified as being most susceptible to groundwater flooding are located close to the Upper Bristol Avon and River Marden. By comparing the data set with Figure 1 (geological map) it is apparent that those grid squares identified as having an area greater than 50% with high to very high susceptibility to groundwater flooding are those where significant River Terrace Deposits are present.

Flooding incidents 4, 5 and 6 are located in grid squares within the >=25% <50% category, owing to the proximity of Alluvium and River Terrace Deposits adjacent to the Upper Bristol Avon River.

Incident numbers 3 and 7 located on the Cornbrash Formation and Kellaways Sand Member are shown to be in grid squares with no shading, which suggests no susceptibility to groundwater flooding. However, this could indicate that no water level data were available to the BGS when creating the original groundwater flood susceptibility Map. This notwithstanding, it is thought that the approximate areas identified by the Environment Agency as being susceptible to groundwater flooding are sensible.

3.4 Importance of Long Term Groundwater Level Monitoring

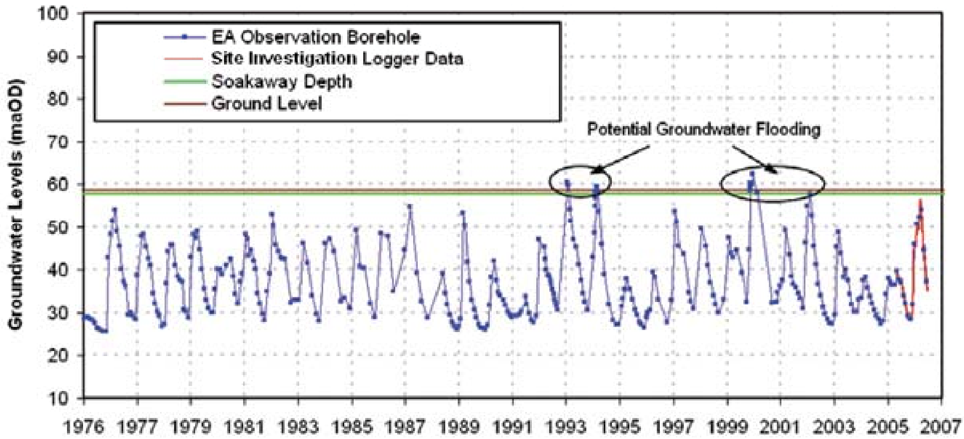
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers, Cornbrash Formation and Kellaways Sand Member are limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

It is not sufficient to rely on the work undertaken by developers through the planning application process, unless long term monitoring (several years) is one of the conditions when granting planning permission. Groundwater levels are often only measured once, or, at most, for a number of weeks. It would be advisable for the Council, in combination with the Environment Agency, to begin long term monitoring of the Cornbrash Formation, Kellaways Sand Member and superficial aquifer groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial flood defences.

It is also important to understand how changing policies relating to infiltration SUDS can impact upon groundwater levels. For example the introduction of infiltration SUDS (e.g. soakaways) may cause a rise in peak groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the Environment Agency owing to its responsibilities under the Water Framework Directive.

Long term groundwater level monitoring is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS.

Schematic demonstrating the importance of long term groundwater level monitoring



4 Water Framework Directive and Infiltration SUDS

The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Thames River Basin District is considered within the current study since infiltration Sustainable Drainage Systems (SUDS) have the potential to impact the water quality and water quantity status of aquifers and surface water courses.

4.1 Current Quantity and Quality Status

The current quantitative assessment for the area South of Malmesbury (Cornbrash Formation aquifer - GB40901G806000) is 'good' and the current quality assessment is 'good'. The quantitative and chemical quality in 2015 is also predicted to be good (Environment Agency, December 2009). The Cornbrash Formation is likely to be suitable for infiltration SUDS and it is important that use of these systems does not have an adverse impact on the status of the aquifer.

There is no equivalent assessment for the River Terrace Gravels or Kellaways Sand Member, which may also be suitable for infiltration SUDS.

4.2 Infiltration SUDS Suitability

Improper use of infiltration SUDS could lead to contamination of the superficial or bedrock geology aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

Environment Agency guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Wiltshire Council when approving or rejecting planning applications.

The areas that may be suitable for infiltration SUDS (e.g. soakaways, permeable paving) exist where there is a combination of higher ground (interfluves) and permeable geology (see Figure 3). However, consideration should be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at the down gradient location. This type of analysis is beyond the scope of the current report.

Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ), which are shown on Figure 3. Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance.

It is understood that the SPZs in the Chippenham area are associated with groundwater abstractions from the Forest Marble Formation and Combe Down Oolite, which are expected to be hydraulically isolated from the aquifers that outcrop in the Chippenham area. This notwithstanding, the developer should present a suitable risk assessment as part of any planning application.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

- The clays of the Forest Marble Formation are expected to hydraulically separate the underlying Combe Down Oolite principal aquifer from the surface aquifers. Therefore, the Combe Down Oolite is not of key interest to the groundwater flooding assessment.
- The key areas of interest are those underlain by Kellaways Sand Member, Cornbrash Formation or River Terrace Deposits (Figure 1). These geological units are expected to behave as aquifers and are likely to contain perched water tables i.e. they are a potential source of groundwater flooding.
- A number of potential groundwater flooding mechanisms have been identified. Key mechanisms are (i) rapid water level fluctuations in the River Terrace Deposits in response to river stage fluctuations (Upper Bristol Avon River), and (ii) response of perched groundwater levels within the Cornbrash Formation and Kallaways Sand Member to increased use of infiltration SUDS, leaking pipes and barriers to groundwater flow such as sheet piling. Properties at greatest risk of flooding are those with basements / cellars.
- Based on the available flood incident data and Environment Agency 'Areas Susceptible to Groundwater Flooding' data set, the areas most susceptible to groundwater flooding are those properties located on River Terrace Deposits, close to the Upper Bristol Avon River.
- The lack of reported groundwater flooding incidents on the Cornbrash Formation and Kellaways Sand Member suggests that whilst a perched aquifer may exist, groundwater levels are sufficiently low and/or there are a lack of receptors (e.g. basements), such that groundwater flooding has not been an issue. However, it is important to note that no groundwater flooding incident data post-2000 were available from the Environment Agency. In addition, increased discharges to these aquifers through infiltration SUDs may lead to future groundwater flooding issues. Therefore, use of infiltration SUDs should be carefully managed.
- The Environment Agency and Council do not currently monitor groundwater levels in the River Terrace Deposits, Kellaways Sand Member or Cornbrash Formation. Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

5.2 Recommendations

The following recommendations are made based on the findings of the current report:

- Data identifying properties with basements / cellars should be collected by Wiltshire Council;
- Site investigation reports for historic development sites could be reviewed to obtain additional groundwater level information, to improve the conceptual understanding of the area;
- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial, pluvial and sewer. An integrated understanding of flood risk will be gained through this exercise;
- Pluvial modelling often assumes that no infiltration of rainfall occurs (a worst case scenario). It is recommended that a sensitivity analysis is undertaken, whereby infiltration is modelled in those areas where permeable superficial geology are located;
- Monitoring boreholes should be installed in the River Terrace Deposits, Cornbrash Formation and the Kellaways Sand Member, fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on infiltration SUDS guidance provided.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered when approving planning applications;
- The impact of infiltration SUDS on groundwater levels (and therefore groundwater risk) should be considered further. This may require the construction of a local groundwater model following collection of groundwater level data.

6 References

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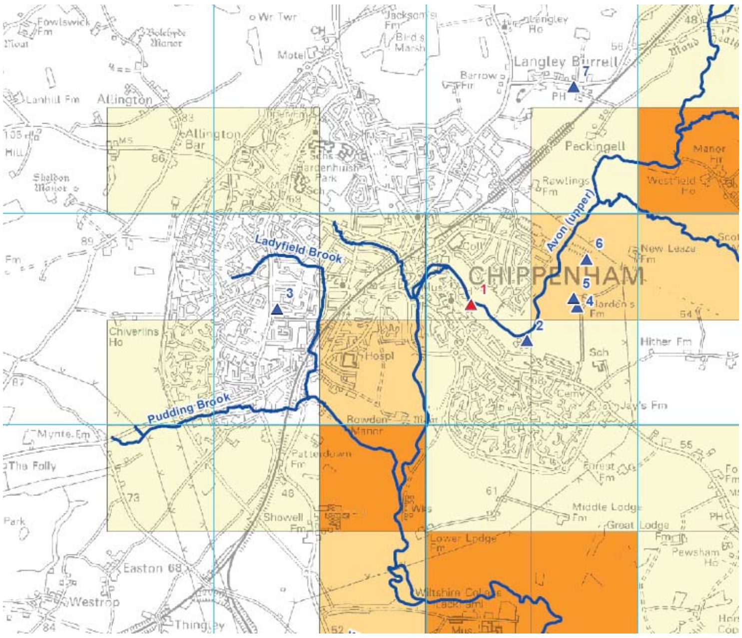
Chippenham Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 1 & 2

November 2011



Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility
November 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	26/01/2011	Draft	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
02	01/02/2011	Draft – for client comment only	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
03	November 2011	Final – No client comments following draft			

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Abbreviations

ACRONYM	DEFINITION
AStGWF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
RBMP	River Basement Management Plan
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Interfluve	A ridge or area of land dividing two river valleys.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, under capacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

Groundwater flooding occurs as a result of water rising up from the underlying aquifer or water flowing from groundwater springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by principal aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

Groundwater flooding tends to occur sporadically in both location and time, and tends to last longer than fluvial, pluvial or sewer flooding. Basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

The need to improve the management of groundwater flood risk in the UK was identified through DEFRA's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

Wiltshire Council has commissioned Scott Wilson to complete Phases 1 and 2 of their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Chippenham study area. From this analysis,

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

The Bristol Avon is the major river in the Chippenham area and rises in the Cotswolds to the north west. The river flows south through Chippenham, before flowing west towards Bath and then to its outlet on the Bristol Channel (Scott Wilson, 2007). The Bristol Avon and its tributaries in the area of Chippenham are shown on Figure 1.

Within the Chippenham area, ground levels range from around 50 maOD in the Bristol Avon's valley floodplain to around 120 maOD on the surrounding interfluve areas.

2.2 Geology

Figure 1 provides geological information for Chippenham and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series. Figure 2 provides a geological cross section, which has been used to improve the conceptual understanding of the area. 34 borehole logs were obtained from the BGS to provide local data and their locations are shown in Figure 1.

2.2.1 Bedrock Geology

Within the Chippenham study area, the bedrock geology of interest comprises the Combe Down Oolite, which in turn is overlain by the Forest Marble Formation, Cornbrash Formation, Kellaways Formation (Kellaways Sand Member overlying Kellaways Clay Member), and the Oxford Clay Formation. Additional details are provided in Table 1.

The Kellaways Formation and the Cornbrash Formation comprise the majority of the outcrop (surface) geology in the area of interest. In the north east of the Chippenham study area there is a significant outcrop of Kellaways Sand Member, which is found at the top of the Kellaways Formation.

The Forest Marble Formation outcrops at surface at a number of smaller localities in the centre and to the north west of the Chippenham study area, where the overlying Cornbrash Formation has been eroded away and superficial geology are absent.

There is geological faulting in the Chippenham area as shown by Figure 1. A laterally extensive fault runs from the north west (near to Kingstone St Michael) to the south east of Chippenham.

Table 1: Bedrock geology of significance to the study

Geological Units		Description	Thickness*
Ancholme Group	Oxford Clay Formation	Mudstone	Up to 150 m
	Kellaways Sand Member	Horizon at top of Kellaways Formation. Interbedded siltstone & sandstone	Up to 4 m
	Kellaways Clay Member	Mudstone	Up to 28 m
Great Oolite Group	Cornbrash Formation	Fine grained shelly limestone with thin clays and marls. Typically rubbly at the base but more sandy and better bedded in the upper part.	Up to 5 m
	Forest Marble Formation	Mudstone with impersistent band of shelly limestone. Acton Turville Beds (mainly limestone) at base.	Up to 35 m
	Combe Down Oolite	Limestone	Logs suggest 25 m
	Fullers Earth (grouped for simplicity)	Clay with chalky white limestone and Fullers Earth Rock beds	>28 m

*Thickness from The properties for secondary aquifers in England and Wales (Jones et al., 2000), Table 6.6 page 91.

2.2.2 Superficial Geology

The superficial geology of the area consists of Alluvium, Head, River Terrace Deposits, and Alluvial Fan Deposits.

In the majority of the study area, superficial geology is not present. However, in the valley of the Upper Bristol Avon River there are significant River Terrace Deposits (sand and gravel). The thickness of River Terrace Deposits to the south of Chippenham is indicated to be around 1 to 1.4 m thick by borehole logs ST97SW1, ST97SW9 and ST97SW156 (See Figure 1 for locations).

In the Upper Bristol Avon's floodplain and some of its tributaries there are deposits of Alluvium (clay, silt, sand & gravel), which in places overlie the River Terrace Deposits. Borehole logs ST97SW156 & ST97SW59 indicate that to the south of Chippenham near to the Upper Bristol Avon River the Alluvium deposits are around 1.2 to 4 m thick. The logs suggest that in this area the Alluvium has a high clay content mixed with sand and gravel.

To the east and west of the Chippenham study area there are small deposits of Head. These comprise a mixture of clay, silt, sand & gravel.

To the south of Chippenham, away from developed areas, there exist Alluvial Fan Deposits on the Kellaways and Oxford Clay Formations. The Alluvial Fan Deposits are expected to consist of a mixture of clay, silt, sand & gravel, but there are no logs to confirm their thickness or lithology.

2.3 Hydrogeology

The hydrogeological significance of the various geological units within the study area is provided in Table 2. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 2 and is shown in Figure 3.

Table 2: Geological Units in the study area and their hydrogeological significance

Geological Units		Expected Permeability Based on geological data	Hydrogeological Significance
Superficial Geology	River Terrace Deposits (Sand & Gravel)	High	Secondary A aquifer
	Head Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
	Alluvium	Low to Moderate	Variable but classified as secondary aquifer
	Alluvial Fan Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
Bedrock Geology	Oxford Clay Formation	Low	Aquiclude
	Kellaways Sand Member	Moderate to High	Secondary A aquifer
	Kellaways Clay Member	Low	Aquiclude
	Cornbrash Formation	Moderate to High	Secondary A aquifer
	Forest Marble Formation	Low to Moderate (mudstone) Moderate to High (limestone)	Aquiclude, although a lower limestone unit is expected to behave as an aquifer.
	Combe Down Oolite	High	Principal aquifer
	Fullers Earth (grouped for simplicity)	Low to Moderate	Variable but classified as Secondary aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale (EA website, 2010).
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers (EA website, 2010).

2.3.1 Bedrock Geology

The Oxford Clay Formation and the Kellaways Clay Member are aquicludes and do not permit groundwater flow. They are classified as unproductive strata.

The Kellaways Sand Member, found at the top of the Kellaways Formation is considered to have a high permeability due to its sand content. There is potential for localised perched water tables in this horizon due to the outcrop at surface and the underlying impermeable Kellaways Clay Member. Therefore the Kellaways Sand Member is of interest to the current study.

The Forest Marble Formation generally has a low permeability in the middle and upper horizons due to a high clay content, although the basal horizon is mostly limestone facies, which are water bearing (also referred to as Acton Turville Beds).

The Cornbrash Formation is classified as a secondary A aquifer (water bearing) and rests above the Forest Marble Formation. The thin aquifer is typically hydraulically separated from the Combe Down Oolite aquifer (Table 2) by the clays in the Forest Marble Formation. This scenario is expected to lead to the development of a perched water table in the Cornbrash Formation. Therefore, the Cornbrash Formation is of interest to this study because it outcrops at surface over much of the study area.

The Combe Down Oolite underlies the Forest Marble Formation and is classified as a principal aquifer. The Forest Marble Formation confines the Combe Down Oolite aquifer in the Chippenham area and therefore the Combe Down Oolite aquifer is not pertinent to the current study.

2.3.2 Superficial Geology

The hydrogeological significance of the Alluvium in the river valleys is expected to be variable, although locally it may behave as an aquifer where the sand and gravel content is high.

Head and Alluvial Fan Deposits are expected to behave as an aquitard, although sand horizons may locally form a secondary aquifer depending on their lateral extent and thickness.

The gravely River Terrace Deposits are expected to behave as a secondary A aquifer and are of interest to the current study.

2.3.3 Bedrock Groundwater Levels

Cornbrash Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Cornbrash Formation. However, Table 3 presents water level data from three BGS borehole logs. Whilst it is important to note that the data is not recent and does not show seasonal fluctuations, it does indicate that a perched water table exists within the thin Formation and is close to ground level in places. The locations of the boreholes identified within Table 3 are shown on Figure 1.

Table 3: Water levels in the Cornbrash Formation obtained from BGS logs

Borehole Reference	Approximate Location	Water Level (mbgl)	Date of record	Base of Cornbrash below GL (m)
ST97SW37	Central Chippenham	1.85	5/02/1988	4
ST97SW204	NW of Chippenham	1.6	1/09/1993	2.7
ST97SW13	SW of Chippenham	0.84	1937	4.5

'mbgl' – meters below ground level.
'GL' – Ground Level; 'NW' – north west; 'SW' - southwest

The Ladyfield Brook and Pudding Brook probably receive groundwater inflow (baseflow) from the Cornbrash Formation. However, there are no available data to confirm groundwater / surface water interactions.

Forest Marble Formation

There is no monitoring of groundwater levels undertaken by the Environment Agency in the Forest Marble Formation. Whilst the lower Forest Marble Formation is water bearing, development of groundwater resources appears to have targeted the deeper and more permeable Combe Down Oolite. However, certain boreholes have been constructed to receive water from both horizons. There may be a degree of hydraulic continuity between the lower Forest Marble Formation and the Combe Down Oolite. BGS borehole log ST97SW13 indicates that in 1937 the water level was at 14.71 m below ground level to the south west of Chippenham.

Combe Down Oolite

Groundwater level data associated with five boreholes has been obtained from the Environmental Agency for the Chippenham area. The borehole locations are shown in Figure 4 and the water levels are presented in Appendix 1. The borehole water level records show that:

- Season fluctuations in the Combe Down Oolite range between 5 to 15 metres as shown by the hydrograph for Arlington Number 1 and Number 2, located to the north west of Chippenham and away from groundwater abstractions.
- The piezometric water level in the Combe Down Oolite can be at or close to ground level during the peak period of winter recharge (December to April). This is evident at Arlington during the particularly wet years of 1994/95 and 2000/01.
- Piezometric water levels in the Combe Down Oolite to the south of Chippenham, close to the Upper Bristol Avon River can be close to or above ground level (artesian) as shown by the hydrograph for Lacock number 2.

Despite piezometric levels within the Combe Down Oolite being at or close to ground level, the overlying clay horizons prevent groundwater flooding from this aquifer.

2.3.4 Superficial Geology Groundwater Levels

The Environment Agency does not monitor groundwater levels in the superficial geology. However, two of the BGS borehole logs (Table 4) indicate a water level of around 3.1 to 3.3 m below ground level in the Chippenham area. Whilst there are no recent water levels it would appear that the River Terrace Deposits form a perched aquifer over the Kellaways Clay Member.

Table 4: Water levels in the River Terrace Deposits obtained from BGS logs

Borehole Name	Approximate Location	Water Level (mbgl)	Date of record	Overlain by Alluvium
ST97SW59	Central Chippenham	3.3	23/06/1994	Yes
ST97SW24	Central Chippenham	3.1	14/07/1986	Yes

‘mbgl’ – meters below ground level

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

River flow and stage data were requested from the Environment Agency. The Stanley station monitors both the river stage and flow of the River Marden to the east of Chippenham (Figure 4). However, the data are not relevant to the current study as the River Marden, upstream of the gauging station, is not in hydraulic continuity with the aquifers in the study area.

In the Chippenham area, bedrock geology groundwater / surface water interactions along the Upper Bristol Avon River will be limited due to the underlying Kellaways Clay Member. However, tributaries such as the Ladyfield Brook, Pudding Brook and Chissell Brook are expected to receive groundwater from the Cornbrash Formation and Kellaway Sands Member.

With regards to superficial geology groundwater / surface water interactions, it is likely that there is some hydraulic continuity between the perched aquifer within the River Terrace Deposits and the Upper Bristol Avon River.

Unfortunately there are no continuous or recent groundwater level data for the aquifers of interest, or stage data for the surface water courses in Chippenham, and therefore it is not possible to gain a more informed understanding of groundwater / surface water interactions.

2.3.6 Abstractions and Discharges

The location of groundwater and surface water abstractions and discharge permits were requested from the Environment Agency (Figure 4). The larger abstractions (e.g. public water supply) are not shown for confidentiality reasons.

Within the Chippenham area there are many small groundwater abstraction licences (<20 m^3/day) and only three of significant volume. There are two agricultural abstractions located around 2 km north east and 2 km south of the town centre, licensed to abstract 27375 m^3/year and 5000 m^3/year, respectively. It is not clear which geological formation the boreholes abstract from.

The third licence is located approximately 4-5 km to the south of Chippenham, allowing 3320000 m^3/year to be abstracted. Again, it is not clear which formation this abstraction occurs from, but it is likely to be the Combe Down Oolite.

Figure 4 identifies many discharge permits within the Chippenham study area. Whilst it is not identified whether these are to ground or surface water, the plotted locations infer that the majority are to surface water courses.

2.3.7 Artificial Groundwater Recharge

Water mains leakage data for the Chippenham area were not provided for this study. It should be noted that additional recharge to perched groundwater tables by leaking mains could result in a local rise in groundwater levels. This rise might not prove significant under dry conditions, but could exacerbate the risk of groundwater flooding following periods of heavy rainfall.

The drainage/sewer network can act as a further source of artificial recharge. When pipes are installed within principal or secondary aquifers, the groundwater and drainage network may be in partial hydraulic connection. When pipes are empty, groundwater may leak into the drainage network with water flowing in through cracks and porous walls, draining the aquifer and reducing groundwater levels. During periods of heavy rainfall when pipes are full, leaking pipes can act as recharge points, artificially recharging the groundwater table and subsequently increasing groundwater levels with potential impacts on groundwater quality.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the Chippenham study area. The key groundwater flooding mechanisms that may exist are:

- **Cornbrash Formation outcrop area in central and west Chippenham:** The available datasets indicate that a perched groundwater table exists within the Cornbrash Formation. Due to the permeable but thin nature of this Formation, basements / cellars and other underground structures may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of infiltration SUDs and / or artificial recharge from leaking pipes.
- **Kellaways Sand Member outcrop area in north east Chippenham:** There is potential for a perched groundwater table to exist within the Kellaways Sand Member. Due to the permeable but thin nature of this aquifer, basements / cellars and other underground structures may be at risk from prolonged groundwater flooding from periods of prolonged rainfall, increased utilisation of SUDs and / or artificial recharge from leaking pipes.
- **Superficial geology aquifers in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding may be associated with the substantial sand and gravel River Terrace Deposits, or to a lesser degree Alluvium, where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain “in-bank”, and this can trigger a rise in groundwater levels in the associated superficial geology. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial geology.
- **Superficial aquifers not in hydraulic continuity with the Upper Bristol Avon River:** Groundwater flooding is also associated with substantial River Terrace Deposits (gravel and sand), Alluvial Fan Deposits and Head deposits, but occurs where they are not in immediate hydraulically connection with surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.
- **Impermeable (silt and clay) areas downslope of aquifer outcrop (various locations):** Groundwater flooding may occur where groundwater springs / seepages form minor flows and ponding over impermeable strata where there is poor drainage. This mechanism may occur as a result of natural (e.g. rainfall) or artificial (e.g. water main leakage) recharge.
- **Uncapped boreholes drilled into the Combe Down Oolite:** The piezometric levels within the Combe Down Oolite are at or close to ground level following sustained wet periods, although overlying clay horizons prevent groundwater flooding from this aquifer. However, uncapped boreholes would provide an artificial pathway for groundwater to flow to surface and cause groundwater flooding.

3.2 Evidence of Groundwater Flooding

Figures 1, 3, 4 and 5 show the location of one historic groundwater flooding incident that was identified by the Environment Agency. The Figures also show the locations of another six flooding incidents that may have been influenced by groundwater conditions, but have been identified as either fluvial or pluvial flooding. These flooding incidents have also been considered by this study, as it is often difficult to identify the cause of a flooding incident. Details of the reported incidents are shown in Table 5, including the local geology and the date of the reported incident.

Table 5: Selected flooding incidents

Geological Units*	Grid Reference	No**	Reported Incident	Date
Cornbrash Formation / River Terrace Deposits	ST 92428 73140	1	Groundwater flooding – no other comment	30/10/2000
Cornbrash Formation / River Terrace Deposits	ST 92960 72800	2	Fluvial flooding – no other comment	12/04/1960
Cornbrash Formation	ST 90605 73101	3	Fluvial flooding – no other comment	12/01/1979
Kellaways Clay Member / River Terrace Deposits	ST 93430 73120	4	Surface Water flooding – no other comment	12/04/1960
	ST 93400 73200	5	Surface Water flooding – no other comment	03/06/1978
	ST 93520 73570	6	Surface Water flooding – no other comment	12/04/1960
Kellaways Sand Member	ST 93400 75200	7	Surface Water flooding – no other comment	03/06/1978

Note: * Geology of incident based on plotted location on Figures 1 & 4.

** Reference number as shown on Figures 1, 3, 4 & 5.

Based on Figure 1, the hydrogeological situation of incidents 1, 2, 4, 5 and 6 are similar, although only incident 1 is listed as a groundwater flooding incident. These locations are shown to be on a shallow aquifer (Cornbrash Formation / River Terrace Deposits) where groundwater levels are likely to be influenced by the Upper Bristol Avon River but also rainfall runoff from the impermeable Kellaways Clay Member on higher ground.

Figure 1 shows that locations 3 and 7 are both located on shallow aquifers but do not appear to be close to any surface water courses. It is plausible that these two flooding incidents were influenced by groundwater conditions.

It is important to note that the listed flooding incidents in Table 5 are not contemporary; there are no available data beyond the end of October 2000. In addition, until recent years there have been few drivers in place to ensure the systematic recording of flood incidents and their likely cause.

3.3 Areas Susceptible to Groundwater Flooding

The Environment Agency has produced a data set referred to as 'Areas Susceptible to Groundwater Flooding (AStGWF)', on a 1 km grid (Figure 5). This utilises the BGS 1:50,000 Groundwater Flood Susceptibility data set for consolidated aquifers (bedrock) and superficial geology.

The Environment Agency data set shows the percentage of each 1 km square that falls within the high to very high BGS groundwater flooding susceptibility categories. It does not show the

probability / risk of groundwater flooding occurring; this can only be determined following site specific investigation works and desk studies. It also does not take into account groundwater level rebound following cessation of abstraction.

An absence of values for any grid square means that no part of that square is identified as being susceptible to groundwater emergence (Environment Agency AStGWF Guidance Document).

The areas that are identified as being most susceptible to groundwater flooding are located close to the Upper Bristol Avon and River Marden. By comparing the data set with Figure 1 (geological map) it is apparent that those grid squares identified as having an area greater than 50% with high to very high susceptibility to groundwater flooding are those where significant River Terrace Deposits are present.

Flooding incidents 4, 5 and 6 are located in grid squares within the >=25% <50% category, owing to the proximity of Alluvium and River Terrace Deposits adjacent to the Upper Bristol Avon River.

Incident numbers 3 and 7 located on the Cornbrash Formation and Kellaways Sand Member are shown to be in grid squares with no shading, which suggests no susceptibility to groundwater flooding. However, this could indicate that no water level data were available to the BGS when creating the original groundwater flood susceptibility Map. This notwithstanding, it is thought that the approximate areas identified by the Environment Agency as being susceptible to groundwater flooding are sensible.

3.4 Importance of Long Term Groundwater Level Monitoring

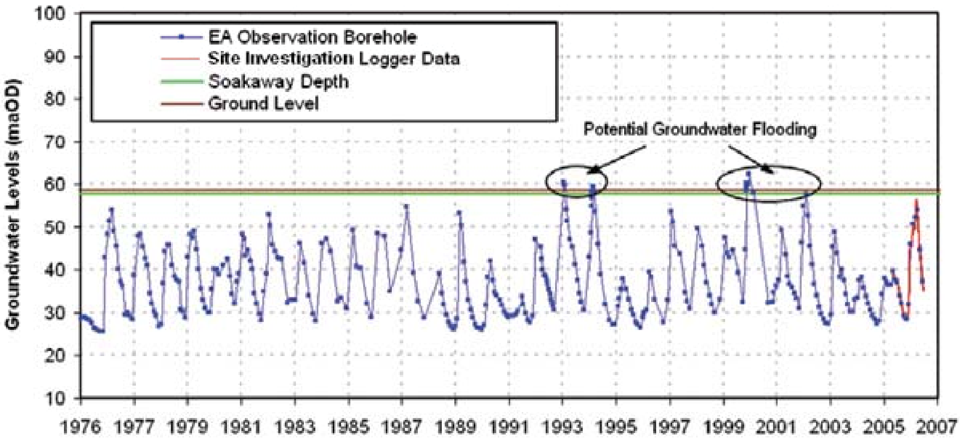
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers, Cornbrash Formation and Kellaways Sand Member are limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

It is not sufficient to rely on the work undertaken by developers through the planning application process, unless long term monitoring (several years) is one of the conditions when granting planning permission. Groundwater levels are often only measured once, or, at most, for a number of weeks. It would be advisable for the Council, in combination with the Environment Agency, to begin long term monitoring of the Cornbrash Formation, Kellaways Sand Member and superficial aquifer groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial flood defences.

It is also important to understand how changing policies relating to infiltration SUDS can impact upon groundwater levels. For example the introduction of infiltration SUDS (e.g. soakaways) may cause a rise in peak groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the Environment Agency owing to its responsibilities under the Water Framework Directive.

Long term groundwater level monitoring is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS.

Schematic demonstrating the importance of long term groundwater level monitoring



4 Water Framework Directive and Infiltration SUDS

The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Thames River Basin District is considered within the current study since infiltration Sustainable Drainage Systems (SUDS) have the potential to impact the water quality and water quantity status of aquifers and surface water courses.

4.1 Current Quantity and Quality Status

The current quantitative assessment for the area South of Malmesbury (Cornbrash Formation aquifer - GB40901G806000) is 'good' and the current quality assessment is 'good'. The quantitative and chemical quality in 2015 is also predicted to be good (Environment Agency, December 2009). The Cornbrash Formation is likely to be suitable for infiltration SUDS and it is important that use of these systems does not have an adverse impact on the status of the aquifer.

There is no equivalent assessment for the River Terrace Gravels or Kellaways Sand Member, which may also be suitable for infiltration SUDS.

4.2 Infiltration SUDS Suitability

Improper use of infiltration SUDS could lead to contamination of the superficial or bedrock geology aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

Environment Agency guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Wiltshire Council when approving or rejecting planning applications.

The areas that may be suitable for infiltration SUDS (e.g. soakaways, permeable paving) exist where there is a combination of higher ground (interfluves) and permeable geology (see Figure 3). However, consideration should be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at the down gradient location. This type of analysis is beyond the scope of the current report.

Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ), which are shown on Figure 3. Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance.

It is understood that the SPZs in the Chippenham area are associated with groundwater abstractions from the Forest Marble Formation and Combe Down Oolite, which are expected to be hydraulically isolated from the aquifers that outcrop in the Chippenham area. This notwithstanding, the developer should present a suitable risk assessment as part of any planning application.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

- The clays of the Forest Marble Formation are expected to hydraulically separate the underlying Combe Down Oolite principal aquifer from the surface aquifers. Therefore, the Combe Down Oolite is not of key interest to the groundwater flooding assessment.
- The key areas of interest are those underlain by Kellaways Sand Member, Cornbrash Formation or River Terrace Deposits (Figure 1). These geological units are expected to behave as aquifers and are likely to contain perched water tables i.e. they are a potential source of groundwater flooding.
- A number of potential groundwater flooding mechanisms have been identified. Key mechanisms are (i) rapid water level fluctuations in the River Terrace Deposits in response to river stage fluctuations (Upper Bristol Avon River), and (ii) response of perched groundwater levels within the Cornbrash Formation and Kallaways Sand Member to increased use of infiltration SUDS, leaking pipes and barriers to groundwater flow such as sheet piling. Properties at greatest risk of flooding are those with basements / cellars.
- Based on the available flood incident data and Environment Agency ‘Areas Susceptible to Groundwater Flooding’ data set, the areas most susceptible to groundwater flooding are those properties located on River Terrace Deposits, close to the Upper Bristol Avon River.
- The lack of reported groundwater flooding incidents on the Cornbrash Formation and Kellaways Sand Member suggests that whilst a perched aquifer may exist, groundwater levels are sufficiently low and/or there are a lack of receptors (e.g. basements), such that groundwater flooding has not been an issue. However, it is important to note that no groundwater flooding incident data post-2000 were available from the Environment Agency. In addition, increased discharges to these aquifers through infiltration SUDs may lead to future groundwater flooding issues. Therefore, use of infiltration SUDs should be carefully managed.
- The Environment Agency and Council do not currently monitor groundwater levels in the River Terrace Deposits, Kellaways Sand Member or Cornbrash Formation. Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

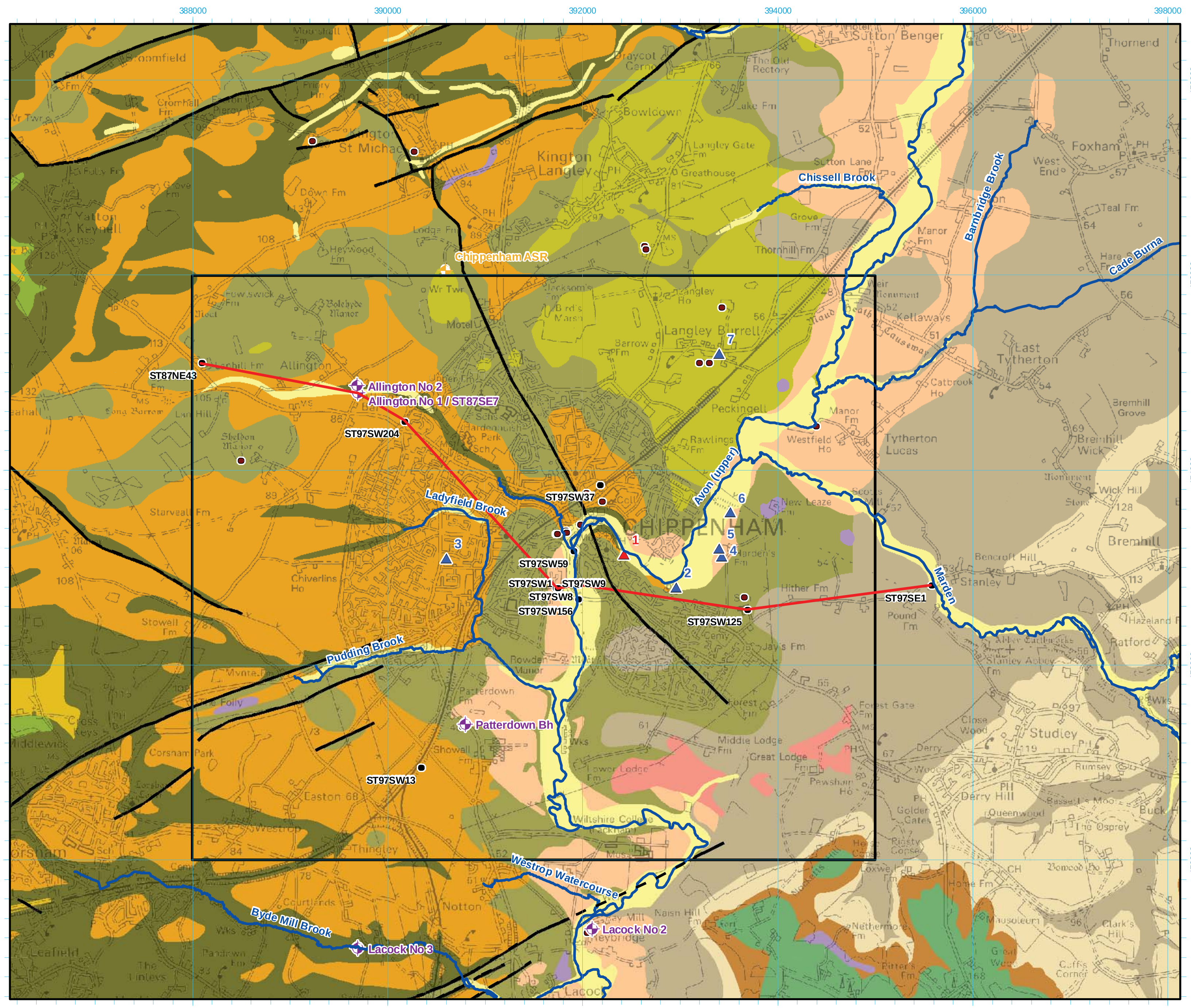
5.2 Recommendations

The following recommendations are made based on the findings of the current report:

- Data identifying properties with basements / cellars should be collected by Wiltshire Council;
- Site investigation reports for historic development sites could be reviewed to obtain additional groundwater level information, to improve the conceptual understanding of the area;
- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial, pluvial and sewer. An integrated understanding of flood risk will be gained through this exercise;
- Pluvial modelling often assumes that no infiltration of rainfall occurs (a worst case scenario). It is recommended that a sensitivity analysis is undertaken, whereby infiltration is modelled in those areas where permeable superficial geology are located;
- Monitoring boreholes should be installed in the River Terrace Deposits, Cornbrash Formation and the Kellaways Sand Member, fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on infiltration SUDS guidance provided.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered when approving planning applications;
- The impact of infiltration SUDS on groundwater levels (and therefore groundwater risk) should be considered further. This may require the construction of a local groundwater model following collection of groundwater level data.

6 References

- DEFRA, March 2010. Surface Water Management Plan Technical Guidance.
- Environment Agency, December 2009. River Basin Management Plan. Thames River Basin District (Annex B).
- Environment Agency, 2010. Areas Susceptible to Groundwater Flooding. Guidance Document
- Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K., 2000. The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 39pp. Environment Agency R&D Publication 68.
- Scott Wilson, October 2007. North Wiltshire District Council, Strategic Flood Risk Assessment Level 1 Report - Final Report.



Legend

- Chippenham Study Area
- Main River
- Chippenham Cross Section (Figure 2)

Environment Agency Monitoring Boreholes

- Great Oolite
- Inferior Oolite

Historic Flooding Incident

- Recorded as Groundwater Flooding Incident
- Potentially a Groundwater Flooding Incident

BGS Borehole Logs

- Referenced within text
- Other

Superficial Geology

- Alluvium (Clay, Silt, Sand & Gravel)
- Head (Clay, Silt, Sand & Gravel)
- Alluvial Fan Deposits (Clay, Silt, Sand & Gravel)
- River Terrace Deposits (Sand & Gravel)

Bedrock Geology

- Lower Greensand Group (Sandstone)
- Coral Rag Fm (Undifferentiated)
- Hazelbury Bryan Fm (Sandstone)
- Oxford Clay Fm
- Kellaways Sand Member
- Kellaways Clay Member
- Cornbrash Fm
- Forest Marble Fm (Mudstone)
- Forest Marble Fm (Limestone)
- Combe Down Oolite (Limestone)
- Fault present at outcrop
- Fault overlain by superficials

NOTES
Fm = Formation

Drawing Status: FINAL

Job Title: Chippenham Surface Water Management Plan

Drawing Title: Geological Map

Scale at A3: 1:40,000

Drawn by	Date	Approved	Date
RAC	8/11/10	SJC	15/11/10

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Basingstoke, Hants, RG21 7PP
Telephone (01256) 310 200
www.scottwilson.com

FIGURE 1

Base Map Details
Projection: Transvers Mercator
Scale Factor: 0.999601
Origin: 2° West, 49° North
Coordinates: 400000,-100000
Units: metres
Datum: OSGB 1936

0 0.25 0.5 1 1.5 Kilometers

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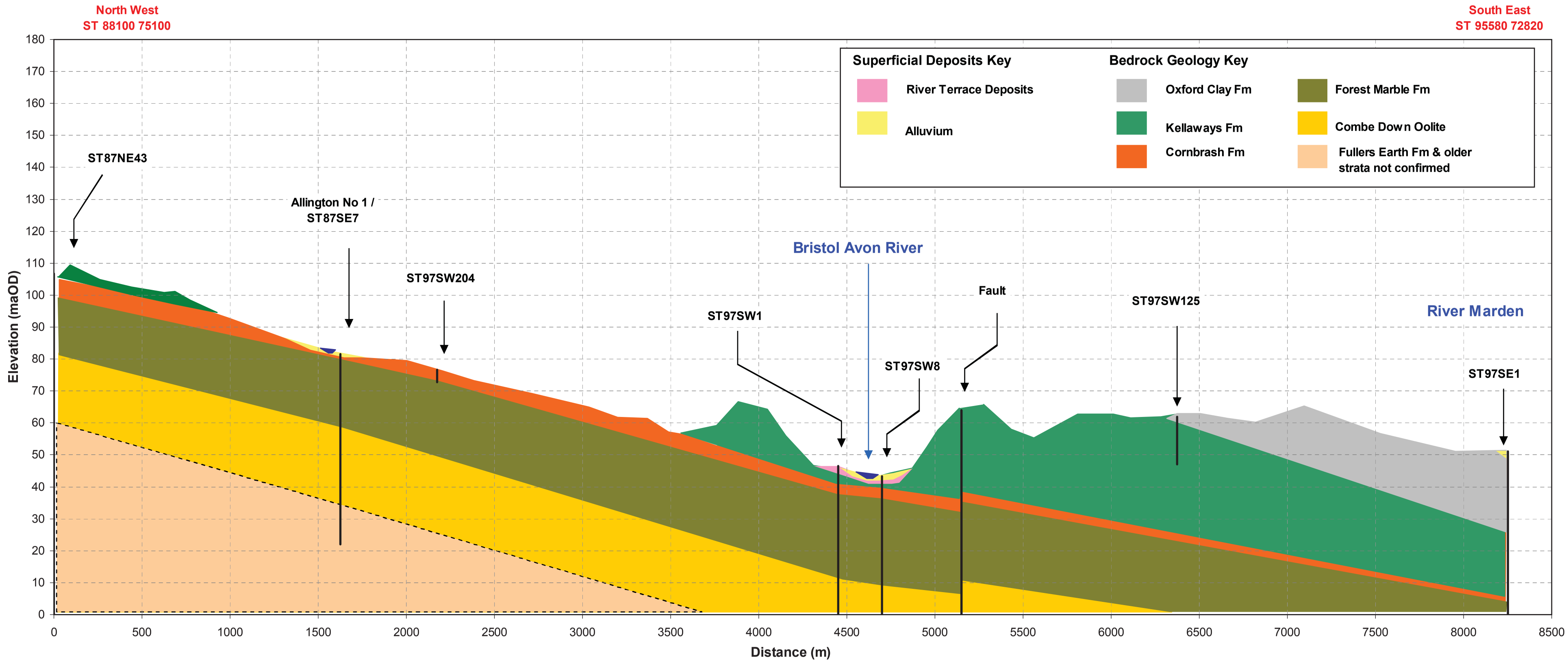

North West - South East Cross Section

D133429 -Wiltshire SWMP | Figure 2

Drawn By	Date	Approved	Date
R.Cox	29/11/2010	S. Cox	01/12/2010

URS / Scott Wilson

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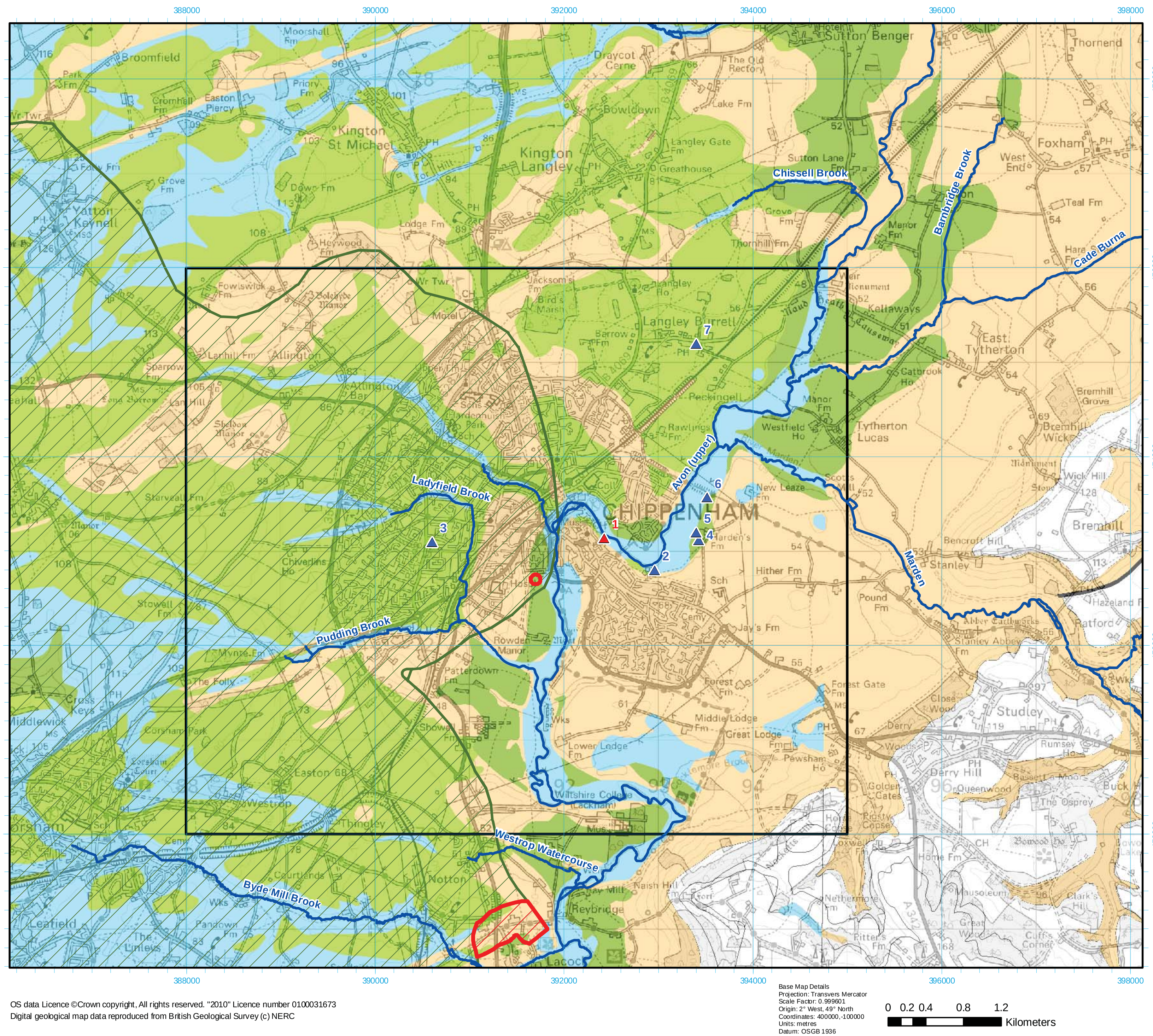
Telephone: (01265) 310200

File :\jobs\D133429\700 Technical\701 Data\Site Cross Section



Legend

Historic Flooding Incident

- Recorded as Groundwater Flooding Incident
- Potentially a Groundwater Flooding Incident
- Main River
- Chippenham Study Area

Source Protection Zones (SPZ)

- Inner (zone 1)
- Outer (zone 2)

Expected Permeability

- High
- Moderate to High
- Low to Moderate
- Low
- Not defined - not pertinent to study

Notes:

This map forms an approximate guide to permeability. However, for all new developments, site investigation is required to confirm local permeabilities and infiltration rates.

Drawing Status: FINAL

Job Title: Chippenham Surface Water Management Plan

Drawing Title: Expected Permeability Map & Source Protection Zones

Scale at A3			
1:40,000			
Drawn by	Date	Approved	Date
RAC	16/11/10	SJC	20/11/10

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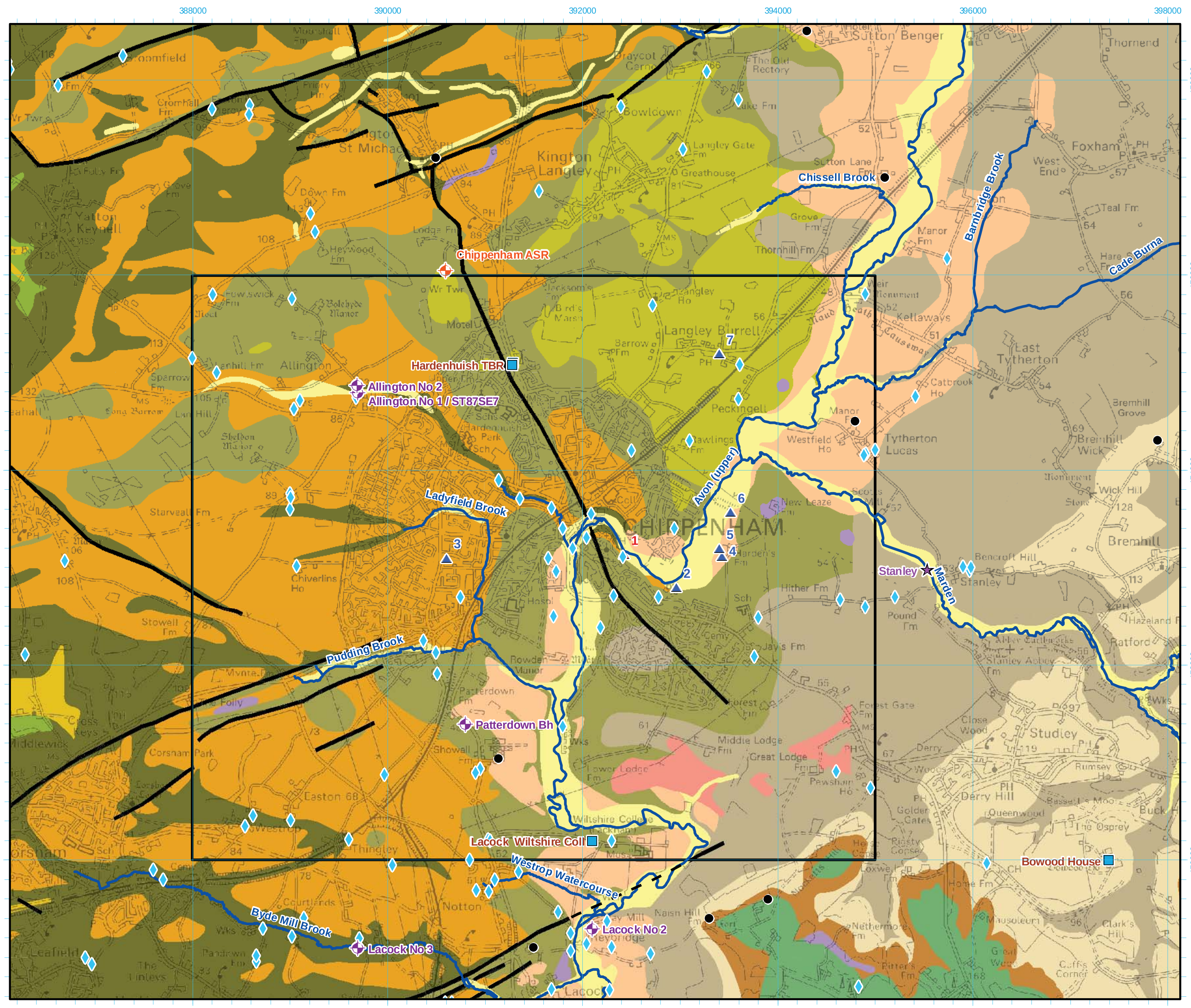
FIGURE 3



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Base Map Details
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Origin: 2° West, 49° North
Coordinates: 400000,-100000
Units: metres
Datum: OSGB 1936

0 0.3 0.6 1.2 1.8 Kilometers

THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Chippenham Study Area
- Main River

Environment Agency Monitoring Boreholes

- Great Oolite
- Inferior Oolite

Minor Abstractions

- Groundwater <20m3/d

Other

- River Flow Gauging Station
- Rainfall Station
- Licensed Discharge

Historic Flooding Incident

- Recorded as Groundwater Flooding Incident
- Potentially a Groundwater Flooding Incident

Superficial Geology

- Alluvium (Clay, Silt, Sand & Gravel)
- Head (Clay, Silt, Sand & Gravel)
- Alluvial Fan Deposits (Clay, Silt, Sand & Gravel)
- River Terrace Deposits (Sand & Gravel)

Bedrock Geology

- Lower Greensand Group (Sandstone)
- Coral Rag Fm (Undifferentiated)
- Hazelbury Bryan Fm (Sandstone)
- Oxford Clay Fm
- Kellaways Sand Member
- Kellaways Clay Member
- Cornbrash Fm
- Forest Marble Fm (Mudstone)
- Forest Marble Fm (Limestone)
- Combe Down Oolite (Limestone)
- Fault present at outcrop
- Fault overlain by superficials

NOTES
Fm = Formation

Drawing Status: FINAL

Job Title: Chippenham Surface Water Management Plan

Drawing Title: Discharge Consents & Groundwater Abstractions

Scale at A3	1:40,000		
Drawn by	Date	Approved	Date
RAC	8/11/10	SJC	15/11/10

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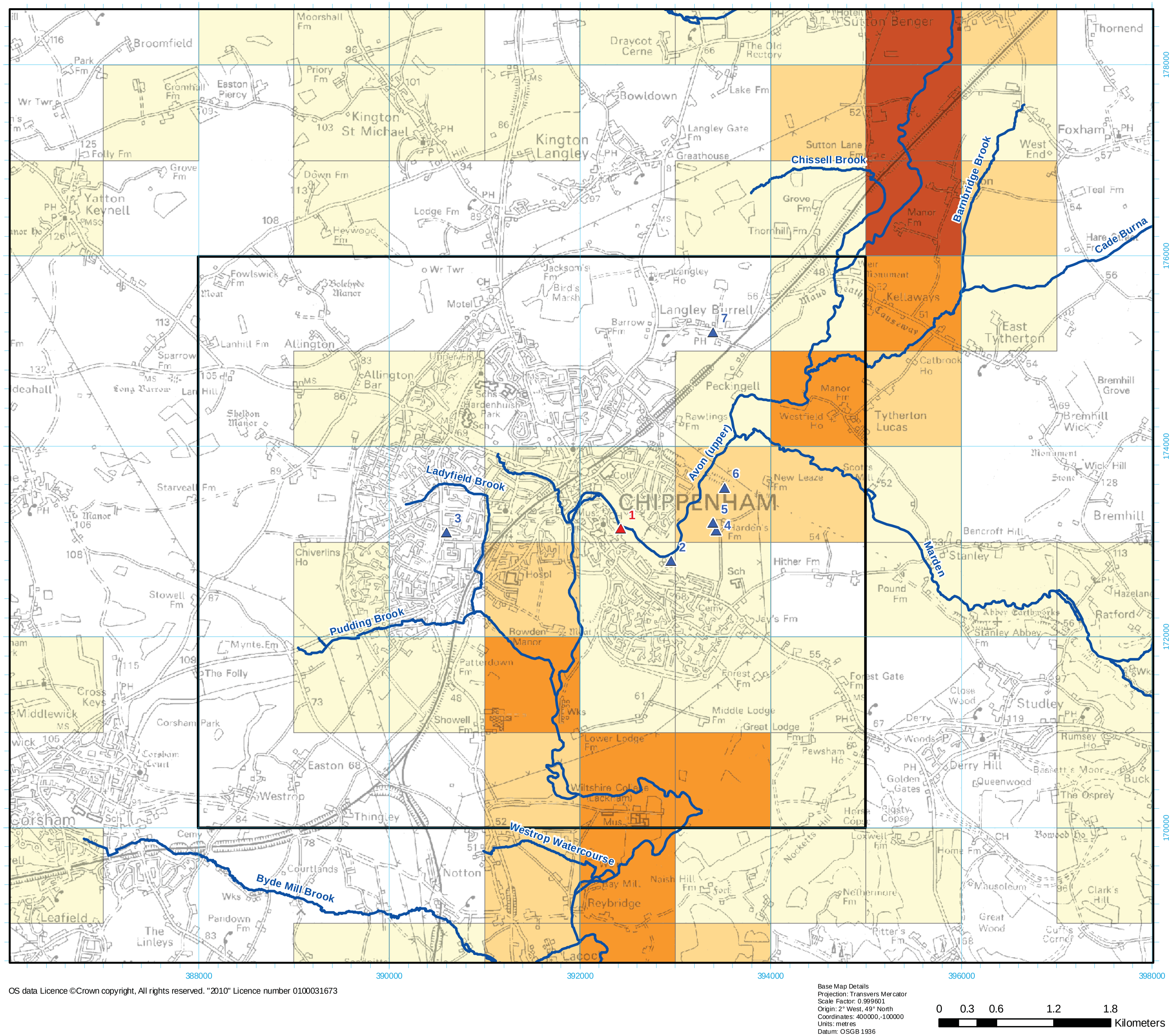
FIGURE 4



OS data Licence ©Crown copyright, All rights reserved. "2010" Licence number 0100031673

Base Map Details
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Scale Factor: 0.999601
Origin: 2° West, 49° North
Coordinates: 400000,-100000
Units: metres
Datum: OSGB 1936

THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Chippenham Study Area
- Main River

Historic Flooding Incident

- Recorded as Groundwater Flooding Incident
- Potentially a Groundwater Flooding Incident

Areas Susceptible to Groundwater Flooding

- >= 75%
- >= 50% <75%
- >= 25% <50%
- < 25%

NOTES

Notes:

This map forms an approximate guide to areas that may be susceptible to groundwater flooding. However, for all new developments, site investigation is required to confirm local groundwater levels and therefore risk of groundwater flooding.

Drawing Status: FINAL

Job Title: Chippenham Surface Water Management Plan

Drawing Title: Areas Susceptible to Groundwater Flooding Map

Scale at A3: 1:40,000

Drawn by	Date	Approved	Date
RAC	24/01/11	SJC	24/01/11

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FIGURE 5

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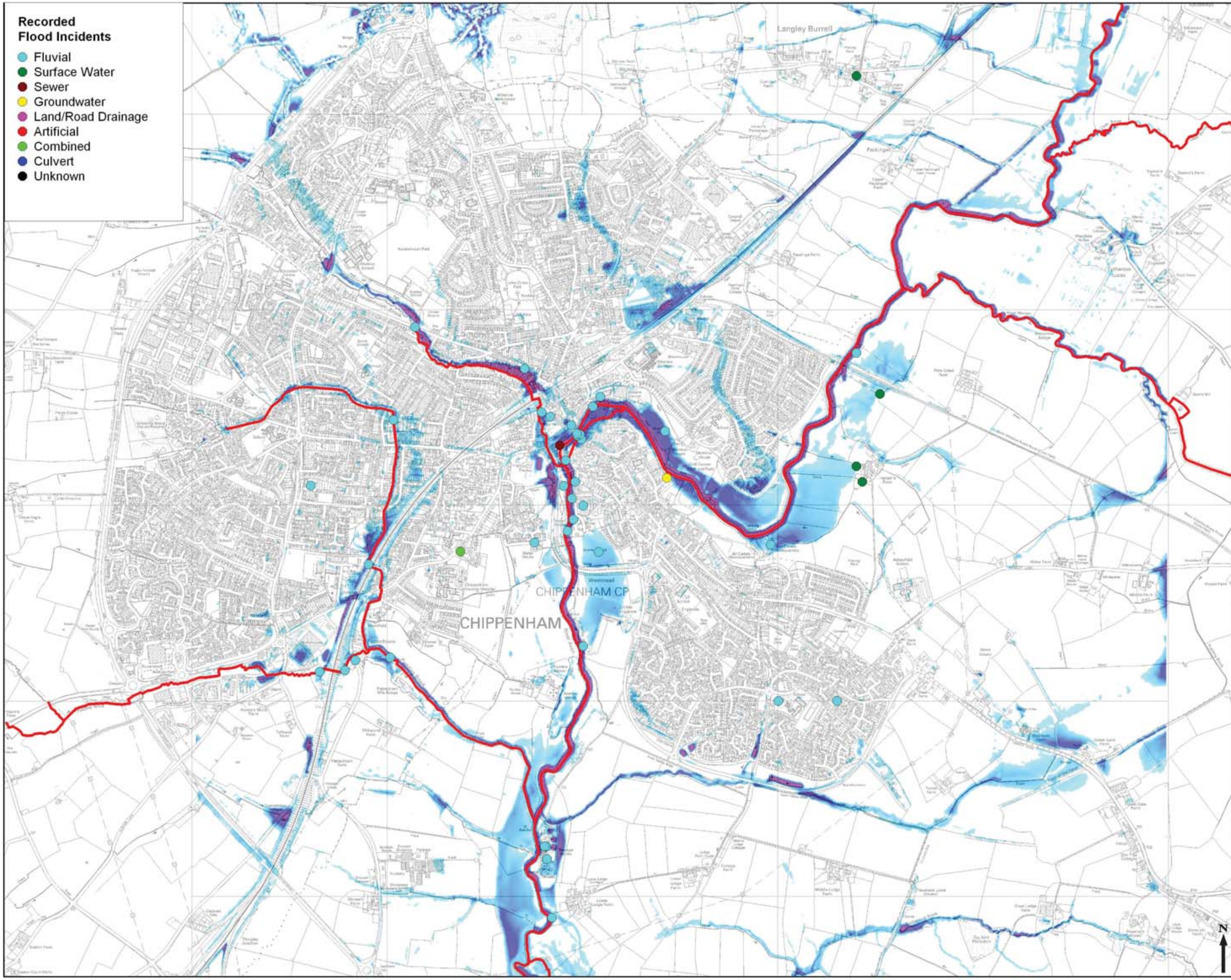

NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency
Main River

Indicative Max Water Depth (m)
1.5
1.0
0.5
0.1

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Water Depth 1 in 30 Year Pluvial Event

Scale at A3: 1:18,000

Drawn	MC	Approved	RS
Stage 1 Check RS	Stage 2 Check RS	Originated RS	Date 19/07/2011

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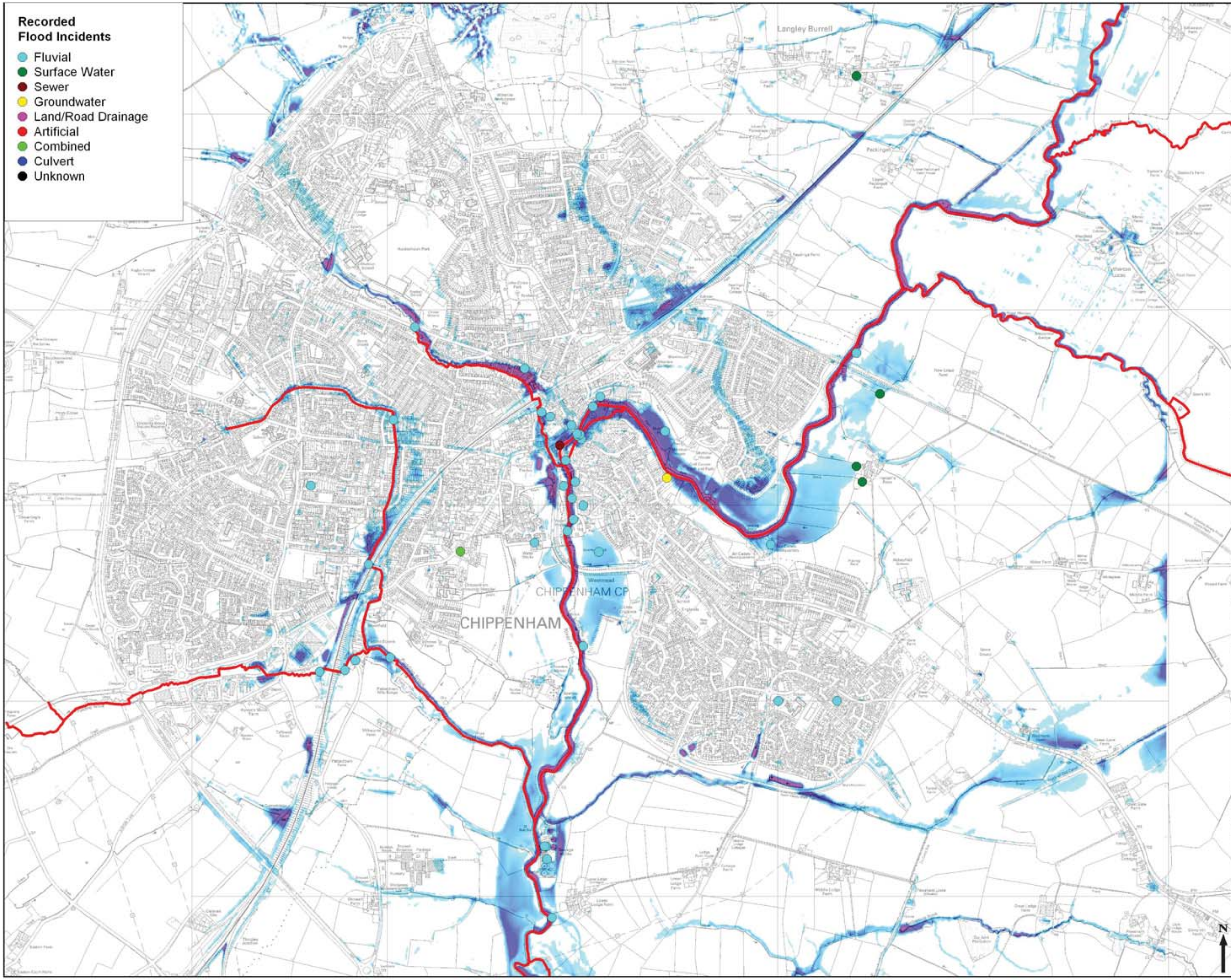
Drawing Number: FIGURE 1

Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency

Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Water Depth 1 in 30 Year Pluvial Event

Scale at A3	1:18,000		
Drawn: MC		Approved: RS	
Stage 1 Check: RS	Stage 2 Check: RS	Originated: RS	Date: 19/07/2011

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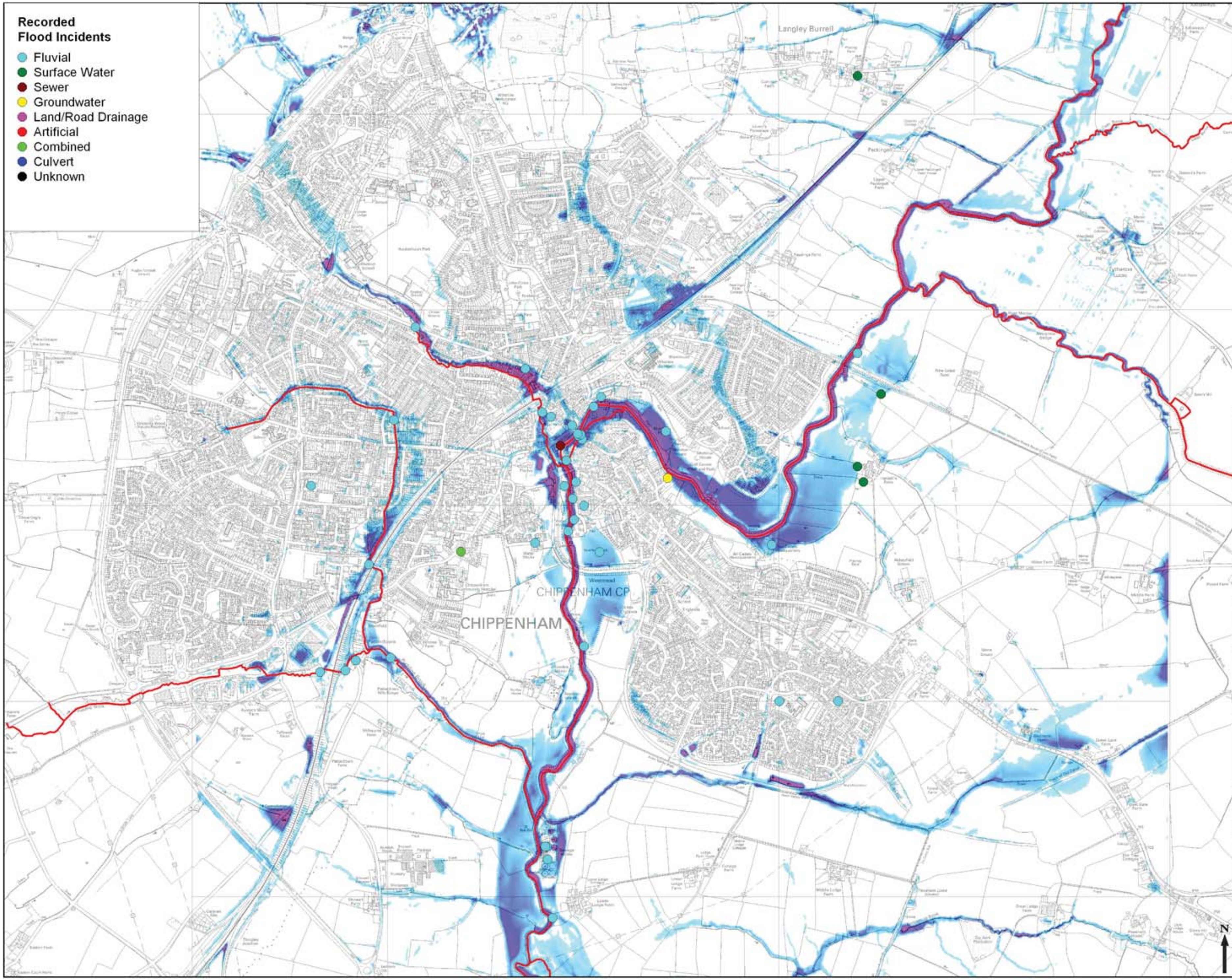
Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Water Depth 1 in 30 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3: 1:18,000

Drawn	Approved
MC	RS

Stage 1 Check	Stage 2 Check	Originated	Date
MC	MC	MC	19/07/2011

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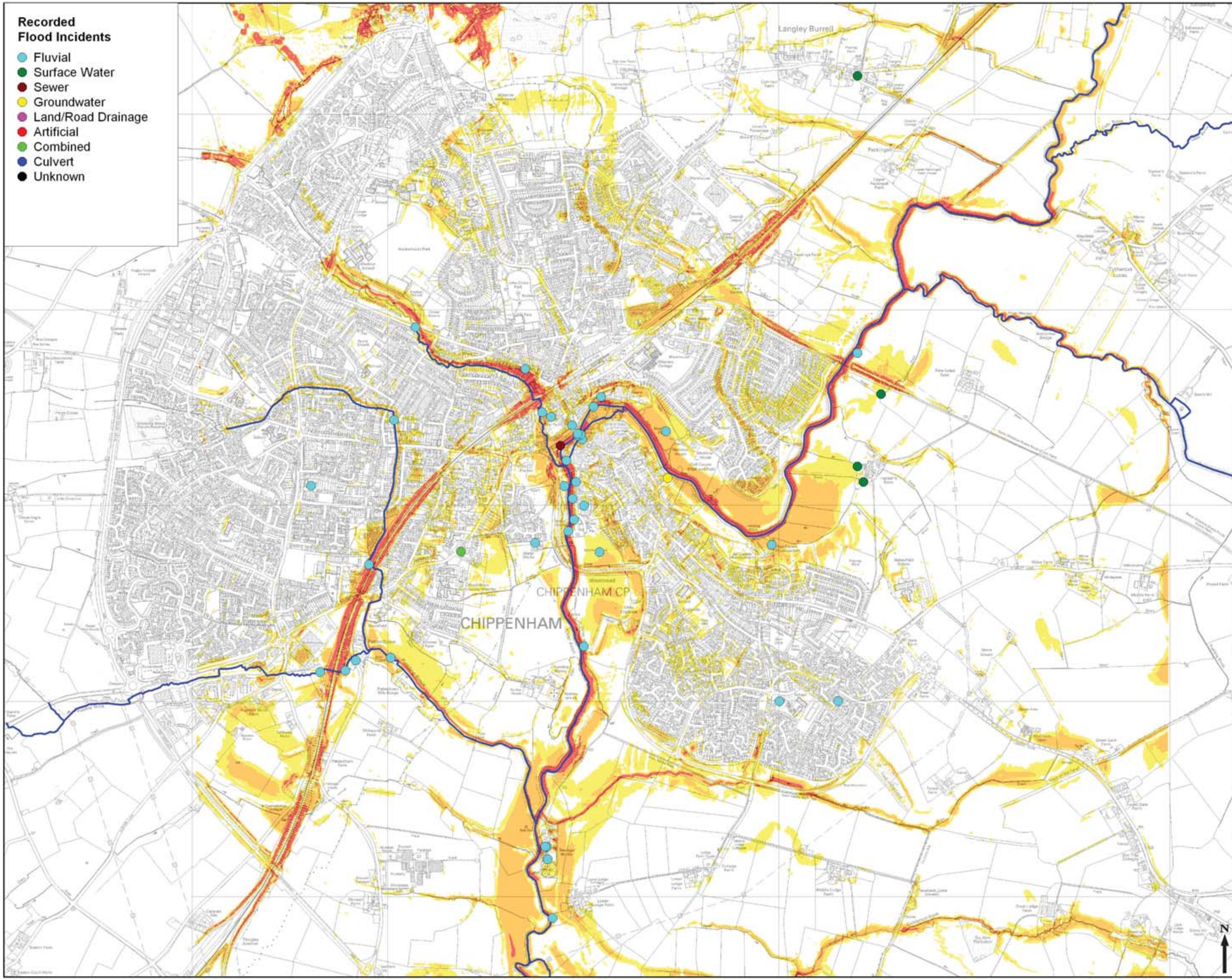
Drawing Number: **FIGURE 3**

Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency
Main River

Indicative Hazard Class
- Low
- Medium
- High

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Hazard 1 in 30 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3	1:18,000		
Drawn	MC	Approved	RS
Stage 1 Check MC	Stage 2 Check MC	Originated MC	Date 19/07/2011

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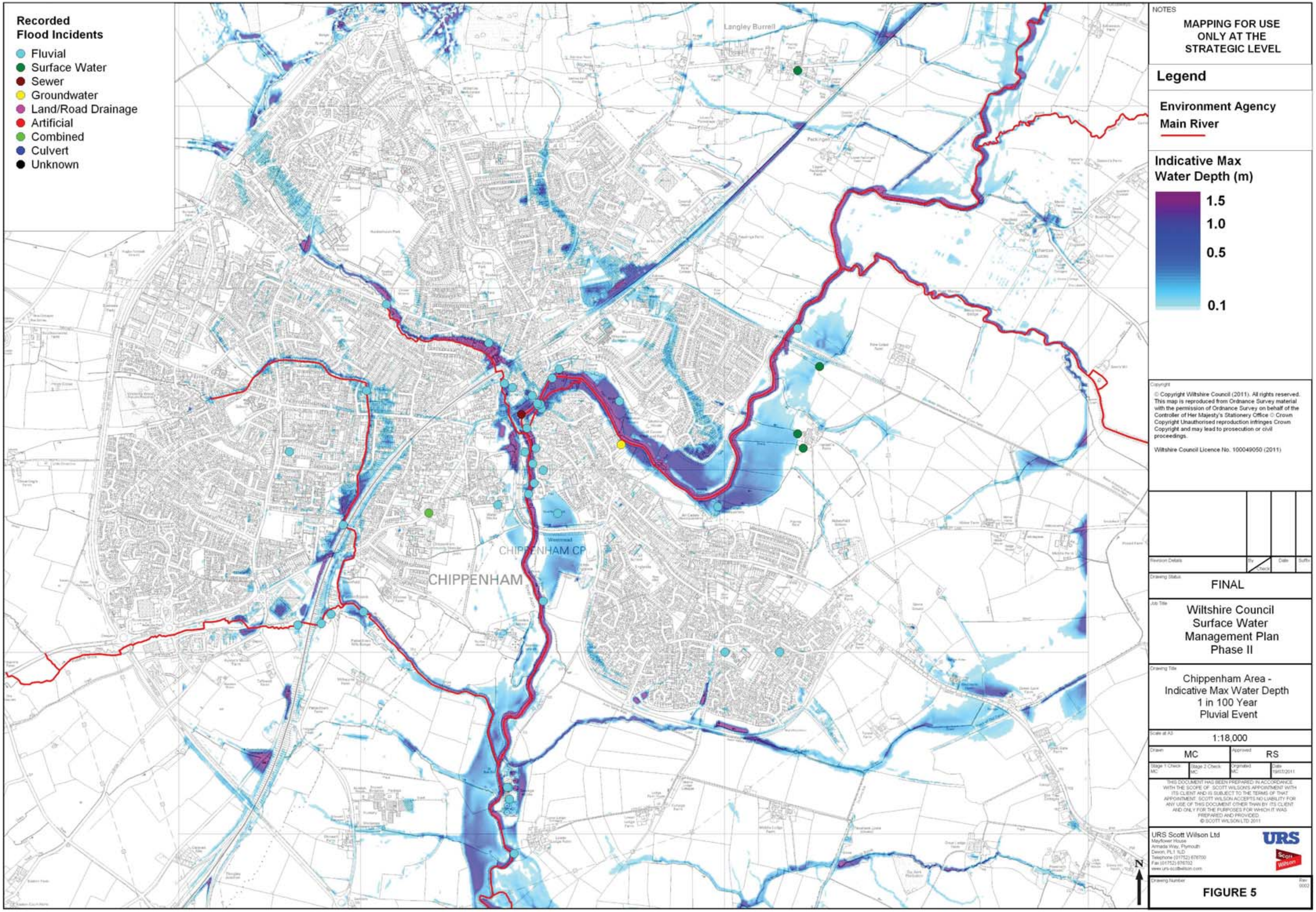
Drawing Number: **FIGURE 4**

Rev 0002


Recorded Flood Incidents
Fluvial
Surface Water
Sewer
Groundwater
Land/Road Drainage
Artificial
Combined
Culvert
Unknown
Langley Burrell
CHIPPENHAM CP
CHIPPENHAM
NOTES
MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL
Legend
Environment Agency Main River
Indicative Max Water Depth (m)
1.5
1.0
0.5
0.1
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Drawing Status
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Job Title
Wiltshire Council Surface Water Management Plan Phase II
Drawing Title
Chippenham Area - Indicative Max Water Depth 1 in 100 Year Pluvial Event
Scale at A3
1:18,000
Drawn
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Approved
RS
Stage 1 Check
MC
Stage 2 Check
MC
Originated
MC
Date
19/07/2011
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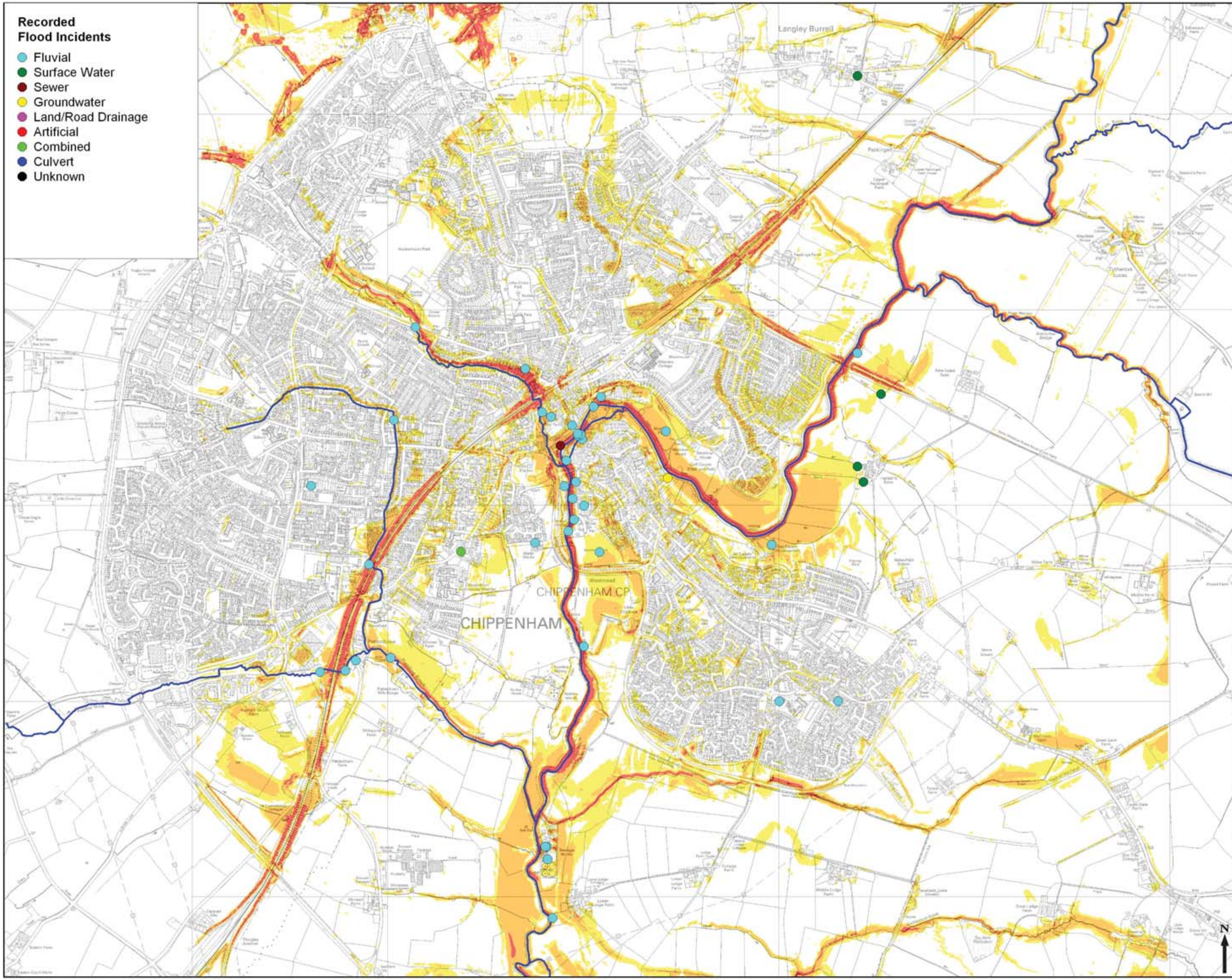
Drawing Number
FIGURE 5
Rev
0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency

Main River

Indicative Hazard Class

- Low
- Medium
- High

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Hazard 1 in 100 Year Pluvial Event

Scale at A3: 1:18,000

Drawn	MC	Approved	RS
Stage 1 Check MC	Stage 2 Check MC	Originated MC	Date 15/07/2011

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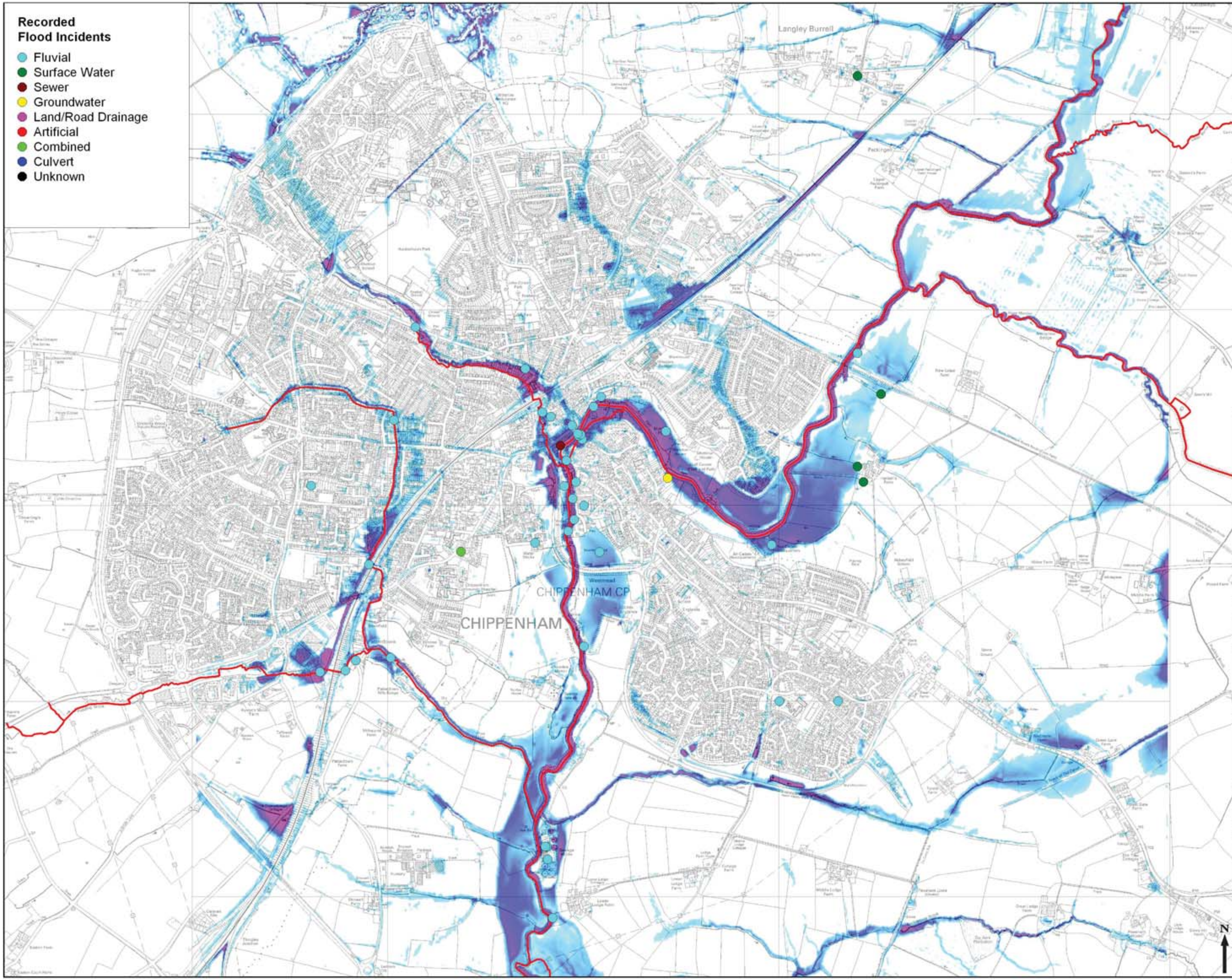
Drawing Number: **FIGURE 6**

Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Water Depth 1 in 100 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3: 1:18,000

Drawn: MC		Approved: RS	
Stage 1 Check: MC	Stage 2 Check: MC	Originated: MC	Date: 19/07/2011

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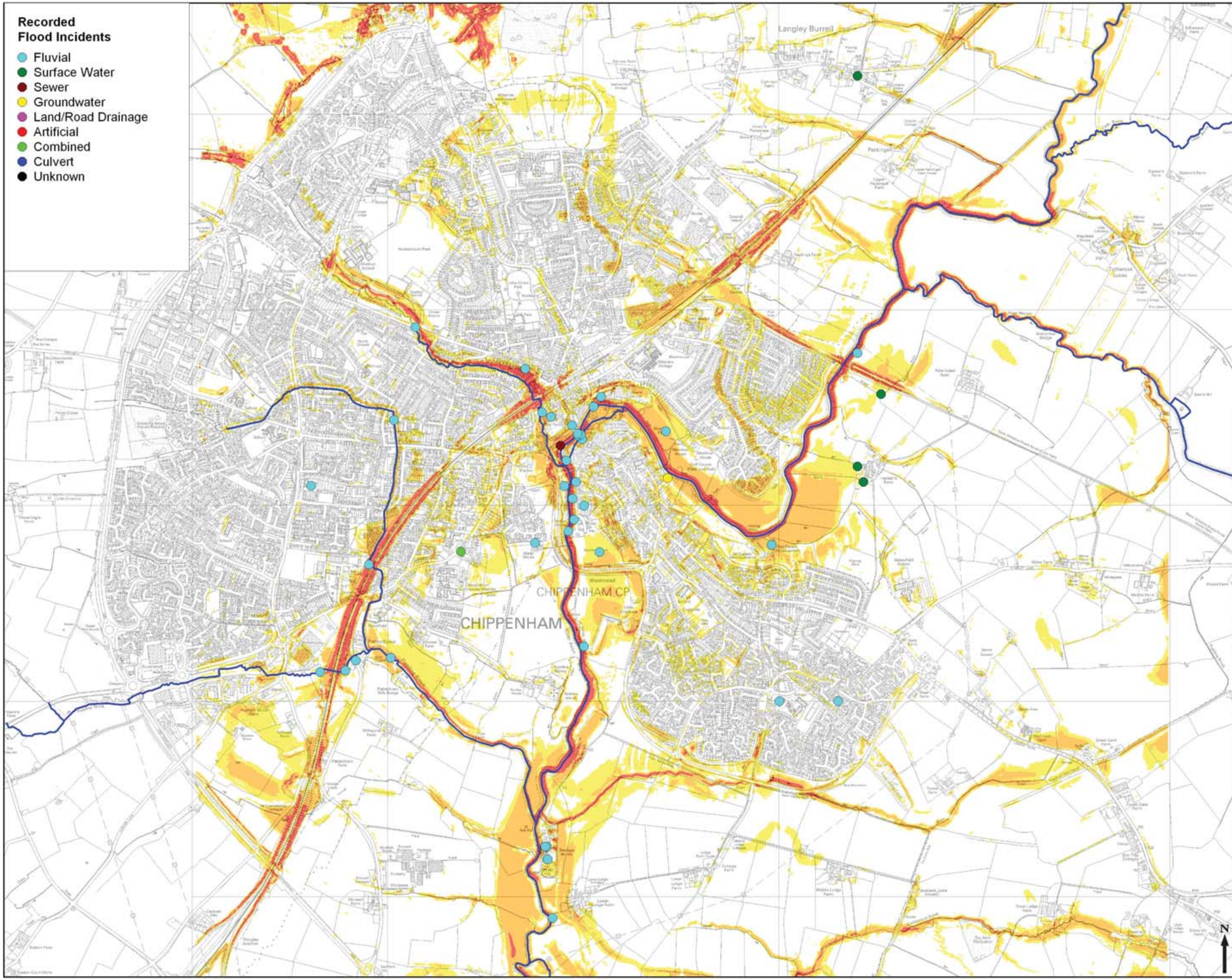
Drawing Number: **FIGURE 7**   Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency

Main River

Indicative Hazard Class

- Low
- Medium
- High

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Hazard 1 in 100 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3: 1:18,000

Drawn	MC	Approved	RS
Stage 1 Check MC	Stage 2 Check MC	Originated MC	Date 19/07/2011

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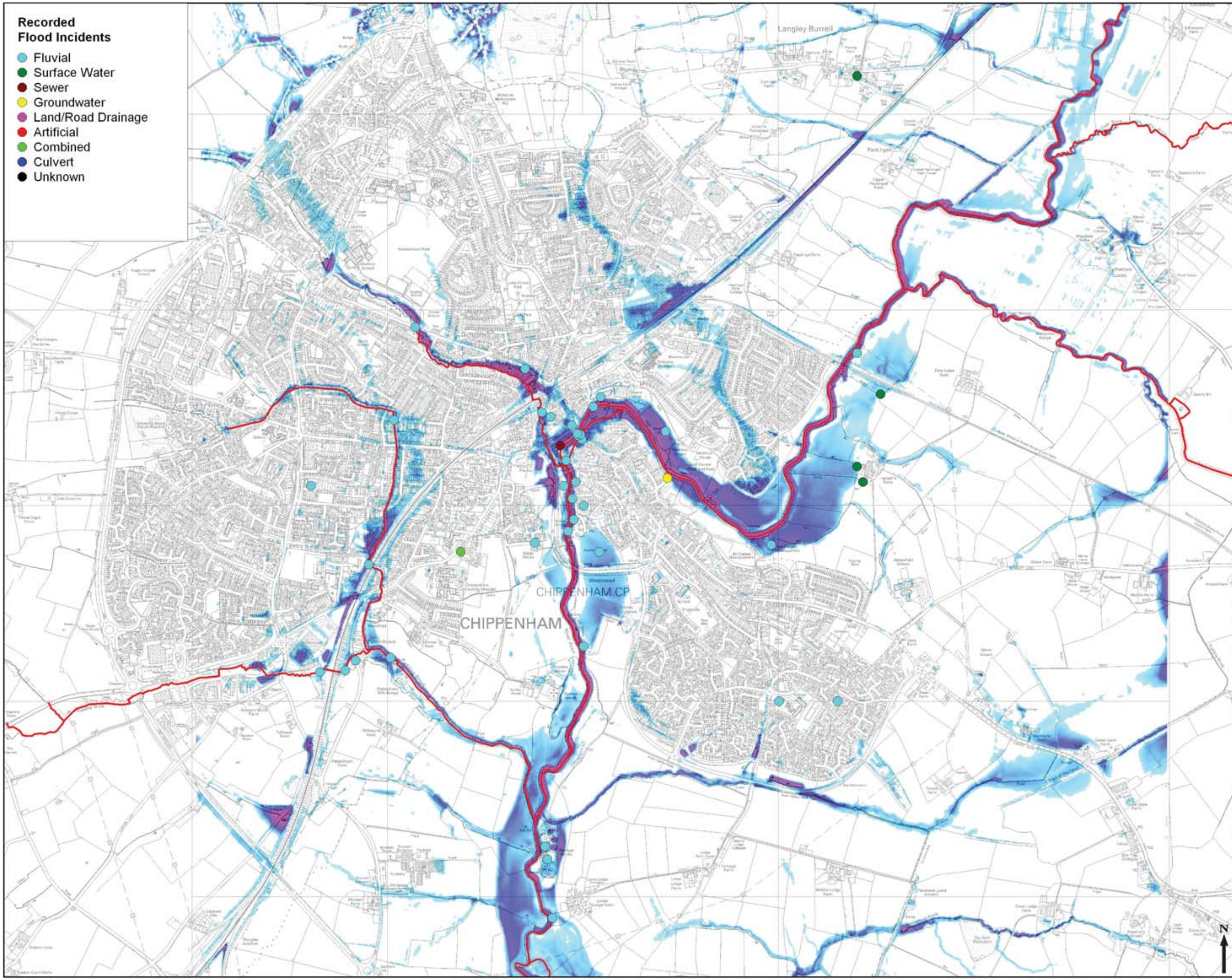
Drawing Number: FIGURE 8

Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Water Depth 1 in 200 Year Pluvial Event

Scale at A3	1:18,000		
Drawn: MC		Approved: RS	
Stage 1 Check: MC	Stage 2 Check: MC	Originated: MC	Date: 19/07/2011

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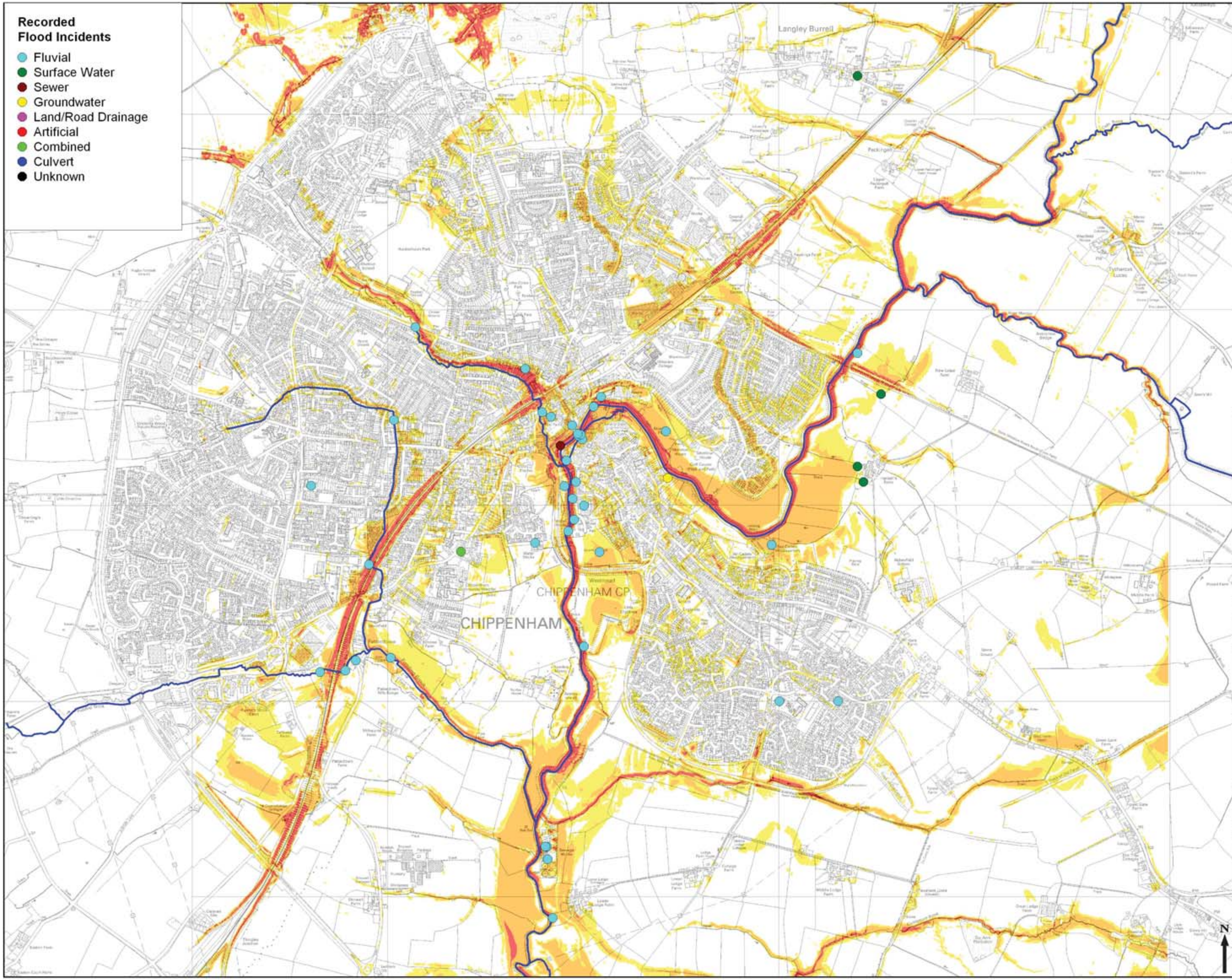
Drawing Number: FIGURE 9

Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency
Main River

Indicative Hazard Class
- Low
- Medium
- High

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Chippenham Area - Indicative Max Hazard 1 in 200 Year Pluvial Event

Scale at A3: 1:18,000

Drawn	MC	Approved	RS
Stage 1 Check MC	Stage 2 Check MC	Originated MC	Date 19/07/2011

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Drawing Number: **FIGURE 10**

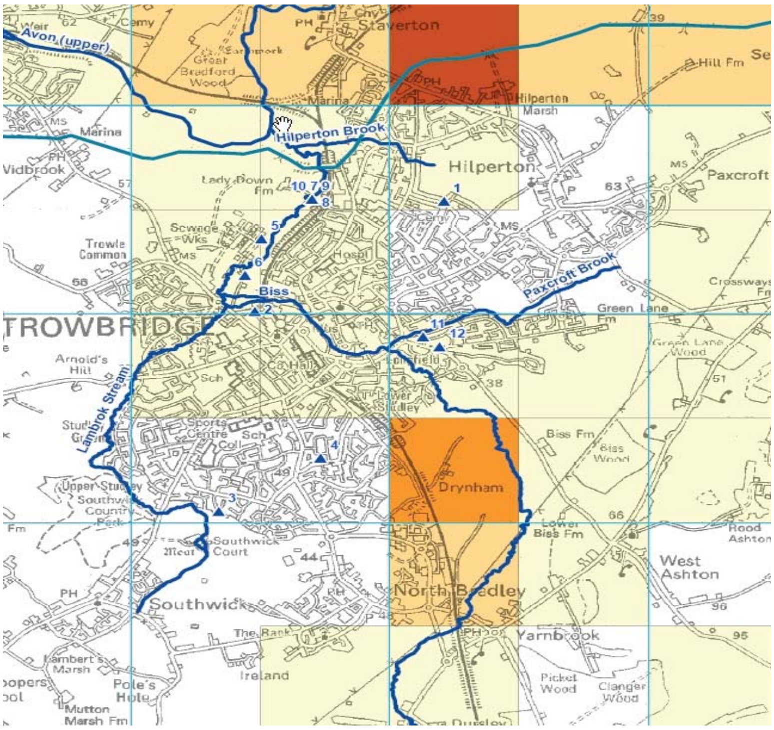
Rev 0002

Trowbridge Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 2

November 2011



Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

Trowbridge Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility
November 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	14/03/2011	Draft	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	
02	24/3/2011	Draft – for client comment only	**Ryan Cox** Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
03	November	Final – no client comments following draft			

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Table of Contents

Abbreviations

ACRONYM	DEFINITION
AStGWF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
RBMP	River Basement Management Plan
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Floods and Water Management Act	Legislation constituting part of the UK Government's response to Sir Michael Pitt's Report on the Summer 2007 floods, the aim of which is to help protect ourselves better from flooding, to manage water more sustainably and to improve services to the public.
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Interfluve	A ridge or area of land dividing two river valleys.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, under capacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

Groundwater flooding occurs as a result of water rising up from the underlying aquifer or from water flowing from springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by principal aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

Groundwater flooding tends to occur sporadically in both location and time, and tends to last longer than fluvial, pluvial or sewer flooding. Basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

The need to improve the management of groundwater flood risk in the UK was identified through Defra's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

Wiltshire Council has commissioned Scott Wilson to complete Phases 1 and 2 of their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Trowbridge study area. From this analysis,

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

The Bristol Avon rises in the Cotswolds and is the major river in the Trowbridge area. The Bristol Avon flows east to west, just north of Trowbridge, towards Bath and then to its outlet on the Bristol Channel. The Kennet and Avon Canal also runs adjacent to the Bristol Avon.

The River Biss flows south to north through the centre of Trowbridge towards a confluence with the Bristol Avon. It is joined by four main tributaries in the study area; the Lambrok Stream, Paxcroft Brook and an unnamed stream, close to the centre of Trowbridge; the Hilperton Brook to the north of Trowbridge. The Bristol Avon, Bitham Brook and tributaries are shown on Figure 1.

Ground levels in the Bitham Brook valley are approximately 40 maOD to the south of the study area, lowering northwards towards the Bristol Avon floodplain, where they are around 29 maOD. Ground levels are higher in the influve areas; 95 maOD in West Ashton and 60 maOD between Upper and Lower Studley in Trowbridge.

2.2 Geology

Figure 1 provides geological information for Trowbridge and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series. Figure 2 provides a geological cross section which has been used to improve the conceptual understanding of the area. 44 borehole logs were obtained from the BGS to provide local data and their locations are shown in Figure 1.

2.2.1 Bedrock Geology

Within the Trowbridge study area, the bedrock geology of interest comprises the Blisworth Limestone Formation[1], which in turn is overlain by the Forest Marble Formation, Cornbrash Formation, Kellaways Formation (including Kellaways Clay Member), Oxford Clay Formation, Hazelbury Bryan Formation, Newton Clay Member and Coral Rag Formation. Additional details are provided in Table 1.

There is geological faulting in the Trowbridge area as shown by Figure 1. The Trowbridge Fault is laterally extensive and runs from the south west (near to Wingfield) to the north east of Trowbridge (near Littleton). The faulting has caused the geology to the south east of Trowbridge to be downthrown and consequently the outcropping geology on either side of the Trowbridge Fault is different.

To the north west of the Trowbridge Fault the Kellaways Formation and the Cornbrash Formation are exposed over the majority of the area of interest. The BGS geological data presented on Figure 1 has subdivided the Kellaways Formation to show the Kellaways Clay Member (mudstone), which is located in the north of the study area. In the north west corner of the study area the Forest Marble Formation and the Blisworth Limestone Formation outcrop. These Formations have a syncline structure as shown by Figure 2. The base of the Blisworth Limestone Formation and the underlying Fullers Earth are not known and consequently are not depicted on Figure 2.

[1] Previously referred to as the Great Oolite Limestone

To the south east of the Trowbridge Fault the geology has been downthrown exposing the Oxford Clay at surface. The thickness of the Oxford Clay close to the Trowbridge Fault is unclear, although the geological log for borehole ST85NE2 suggests that it is around 130 m (Figure 2).

Further south east on higher ground near West Ashton, the Oxford Clay is overlain by the Hazelbury Bryan Formation (sub divided into sandstone and mudstone members), Newton Clay Member (sandy mudstone) and Coral Rag Formation (ooidal limestone).

Table 1 Bedrock geology of significance to the study

<table>
<tr><th colspan="2">Geological Units</th><th>Description</th><th>Thickness*</th></tr>
<tr><td rowspan="3">Corallian Group</td><td>Coral Rag Formation</td><td>Ooidal Limestone</td><td rowspan="3">25 to 35 m</td></tr>
<tr><td>Newton Clay Member</td><td>Sandy mudstone</td></tr>
<tr><td>Hazelbury Bryan Fm (Previously Lower Calcareous Grit),</td><td>Sub divided into sandstone and mudstone horizons</td></tr>
<tr><td rowspan="2">Ancholme Group</td><td>Oxford Clay Formation</td><td>Mudstone</td><td>Up to 150 m</td></tr>
<tr><td>Kellaways Formation (Kellaway Clay Member)</td><td>Mudstone / Sandy Mudstone</td><td>Up to 28 m</td></tr>
<tr><td rowspan="4">Great Oolite Group</td><td>Cornbrash Formation</td><td>Fine grained shelly limestone with thin clays and marls. Typically rubbly at the base but more sandy and better bedded in the upper part.</td><td>Up to 5 m</td></tr>
<tr><td>Forest Marble Formation</td><td>Clay with impersistent band of shelly limestone. Acton Turville Beds (mainly limestone) at base</td><td>Up to 35 m</td></tr>
<tr><td>Blisworth Limestone Formation</td><td>Limestone</td><td>20 to 30 m</td></tr>
<tr><td>Fullers Earth (grouped for simplicity)</td><td>Clay with chalky white limestone and Fullers Earth Rock beds</td><td>5 to 15 m</td></tr>
</table>

*Thickness from The properties for secondary aquifers in England and Wales (Jones et al., 2000), Table 6.6 page 91.

2.2.2 Superficial Geology

The superficial geology within the area of interest consists of Alluvium, Head and River Terrace Deposits.

In the majority of the study area, superficial geology is not present. However, in the northern reaches of the study area in the valley of the Bristol Avon River, there are significant River Terrace Deposits (sand and gravel).

Within the valley floor of the River Biss and its un-named tributary there are deposits of Alluvium (clay, silt, sand & gravel). Boreholes ST85NE77, ST85NE76 and ST85NE106 indicate that the thickness of Alluvium in Trowbridge town centre is around 2.1 – 3.5 m (see Figure 1 for locations). The logs suggest that the in this area the proportions of clay, silt, sand & gravel are variable.

To the south east, west and north of Trowbridge there are also deposits of Head, which comprise a mixture of clay, silt, sand & gravel. The most significant deposits within the study area are those close to Drynham and Staverton / Hilperton Marsh. The borehole logs ST86SE35 & ST85NE31 suggest that the Head deposits are around 0.6 -1.3 m thick and consist of slightly silty sandy clay (with made ground at surface).

2.3 Hydrogeology

The hydrogeological significance of the various geological units within the study area is provided in Table 2. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 2 and is shown in Figure 3.

Table 2: Geological Units in the Study Area and their Hydrogeological Significance

Geological Units		Expected Permeability Based on geological data	Hydrogeological Significance
Superficial Geology	River Terrace Deposits (Sand & Gravel)	High	Secondary A aquifer
	Head Deposits	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
	Alluvium	Low to Moderate	Variable but classified as Secondary aquifer
Bedrock Geology	Coral Rag Formation	Moderate to High	Secondary A aquifer
	Newton Clay Member	Low	Aquiclude
	Hazelbury Bryan Fm (sandstone) Hazelbury Bryan Fm (mudstone)	Moderate to High Low	Secondary A aquifer Aquiclude
	Oxford Clay Formation	Low	Aquiclude
	Kellaways Formation	Low to Moderate	Aquitard
	Kellaways Clay Member	Low	Aquiclude
	Cornbrash Formation	Moderate to High	Secondary A aquifer
	Forest Marble Formation – Mudstone Forest Marble Formation - Limestone	Low to Moderate Moderate to High	Classified as principal aquifer but generally lower horizon is more permeable.
	Blisworth Limestone Formation	High	Principal aquifer
	Fullers Earth (grouped for simplicity)	Low to Moderate	Variable but classified as Secondary aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale.
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers.

2.3.1 Bedrock Geology

The Oxford Clay Formation, Hazelbury Bryan Formation (mudstone) and Newton Clay Member are aquicludes and do not permit groundwater flow. The Environment Agency has classified these units as unproductive strata (Environment Agency website).

The BGS mapping indicates that the Kellaways Formation has a higher sand content than the Kellaway Clay Member, which is considered to behave as an aquiclude. The Environment Agency does not classify the Kellaways Formation as productive strata, and borehole log ST85NW10 indicates high clay content for the full thickness of the unit, Therefore, the Formation is assumed to behave as an aquitard for the purpose of this study.

The Hazelbury Bryan Formation (sandstone) and Coral Rag Formation are classified as aquifers (water bearing) and sit above the impermeable Oxford Clay Formation. The two units are separated by the Newton Clay Member aquiclude. These aquifers are of interest in the south east of the study area where they outcrop at surface.

The properties for primary aquifers in England and Wales (Jones et al., 1997) considers the Forest Marble Formation in this region to be a principal aquifer. The Formation has a lower permeability in the upper horizon due to a higher clay content, although the basal horizon is generally limestone facies, which are water bearing. Due to the structural geology and the River Biss, this unit has a small outcrop in the centre of Trowbridge and also in the north west corner of the study area. Therefore, the Forest Marble Formation is of some interest to the study.

The Cornbrash Formation is classified as a secondary A aquifer (water bearing) and rests above the Forest Marble Formation. The thin aquifer is expected to be hydraulically separated from the underlying Blisworth Limestone Formation (Table 1) by the clays in the Forest Marble Formation. This should allow for the development of a perched water table in the Cornbrash Formation. The Cornbrash Formation is of interest to this study because it has a significant outcrop area within the study area.

The Blisworth Limestone Formation underlies the Forest Marble Formation and is classified as a principal aquifer. The Forest Marble Formation confines the Blisworth Limestone aquifer in the Trowbridge area and therefore the aquifer is not pertinent to the current study.

2.3.2 Superficial Geology

The hydrogeological significance of the Alluvium in the river valleys is expected to be variable, although locally it may behave as an aquifer where the sand and gravel content is high. Borehole logs ST85NE77, ST85NE76 and ST85NE106 suggest that there is a perched water table within this unit in the Trowbridge area and so it is of interest to the current study.

Head deposits are expected to behave as an aquitard, although sand horizons may locally form a secondary aquifer depending on their lateral extent and thickness. Head deposits are of interest to the study in the localities where they are present.

The sand and gravel River Terrace Deposits are expected to behave as a secondary aquifer and are of interest in the northern reaches of the study area where they are present.

2.3.3 Bedrock Groundwater Levels

Cornbrash Formation

There is no monitoring undertaken by the Environment Agency in the Cornbrash Formation. In addition, the majority of the borehole logs obtained from the BGS do not contain water level data for the Cornbrash Formation. Nonetheless, Table 3 does present water level data / comments for three borehole logs. Whilst it is important to note that the data is not current and does not show seasonal fluctuations, it does suggest that a perched water table may exist at some localities. The locations of the boreholes identified within Table 3 are shown on Figure 1.

Table 3: BGS Borehole Logs - Water level Comments for the Cornbrash Formation

Borehole Name	Approximate Location	Water Level (mbgl)	Date of record	Base of Cornbrash below GL (m)
ST85NE1	Hilperton	No water level data – log comments surface geology is Cornbrash and stream present	N/a	<2
ST85NW29	Widbrook	1.8 – 1.43	08/1987	3.43
ST85NW24	Widbrook Bridge	'No water'	1983	2.6

'mbgl' – meters below ground level.
'GL' – Ground Level.

Forest Marble Formation

There is no groundwater level monitoring undertaken by the Environment Agency in the Forest Marble Formation. Whilst the lower Forest Marble Formation may be water bearing, development of groundwater resources appears to have targeted the deeper and more permeable Blisworth Limestone Formation.

Blisworth Limestone Formation

Groundwater level data for one borehole has been obtained from the Environmental Agency for the Trowbridge area. The borehole, referred to as Hilperton No 1, is located at Hilperton (Figure 1) and the water level data are provided in Appendix 1. The water level record shows that:

- Season fluctuations in the Blisworth Limestone Formation (near to Hilperton) range between 2.5 and 7.5 metres; and
- The piezometric water level in the Blisworth Limestone Formation is at significant depth below ground level in the Hilperton area. The highest water levels were recorded in 1982 (7.5 metres below ground level), although in recent years maximum piezometric water levels have been around 15 metres below ground level.

Piezometric water levels within the Blisworth Limestone Formation may be closer to ground level in other parts of the study area. However, the overlying clay horizons in the Forest Marble Formation are expected to prevent groundwater flooding from this aquifer.

2.3.4 Superficial Deposit Groundwater Levels

The Environment Agency does not monitor groundwater levels in the superficial deposits. However, four borehole logs collated from the BGS (Table 4) indicate that the water level in the Alluvium ranges between 2.8 and 6.6 metres below ground level in the centre of Trowbridge. Whilst there are no recent water level data, it would appear that in certain locations the Alluvium forms a perched aquifer over the bedrock geology.

Table 4: BGS Borehole Logs - Water level Comments for the Alluvium

Borehole Name	Water Level (mbgl)	Water Level (mAOD)	Date of record	Base of Alluvium
ST85NE12	6.4 – 6.6	Unknown	06/1976	6.5
ST85NE13	2.8	Unknown	Unknown	3.9
ST85NE106	4	32.17	11/1991	5.4
ST85NE76	4.45	Unknown	06/1994	4.9

'mbgl' – meters below ground level

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

River flow and stage data were requested from the Environment Agency and the locations of gauging stations are shown of Figure 4.

The Trowbridge gauging station monitors the stage of the River Biss before it merges with the Lambroc Stream. However, the stage data cannot be used to identify the nature of any groundwater / surface water interactions, as there are no groundwater level data for the permeable outcrop geology in this area (primarily the Cornbrash Formation).

The Hawkeridge station located further upstream of the Trowbridge station measures flow in the River Biss at North Bradley (Figure 4). The data are not relevant to the current study as the River Biss is not in hydraulic continuity with the bedrock aquifers in the study area.

With regard to superficial geology groundwater / surface water interactions, it is likely that there is some hydraulic continuity between a perched water table in the River Terrace Deposits and the Bristol Avon River. There may also be groundwater / surface water interactions associated with the Alluvium and Head Deposits along the River Biss.

Unfortunately there are no continuous or recent groundwater level data for the aquifers of interest and therefore it is not possible to gain a more informed understanding of groundwater / surface water interactions.

2.3.6 Abstractions and Discharges

Groundwater and surface water abstraction and discharge data were requested from the Environment Agency. The locations of licensed discharges and minor abstractions are shown on Figure 4.

There are no major groundwater abstractions (>20 m^3/day) within the Trowbridge study area. However, there are three small groundwater abstractions (<20 m^3/day); two near Southwick and a third near West Ashtown.

2.3.7 Artificial Groundwater Recharge

Water mains leakage data for the Trowbridge area were not provided for this study. It should be noted that additional recharge to perched groundwater tables by leaking mains could result in a local rise in groundwater levels. This rise might not prove significant under dry conditions, but could exacerbate the risk of groundwater flooding following periods of heavy rainfall.

The drainage/sewer network can act as a further source of artificial recharge. When pipes are installed within principle or secondary aquifers, the groundwater and drainage network can become hydraulically connected due to leakage. When pipes are empty, groundwater may leak into the drainage network with water flowing in through cracks and porous walls, draining the aquifer and reducing groundwater levels. During periods of heavy rainfall when pipes are full, leaking pipes can act as recharge points, artificially recharging the groundwater table and subsequently increasing groundwater levels.

These groundwater level / pipe network interactions are expected to be limited to those areas where there are outcrops of Cornbrash Formation and River Terrace Gravels, and perhaps Alluvium and Head deposits (Figure 1).

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

Based on the current hydrogeological conceptual understanding, there is potential for minor groundwater flooding in the Trowbridge study area. The key groundwater flooding mechanisms that may exist are:

- **Cornbrash Formation outcrop running south west to northeast across the study area, including central Trowbridge:** There is the potential for a perched groundwater table to exist within the Cornbrash Formation. Due to the permeable but thin nature of this Formation, basements / cellars and other underground structures may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of infiltration SUDs and / or artificial recharge from leaking pipes.
- **Hazelbury Bryan Formation (sandstone) and Coral Rag Formation outcrop area in the south east of the study area (West Ashton):** These two Formations are classified as aquifers and whilst there is no supporting water level data it is likely that a perched groundwater table exists within these Formations. Basements / cellars and other underground structures may be at risk from groundwater flooding following periods of prolonged rainfall, increased utilisation of SUDs and / or artificial recharge from leaking pipes.
- **Superficial geology aquifers in hydraulic continuity with the Bristol Avon River and its tributaries:** Groundwater flooding may be associated with the substantial sand and gravel River Terrace Deposits, or to a lesser degree Head and Alluvium deposits, where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain “in-bank”, and this can trigger a rise in groundwater levels in the associated superficial deposits. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial deposits.
- **Superficial aquifers not in hydraulic continuity with surface water courses:** groundwater flooding is also associated with substantial River Terrace Deposits (gravel and sand) and Head deposits, but occurs where they are not hydraulically connected to surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars.
- **Impermeable (silt and clay) areas downslope of aquifers in various locations:** Groundwater flooding may occur where groundwater springs / seepages form minor flows and ponding over impermeable strata where there is poor drainage. This mechanism may occur as a result of natural (e.g. rainfall) or artificial (e.g. water main leakage) recharge.
- **Made ground in various locations:** a final mechanism for groundwater flooding may occur where the ground has been artificially modified to a significant degree. If this ‘made ground’ is of substantial thickness and permeability, then a shallow perched water table may exist. This could potentially result in groundwater flooding at properties with basements, or may equally be considered a drainage issue.

3.2 Evidence of Groundwater Flooding

There are no reported groundwater flooding incidents within the study area However, other sources of flooding have been identified and the locations of historic flood incidents are shown on Figures 1, 3, 4 and 5 and details are provided in Table 5. It is possible that some of these incidents were influenced by groundwater conditions, although there are no available data to confirm this.

Table 5: Historic Flooding Incidents within the Study Area.

Bedrock Geological Units*	Superficial Deposits*	Grid Reference	No**	Reported Incident	Date
Cornbrash Fm	None	159084 386421	1	Sewer - 2 in 10 years	09/01/2007
Cornbrash Fm	None	158024 384954	2	Sewer - 2 in 10 years	09/01/2007
Kellaways Fm	None	156104 384675	3	Sewer - 2 in 10 years	09/01/2007
Oxford Clay Fm	None	156616 385466	4	Sewer - 2 in 10 years	09/01/2007
Kellaways Fm	Alluvium	158720385006	5	Sewage Treatment Works, pumping stopped for a while	12/05/1960
Kellaways Fm	Alluvium	158370 384880	6	Fluvial - Ladydown Mill, Trowbridge up to confluence with the Lambrok Stream. No further details.	12/04/1960
Kellaways Fm	Alluvium	159100 385400	7		07/10/1968
Kellaways Fm	Alluvium	159100 385400	8		01/01/1991
Kellaways Fm	Alluvium	159100 385400	9		01/01/1991
Kellaways Fm	Alluvium	159100 385400	10		01/01/1991
Oxford Clay Fm	None	157780 386258	11	Sewer - 2 in 10 years	09/01/2007
Oxford Clay Fm	None	157687 386386	12	Sewer - 2 in 10 years	09/01/2007

3.3 Areas Susceptible to Groundwater Flooding

The Environment Agency has produced a data set referred to as 'Areas Susceptible to Groundwater Flooding (AStGWF)', on a 1 km grid (Figure 5). This utilises the BGS 1:50,000 Groundwater Flood Susceptibility data set for consolidated aquifers (bedrock) and superficial geology.

The Environment Agency data set shows the percentage of each 1 km square that falls within the high to very high BGS groundwater flooding susceptibility categories. It does not show the probability / risk of groundwater flooding occurring; this can only be determined following site specific investigation works and desk studies. It also does not take into account groundwater level rebound following cessation of abstraction.

An absence of values for any grid square means that no part of that square is identified as being susceptible to groundwater emergence (Environment Agency AStGWF Guidance Document).

The areas that are identified as being most susceptible to groundwater flooding are located close to the Upper Bristol Avon River in the north of the study area, or close to the River Biss in the south of the study area (Drynham / North Bradley). By comparing the data with Figure 1 (geological map) it is apparent that the areas susceptible to groundwater flooding are those where significant superficial deposits are present, particularly River Terrace Deposits.

It is interesting to note that many of the grid squares representing outcrops of Cornbrash Formation (e.g. Hilperton), Hazelbury Bryan Formation and Coral Rag Formation (West Ashton) have not been identified as areas susceptible to groundwater flooding. This may reflect the lack of water level data available to the BGS when creating the original Groundwater Flood Susceptibility Map. This notwithstanding, it is thought that the approximate areas identified by the Environment Agency as being susceptible to groundwater flooding are sensible.

3.4 Importance of Long Term Groundwater Level Monitoring

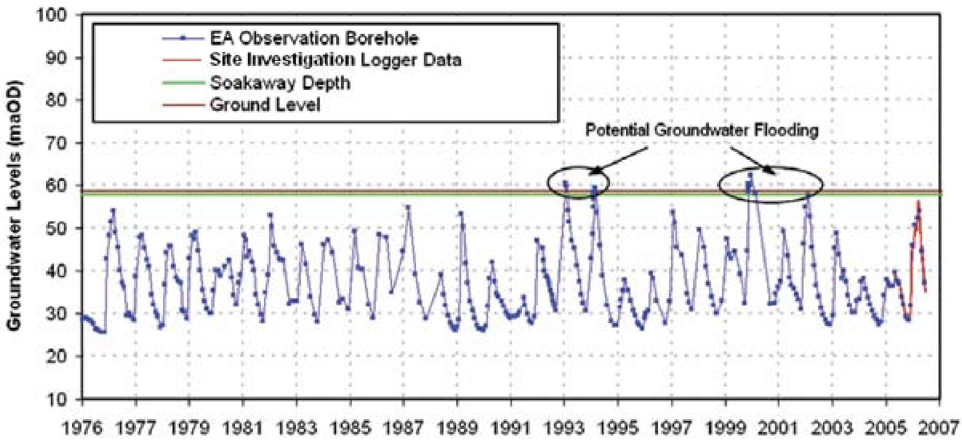
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibly of an area to groundwater flooding. Unfortunately groundwater level data for the superficial aquifers is limited to recorded water strikes or rest water levels on BGS borehole logs, which only provide groundwater levels at one location and for one point in time. Without long term groundwater monitoring, it is not possible to derive groundwater level contours, or understand maximum seasonal fluctuations. Therefore it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

It is not sufficient to rely on the work undertaken by developers through the planning application process, unless long term monitoring (several years) is one of the conditions when granting planning permission. Groundwater levels are often only measured once, or, at most, for a number of weeks. It would be advisable for the Council, in combination with the Environment Agency, to begin long term monitoring of the Cornbrash Formation and River Terrace Deposit groundwater levels. This data would also be useful for understanding groundwater / surface water interactions, which is important when considering the design of fluvial flood defences.

It is also important to understand how changing policies relating to infiltration SUDS can impact groundwater levels. For example the introduction of infiltration SUDS (e.g. soakaways) may cause a rise in peak groundwater levels. This could prevent soakaways from operating and the reduction in unsaturated zone thickness may not be acceptable to the Environment Agency owing to its responsibilities under the Water Framework Directive.

Long term groundwater level monitoring is required to support decision making with respect to future land development and future co-ordinated investments to reduce the risk and informing the assessment of suitability for infiltration SUDS.

Schematic demonstrating the importance of long term groundwater level monitoring



4 Water Framework Directive and Infiltration SUDS

The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The Thames River Basin District is considered within the current study since infiltration Sustainable Drainage Systems (SUDS) have the potential to impact the water quality and water quantity status of aquifers and surface water courses.

4.1 Current Quantity and Quality Status

The current quantitative assessment for the Bristol Avon Forest Marble aquifer (GB40902G302900) is 'poor' but the current quality assessment is 'good'. The quantitative assessment in 2015 is predicted to remain as poor due to a poor resource balance. However, the chemical quality in 2015 is predicted to remain as 'good'. The current overall status is classified as 'poor' but the status objective is to have 'Good Quantitative Status by 2027, Good Chemical Status by 2015'.

The RBMPs only consider the quantitative and quality assessment for the Bristol Avon Forest Marble aquifer in the Trowbridge study area. There is no assessment for the Cornbrash Formation, Hazelbury Bryan Formation or Coral Rag Formation in the study area.

4.2 Infiltration SUDS Suitability

Improper use of infiltration SUDS could lead to contamination of the superficial or bedrock geology aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

Environment Agency guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Wiltshire Council when approving or rejecting planning applications.

The areas that may be suitable for infiltration SUDS (e.g. soakaways, permeable paving) exist where there is a combination of higher ground (interfluves) and permeable geology (see Figure 3). For example, although the River Terrace Deposits to the north of the study area are expected to be permeable, they are close to a major surface water course and the depth to groundwater may be unsuitable for infiltration SUDS.

Consideration should also be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at the down gradient location. This type of analysis is beyond the scope of the current report.

Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ), which are shown on Figure 3. However, Figure 3 shows that currently there are no SPZs in the Trowbridge study area.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

- The clays of the Forest Marble Formation are expected to hydraulically separate the underlying Blisworth Limestone Formation principal aquifer from the surface aquifers. Therefore, the Blisworth Limestone Formation is not of key interest to the groundwater flooding assessment.
- The key areas of interest are those underlain by the Cornbrash Formation, Hazelbury Bryan or River Terrace Deposits (Figure 1). These geological units are expected to behave as aquifers and are likely to contain perched water tables i.e. they are a potential source of groundwater flooding. Where Alluvium and Head deposits exist, these may also contain perched water tables.
- A number of potential groundwater flooding mechanisms have been identified. Key mechanisms are (i) rapid water level fluctuations in the River Terrace Deposits (Bristol Avon River) and Alluvium / Head deposits (River Biss) in response to river stage fluctuations, and (ii) response of perched groundwater levels within the Cornbrash Formation and Hazelbury Bryan Formation to increased use of infiltration SUDS, leaking pipes and barriers to groundwater flow such as sheet piling. Properties at greatest risk of flooding are those with basements / cellars.
- Based on the available flood incident data and Environment Agency 'Areas Susceptible to Groundwater Flooding' data set, the areas most susceptible to groundwater flooding are those associated with River Terrace Deposits (close to the Bristol Avon) or Alluvium / Head deposits (River Biss).
- The lack of reported groundwater flooding incidents suggests that whilst a perched aquifers may exist, groundwater levels are sufficiently low and/or there are a lack of receptors (e.g. basements), such that groundwater flooding has not been an issue. However, it is important to note that increased discharges to these aquifers through infiltration SUDs may lead to future groundwater flooding issues. Therefore, use of infiltration SUDs should be carefully managed.
- The Environment Agency and Council do not currently monitor groundwater levels in the aquifers that outcrop in this area. Without long term groundwater monitoring, it is not possible to derive groundwater level contours or understand maximum seasonal fluctuations and potential climate change impacts. Therefore, at this stage, it is not possible to provide a detailed assessment of groundwater flood risk or provide detailed advice on suitability for infiltration SUDS.

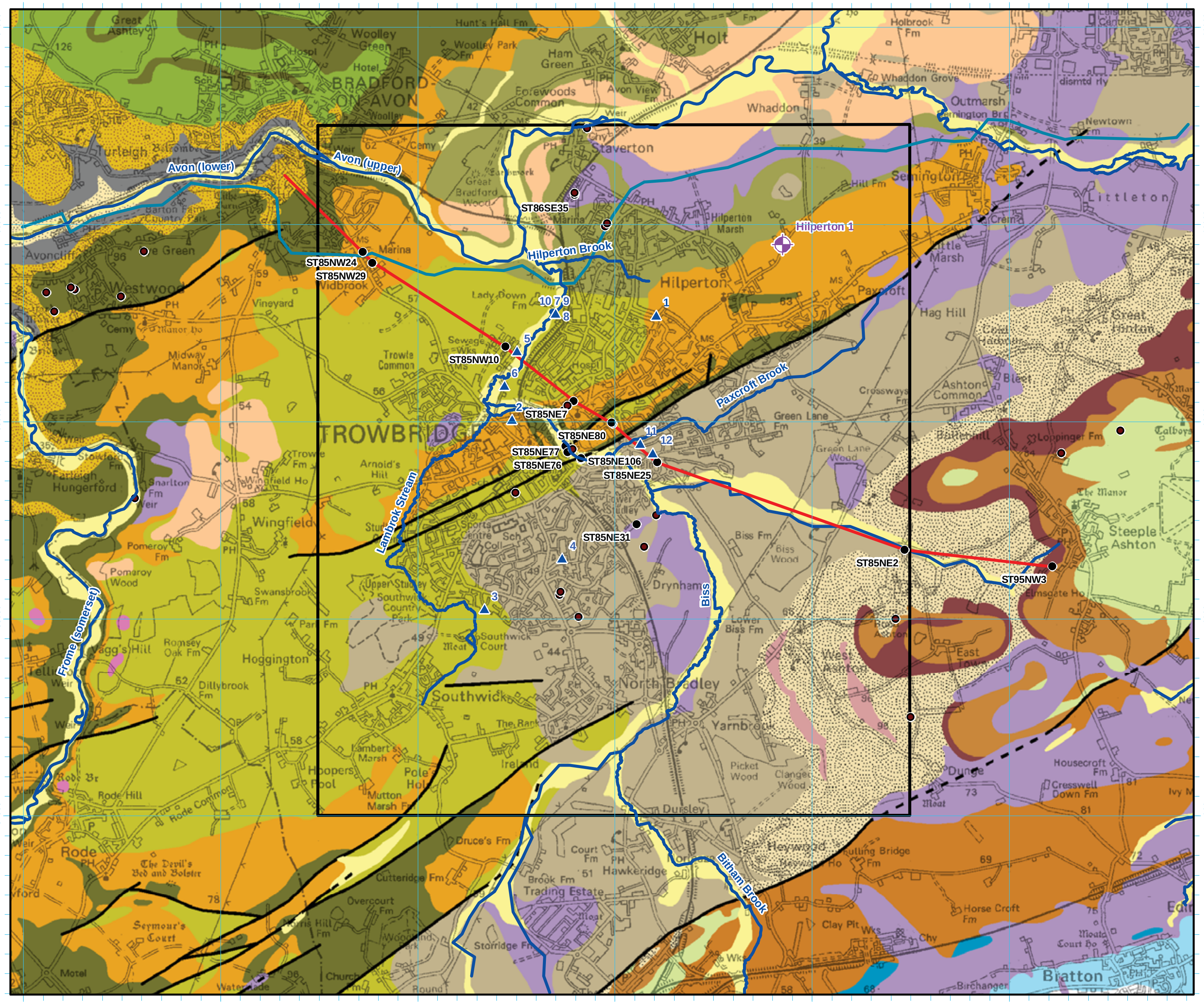
5.2 Recommendations

The following recommendations are made based on the current draft report:

- Data identifying properties with basements / cellars should be collected by Wiltshire Council;
- Site investigation reports for historic development sites could be reviewed to obtain additional groundwater level information, to improve the conceptual understanding of the area;
- The areas identified as being susceptible to groundwater flooding should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial, pluvial and sewer. An integrated understanding of flood risk will be gained through this exercise;
- Pluvial modelling often assumes that no infiltration of rainfall occurs (a worst case scenario). It is recommended that a sensitivity analysis is undertaken, whereby infiltration is modelled in those areas where permeable superficial geology are located;
- Monitoring boreholes should be installed in the River Terrace Deposits, Cornbrash Formation and Hazelbury Bryan fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. At this point a review of the monitoring network should be undertaken and an update on infiltration SUDS guidance provided.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered when approving planning applications;
- The impact of infiltration SUDS on groundwater levels (and therefore groundwater risk) should be considered further. This may require the construction of a local groundwater model following collection of groundwater level data.

6 References

- DEFRA, March 2010. Surface Water Management Plan Technical Guidance.
- Environment Agency, December 2009. River Basin Management Plan. Thames River Basin District (Annex B).
- Environment Agency, 2010. Areas Susceptible to Groundwater Flooding. Guidance Document
- Jones, H K, Morris, B L, Cheney, C S, Brewerton, L J, Merrin, P D, Lewis, M A, MacDonald, A M, Coleby, L M, Talbot, J C, McKenzie, A A, Bird, M J, Cunningham, J, and Robinson, V K., 2000. The physical properties of minor aquifers in England and Wales. British Geological Survey Technical Report, WD/00/4. 39pp. Environment Agency R&D Publication 68.



THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Trowbridge Study Area
- Trowbridge Cross Section (Figure 2)
- Main River
- Kennet and Avon Canal
- Historic Flooding Incident

Environment Agency Monitoring Boreholes

- Great Oolite

BGS Borehole Logs

- Referenced within text
- Other

Superficial Geology

- Alluvium (Clay, Silt, Sand & Gravel)
- Head (Clay, Silt, Sand & Gravel)
- River Terrace Deposits (Sand & Gravel)
- Sand & Gravel (Uncertain Age & Origin)

Bedrock Geology

- Upper Greensand Fm (Sandstone)
- Gault Fm
- Kimmeridge Clay Fm (Mudstone)
- Sandsfoot Fm (Sandstone)
- Coral Rag Fm (Ooidal Limestone)
- Newton Clay Member (Sandy Mudstone)
- Hazelbury Bryan Fm (Sandstone)
- Hazelbury Bryan Fm (Mudstone)
- Oxford Clay Fm (Mudstone)
- Kellaways Fm (Sandy Mudstone)
- Kellaways Clay Member (Mudstone)
- Cornbrash Fm (Limestone)
- Forest Marble Fm (Mudstone)
- Forest Marble Fm (Limestone)
- Blisworth Limestone Formation
- Fullers Earth Fm (undifferentiated)
- Inferior Oolite Group (Ooidal Limestone)
- Bridport Sand Fm (Sandstone)
- Fault overlain by superficials
- Fault present at outcrop

NOTES
Sandsfoot Fm - Grouping of Wesbury Ironstone Member + Sandsfoot Fm Mudstone & Sandsfoot Fm Limestone

Drawing Status: FINAL

Job Title: Trowbridge Surface Water Management Plan

Drawing Title: Geological Map

Scale at A3: 1:40,000

Drawn by	Date	Approved	Date
RAC	16/03/11	SJC	18/03/11

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FIGURE 1

Base Map Details
Projection: Transvers Mercator
Scale Factor: 0.999601
Origin: 2° West, 49° North
Coordinates: 400000,-100000
Units: metres
Datum: OSGB 1936

0 0.35 0.7 1.4 2.1 Kilometers

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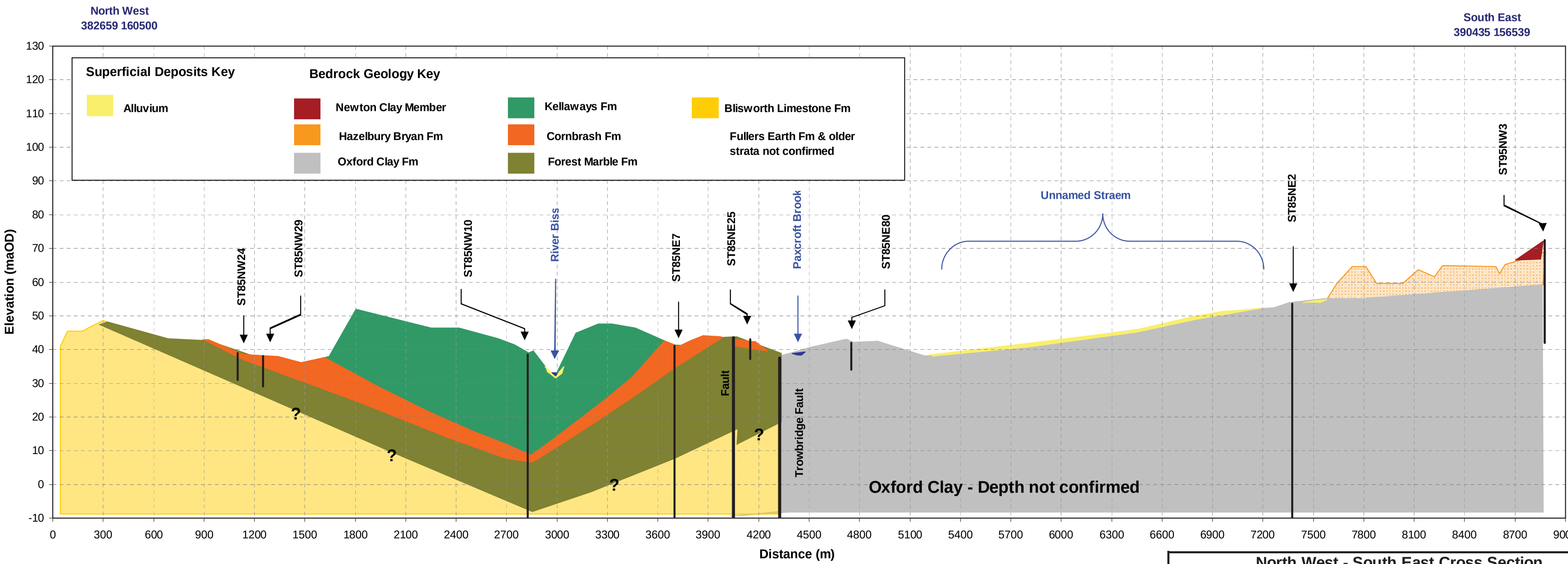

North West - South East Cross Section			
D133429		Figure 2	
Drawn By	Date	Approved	Date
R.Cox	15/02/2011	S. Cox	29/02/2011

URS / Scott Wilson
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Basingstoke, Hampshire RG21 7PP
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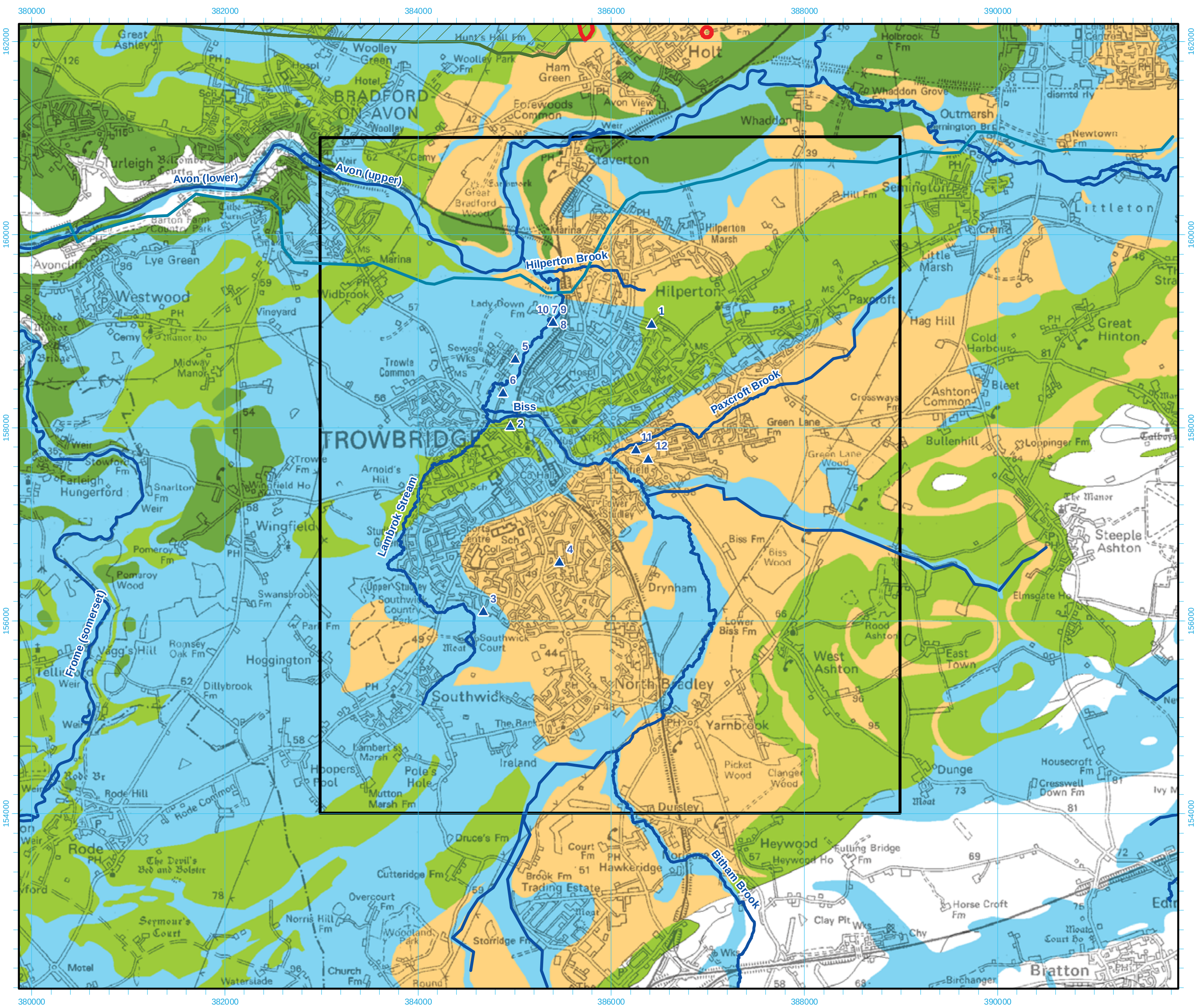
File :\jobs\DCT1971\700 Technical\701 Data\Site Cross Section_West_East



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Base Map Details
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Origin: 2° West, 49° North
Coordinates: 400000,-100000
Units: metres
Datum: OSGB 1936

0 0.35 0.7 1.4 2.1 Kilometers

Filepath: K:\jobs\D133429 Wiltshire Council SWMP\700 Technical\711 GIS\01 Layout\Trowbridge

THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Trowbridge Study Area
- Main River
- Kennet and Avon Canal
- Historic Flooding Incident

Source Protection Zones (SPZ)

- Inner (zone 1)
- Outer (zone 2)

Expected Permeabilty

- High
- Moderate to High
- Low to Moderate
- Low
- Not defined - not pertinent to study

Notes:

This map forms an approximate guide to permeability. However, for all new developments, site investigation is required to confirm local permeabilities and infiltration rates.

Drawing Status: FINAL

Job Title: Trowbridge Surface Water Management Plan

Drawing Title: Expected Permeability Map & Source Protection Zones

Scale at A3: 1:40,000

Drawn by	Date	Approved	Date
RAC	10/02/11	SJC	15/02/11

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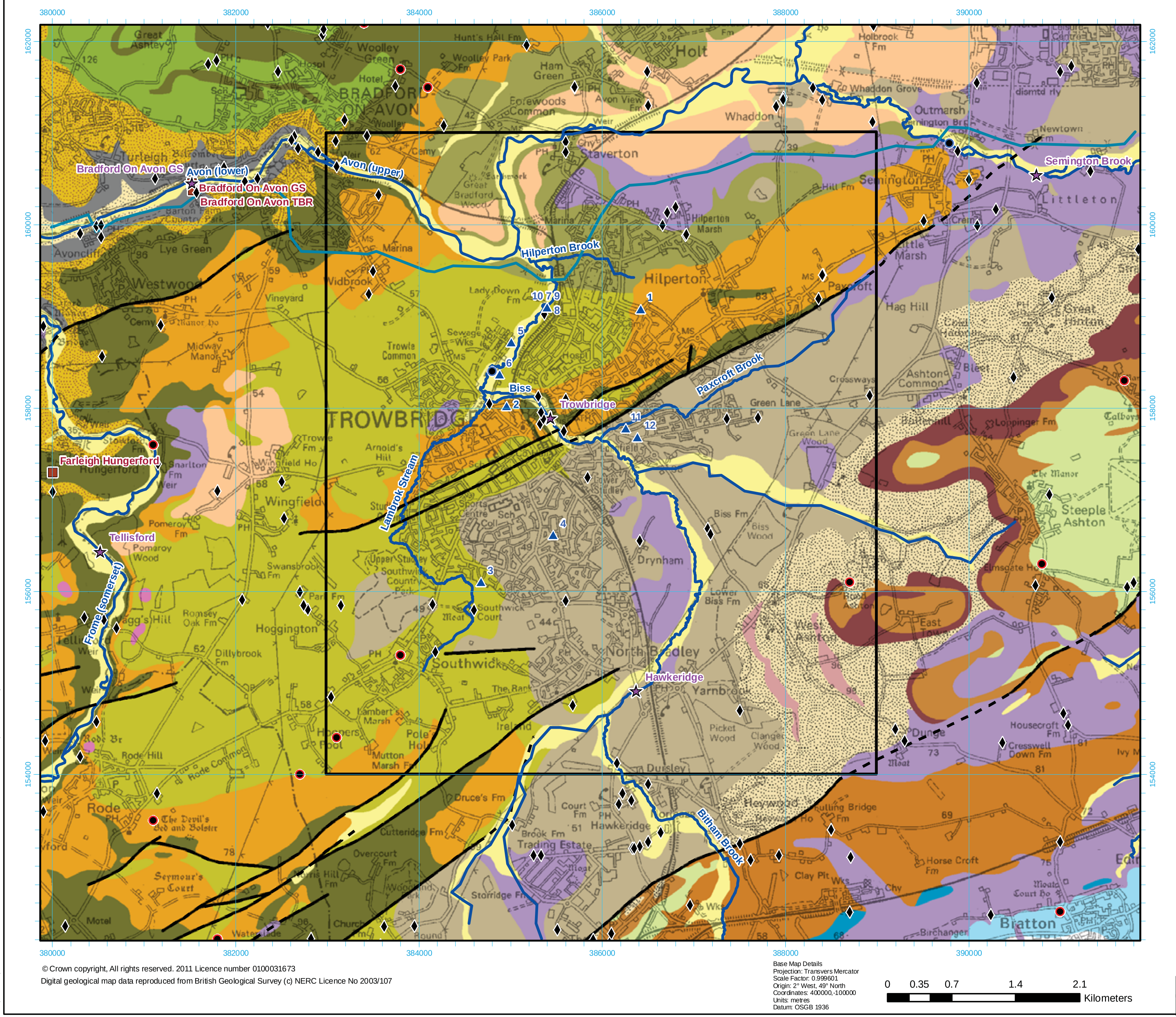
FIGURE 3



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THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Trowbridge Study Area
- Main River
- Kennet and Avon Canal
- Historic Flooding Incident

Minor Abstractions <20m3/d

- Groundwater
- Surface Water

Other

- River Flow Station
- Rainfall Station Events
- Licensed Discharge

Superficial Geology

- Alluvium (Clay, Silt, Sand & Gravel)
- Head (Clay, Silt, Sand & Gravel)
- River Terrace Deposits (Sand & Gravel)
- Sand & Gravel (Uncertain Age & Origin)

Bedrock Geology

- Upper Greensand Fm (Sandstone)
- Gault Fm
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- Hazelbury Bryan Fm (Mudstone)
- Oxford Clay Fm (Mudstone)
- Kellaways Fm (Sandy Mudstone)
- Kellaways Clay Member (Mudstone)
- Cornbrash Fm (Limestone)
- Forest Marble Fm (Mudstone)
- Forest Marble Fm (Limestone)
- Blisworth Limestone Fm
- Fullers Earth (undifferentiated)
- Inferior Oolite Group (Ooidal Limestone)
- Bridport Sand Fm (Sandstone)
- Fault present at outcrop
- Fault overlain by superficials

NOTES
Sandsfoot Fm - Grouping of Wesbury Ironstone Member + Sandsfoot Fm Mudstone & Sandsfoot Fm Limestone

Drawing Status: FINAL

Job Title: Trowbridge Surface Water Management Plan

Drawing Title: Discharge Consents & Groundwater Abstractions

Scale at A3: 1:40,000

Drawn by	Date	Approved	Date
RAC	15/03/11	SJC	17/03/11

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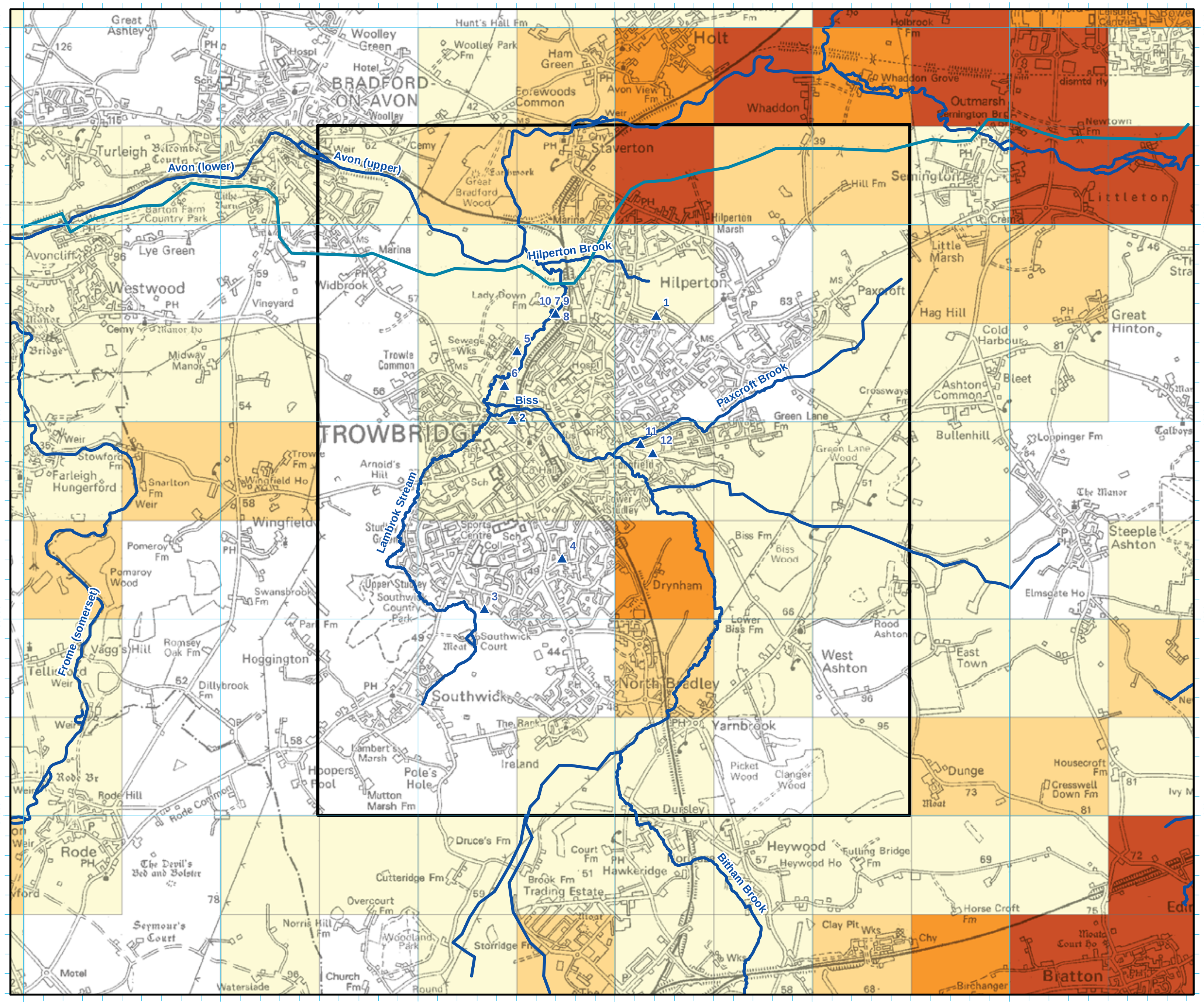
FIGURE 4



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Units: metres
Datum: OSGB 1936

0 0.35 0.7 1.4 2.1 Kilometers

THIS DRAWING MAY BE USED ONLY FOR THE PURPOSE INTENDED

Legend

- Trowbridge Study Area
- Main River
- Kennet and Avon Canal
- Historic Flooding Incident

Areas Susceptible to Groundwater Flooding

- >= 75%
- >= 50% <75%
- >= 25% <50%
- < 25%

Notes:

This map forms an approximate guide to areas that may be susceptible to groundwater flooding. However, for all new developments, site investigation is required to confirm local groundwater levels and therefore risk of groundwater flooding.

Drawing Status: FINAL

Job Title: Trowbridge Surface Water Management Plan

Drawing Title: Areas Susceptible to Groundwater Flooding Map

Scale at A3	1:40,000		
Drawn by: RAC	Date: 10/02/11	Approved: SJC	Date: 15/02/11

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FIGURE 5

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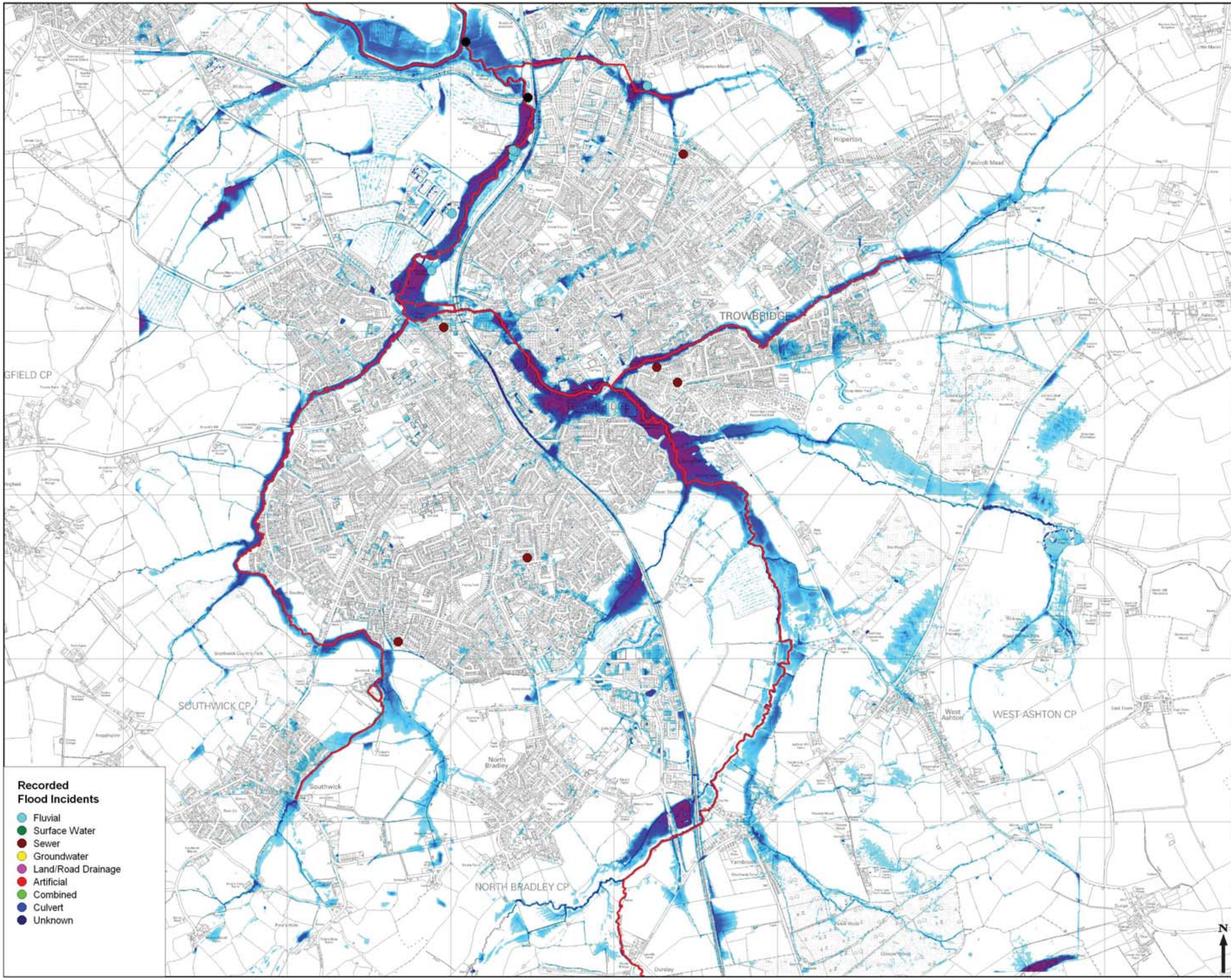

NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Water Depth 1 in 30 Year Pluvial Event

Scale at A3: 1:21,500

Drawn	MJC	Approved	RS
Stage 1 Check MJC	Stage 2 Check MJC	Originated MJC	Date 19/07/2011

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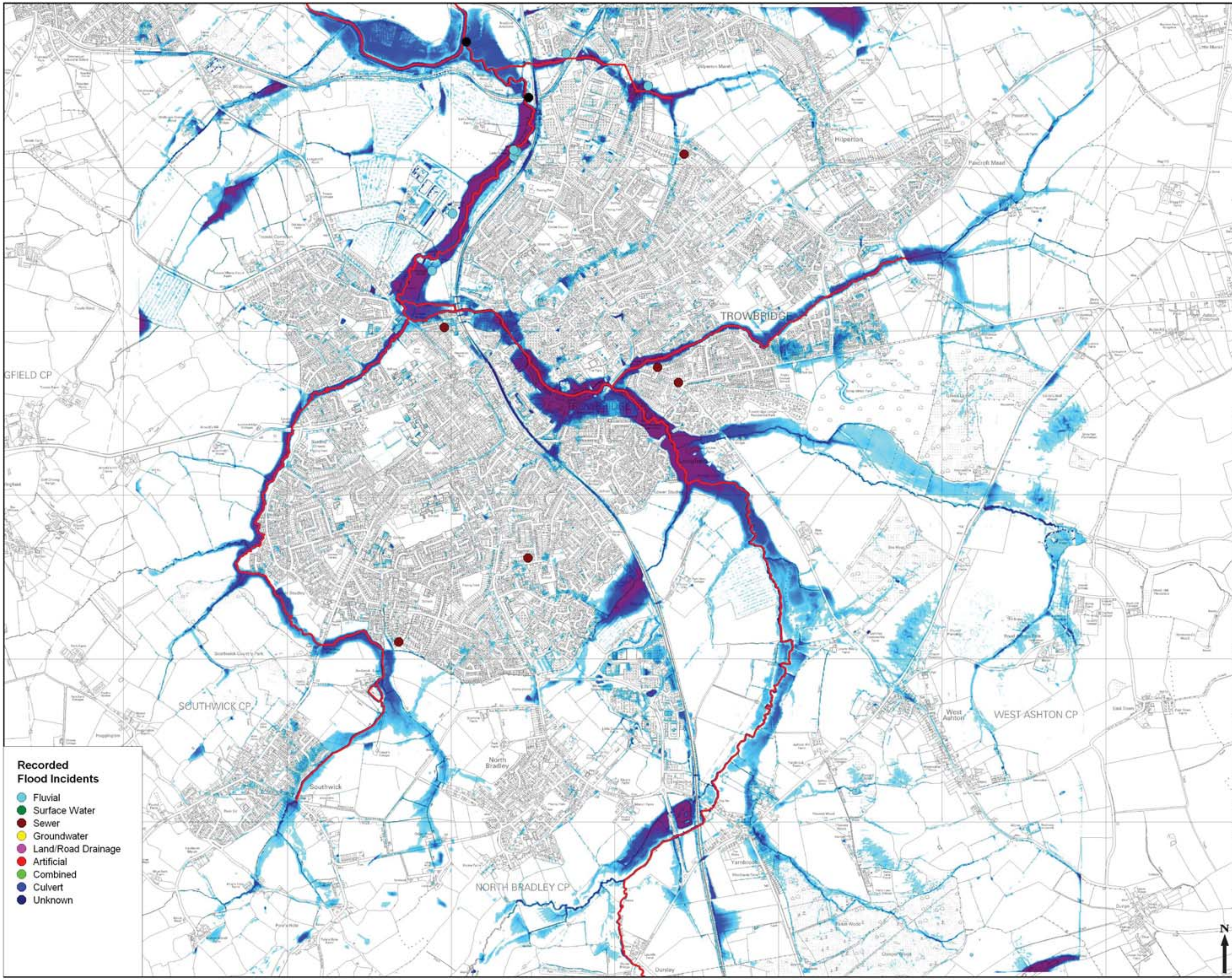
Drawing Number: **FIGURE 1**

Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Water Depth 1 in 30 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3	1:21,500
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Stage 1 Check: MJC	Stage 2 Check: MJC
Originated: MJC	Date: 19/07/2011

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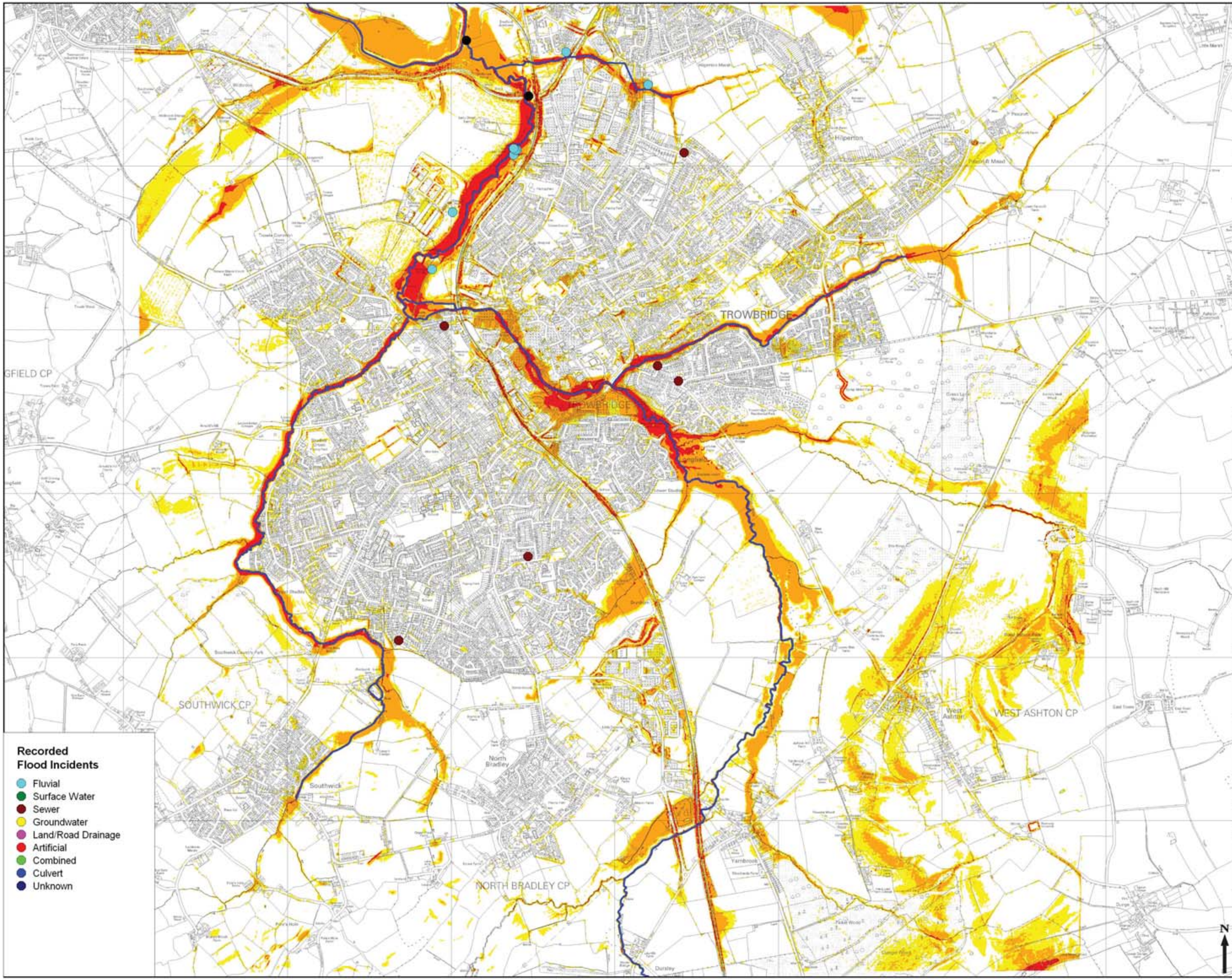
Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Hazard Class

- Low
- Medium
- High

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Revision Details	By / Check	Date	Suffix

Drawing Status: **FINAL**

Job Title: **Wiltshire Council Surface Water Management Plan Phase II**

Drawing Title: **Trowbridge Area - Indicative Max Hazard 1 in 30 Year (Inclusive of Climate Change) Pluvial Event**

Scale at A3: 1:21,500

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Stage 1 Check MJC	Stage 2 Check MJC	Originated MJC	Date 19/07/2011

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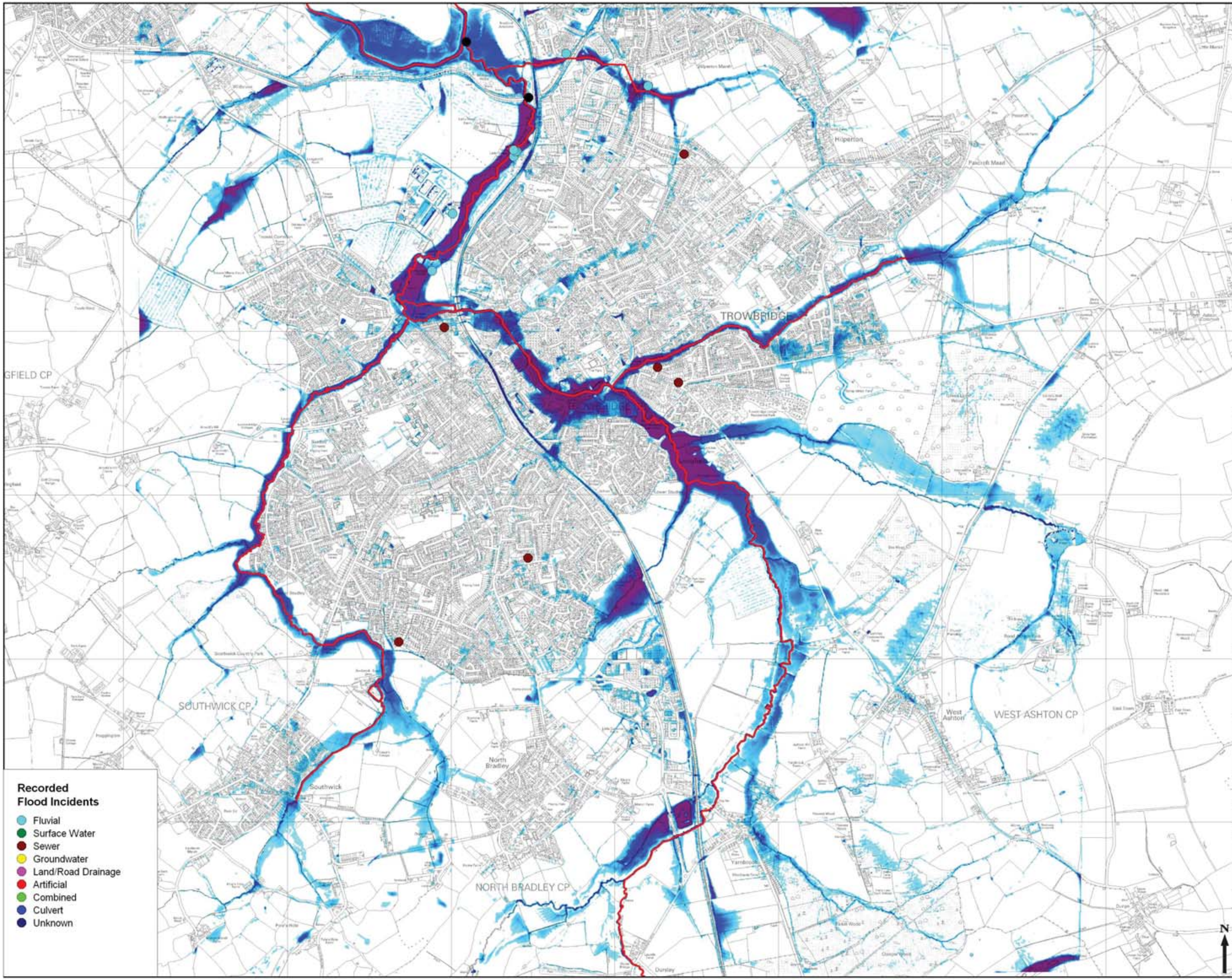
Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Water Depth 1 in 100 Year Pluvial Event

Scale at A3	1:21,500		
Drawn	MJC	Approved	RS
Stage 1 Check MJC	Stage 2 Check MJC	Originated MJC	Date 19/07/2011

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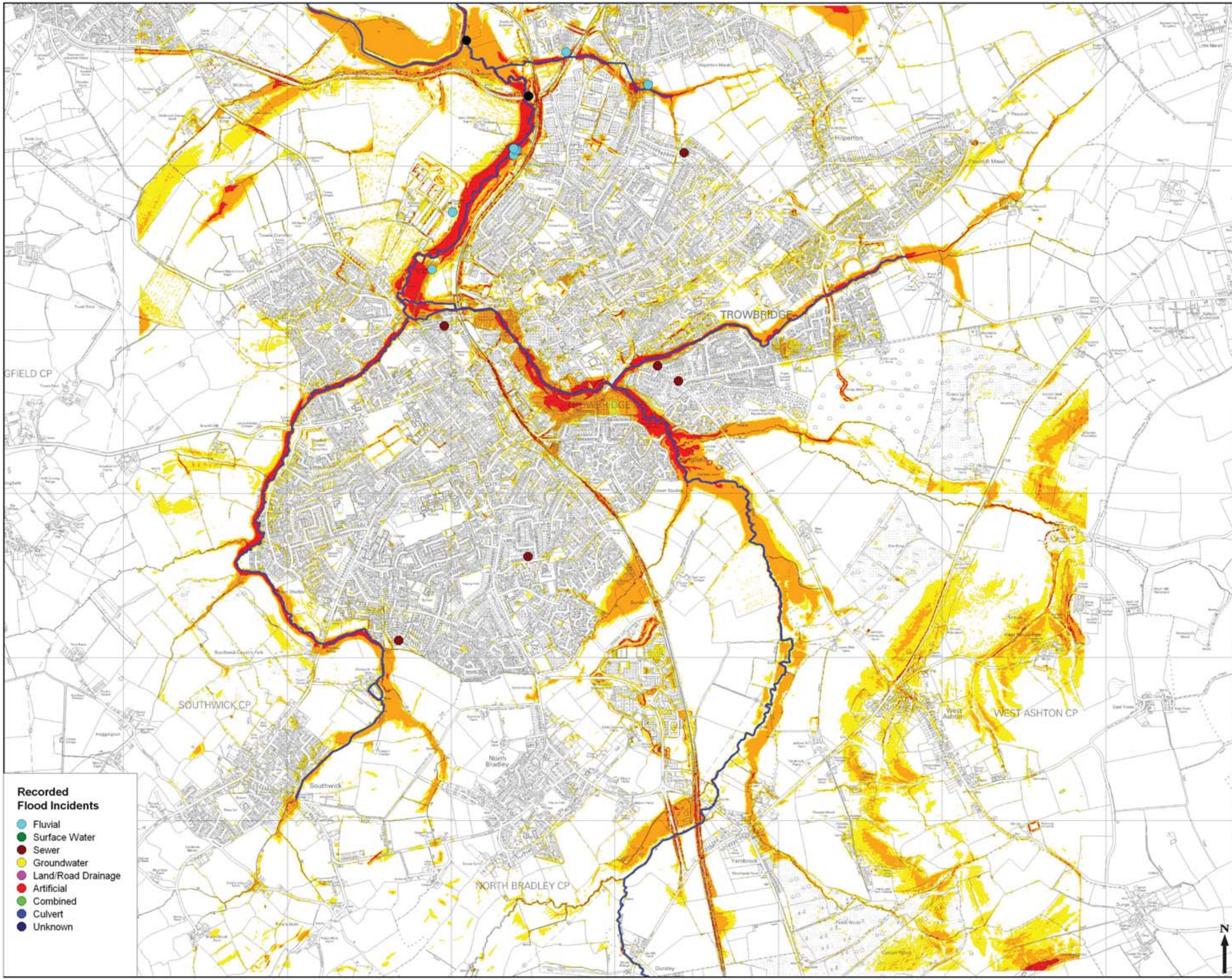
Rev 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency

Main River

Indicative Hazard Class

- Low
- Medium
- High

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Hazard 1 in 100 Year Pluvial Event

Scale at A3	1:21,500		
Drawn	MJC	Approved	RS
Stage 1 Check MJC	Stage 2 Check MJC	Originated MJC	Date 19/07/2011

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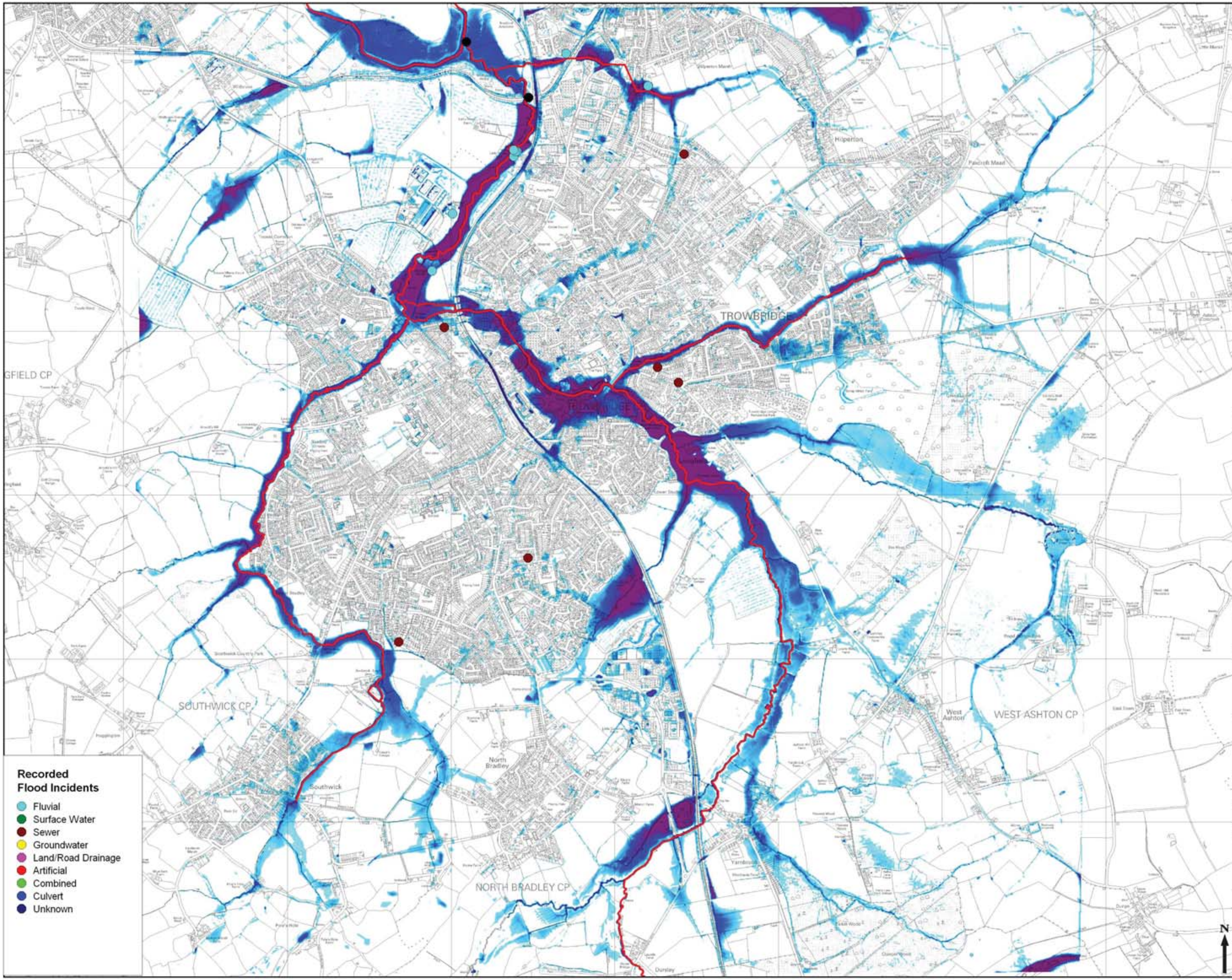

NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

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Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Water Depth 1 in 100 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3: 1:21,500

Drawn	MJC	Approved	RS
Stage 1 Check: MJC	Stage 2 Check: MJC	Originated: MJC	Date: 19/07/2011

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Drawing Number: FIGURE 7

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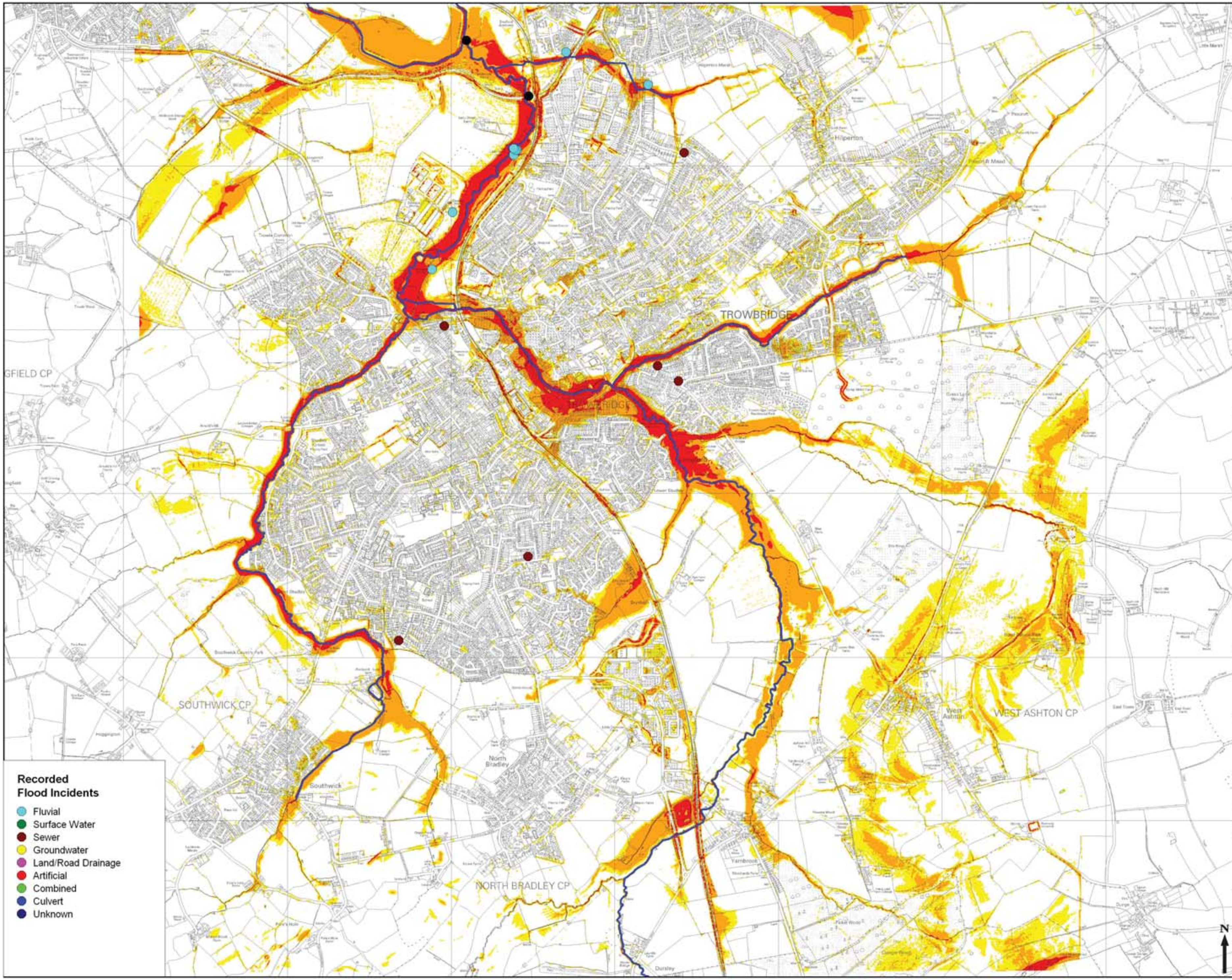

NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency
Main River

Indicative Hazard Class
- Low
- Medium
- High

Copyright

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Hazard 1 in 100 Year (Inclusive of Climate Change) Pluvial Event

Scale at A3: 1:21,500

Drawn: MJC		Approved: RS	
Stage 1 Check: MJC	Stage 2 Check: MJC	Originated: MJC	Date: 19/07/2011

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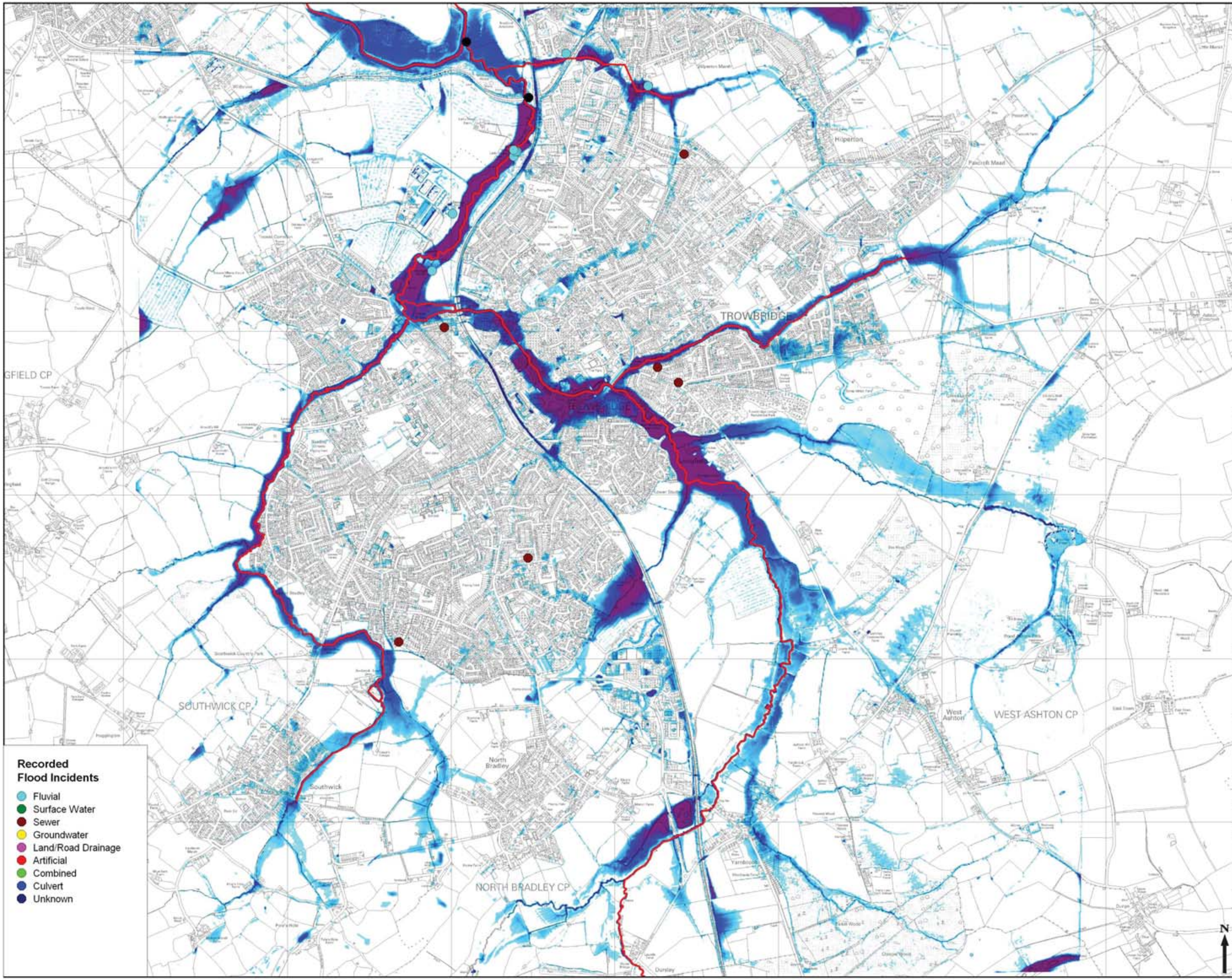
Drawing Number: **FIGURE 8**   Rev: 0002



NOTES

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Legend

Environment Agency Main River

Indicative Max Water Depth (m)

1.5
1.0
0.5
0.1

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Water Depth 1 in 200 Year Pluvial Event

Scale at A3: 1:21,500

Drawn: MJC | Approved: RS

Stage 1 Check: MJC | Stage 2 Check: MJC | Originated: MJC | Date: 19/07/2011

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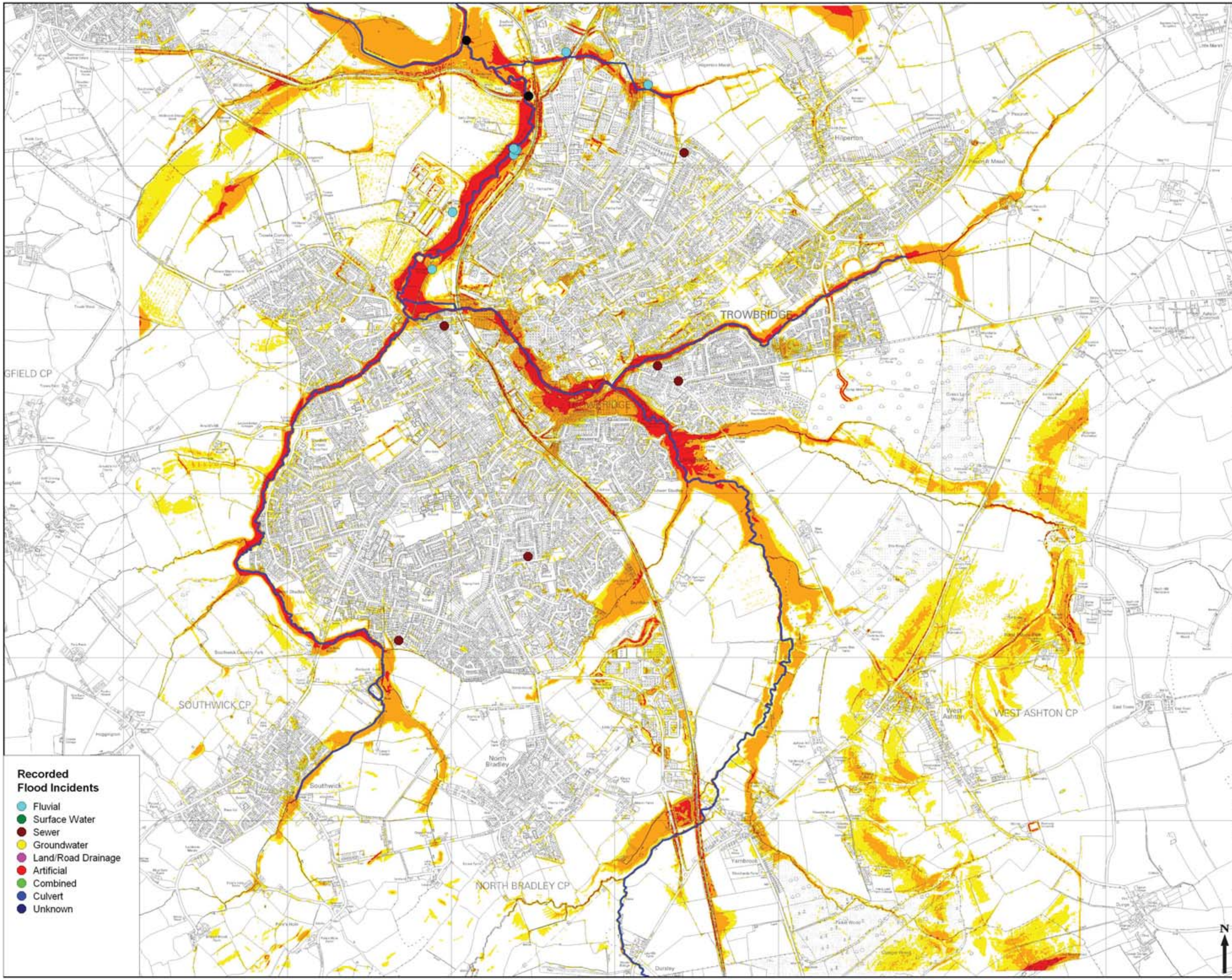
Drawing Number: **FIGURE 9** Rev: 0002



NOTES

MAPPING FOR USE ONLY AT THE STRATEGIC LEVEL

Legend

Environment Agency Main River

Indicative Hazard Class

- Low
- Medium
- High

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: Wiltshire Council Surface Water Management Plan Phase II

Drawing Title: Trowbridge Area - Indicative Max Hazard 1 in 200 Year Pluvial Event

Scale at A3: 1:21,500

Drawn	MJC	Approved	RS
Stage 1 Check MJC	Stage 2 Check MJC	Originated MJC	Date 19/07/2011

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Drawing Number: FIGURE 10

Rev: 0002

Salisbury Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 2

November 2011

Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

Surface Water Management Plan – Intermediate Assessment of Groundwater Flooding Susceptibility
November 2011

Rev	Date	Details	Prepared by	Reviewed by	Approved by
01	06/04/2011	Draft - for client comment only	**Trevor Muten** Principal Hydrogeologist	**Stephen Cox** Senior Hydrogeologist	**Jane Sladen** Technical Director
02	November 2011	Final – No client comments following draft			

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Abbreviations

ACRONYM	DEFINITION
AStGWF	Areas Susceptible to Groundwater Flooding
BGS	British Geological Survey
DEFRA	Department for Environment, Fisheries and Rural Affairs
EA	Environment Agency
RBMP	River Basement Management Plan
SFRA	Strategic Flood Risk Assessment
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan

Glossary

TERM	DEFINITION
Aquiclude	Formations that may be sufficiently porous to hold water, but do not allow water to move through them.
Aquifer	Layers of rock sufficiently porous to hold water and permeable enough to allow water to flow through them in quantities that are suitable for water supply.
Aquitard	Formations that permit water to move through them, but at much lower rates than through the adjoining aquifers.
Climate Change	Long term variations in global temperature and weather patterns, caused by natural and human actions.
Flood defence	Infrastructure used to protect an area against floods, such as floodwalls and embankments; they are designed to a specific standard of protection (design standard).
Fluvial flooding	Flooding by a river or a watercourse.
Groundwater	Water that is underground. For the purposes of this study, it refers to water in the saturated zone below the water table.
Interfluve	A ridge or area of land dividing two river valleys.
Pluvial Flooding	Flooding as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity.
Risk	The product of the probability and consequence of the occurrence of an event.
Sewer flooding	Flooding caused by a blockage, under capacity or overflowing of a sewer or urban drainage system.
Sustainable Drainage Systems	Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques. The current study refers to the 'infiltration' category of sustainable drainage systems e.g. soakaways, permeable paving.

1 Introduction

1.1 Groundwater Flooding

Groundwater flooding occurs as a result of water rising up from the underlying aquifer or water flowing from groundwater springs. This tends to occur after long periods of sustained high rainfall, and the areas at most risk are often low-lying where the water table is more likely to be at shallow depth. Groundwater flooding is known to occur in areas underlain by principal aquifers, although increasingly it is also being associated with more localised floodplain sands and gravels.

Groundwater flooding tends to occur sporadically in both location and time, and tends to last longer than fluvial, pluvial or sewer flooding. Basements and tunnels can flood, buried services may be damaged, and storm sewers may become ineffective, exacerbating the risk of surface water flooding. Groundwater flooding can also lead to the inundation of farmland, roads, commercial, residential and amenity areas.

It is also important to consider the impact of groundwater level conditions on other types of flooding e.g. fluvial, pluvial and sewer. High groundwater level conditions may not lead to widespread groundwater flooding. However, they have the potential to exacerbate the risk of pluvial and fluvial flooding by reducing rainfall infiltration capacity, and to increase the risk of sewer flooding through sewer / groundwater interactions.

The need to improve the management of groundwater flood risk in the UK was identified through DEFRA's Making Space for Water strategy. The review of the July 2007 floods undertaken by Sir Michael Pitt highlighted that at the time no organisation had responsibility for groundwater flooding. The Flood and Water Management Act identified new statutory responsibilities for managing groundwater flood risk, in addition to other sources of flooding and has a significant component which addresses groundwater flooding.

1.2 The Current Report

Wiltshire Council has commissioned Scott Wilson to complete Phases 1 and 2 of their Surface Water Management Plan (SWMP). A SWMP is a plan which outlines the preferred surface water management strategy in a given location. In this context surface water flooding describes flooding from sewers, drains, groundwater, and run-off from land, small water courses and ditches that occurs as a result of heavy rainfall (DEFRA, March 2010).

The current report provides an intermediate assessment of groundwater flooding susceptibility as part of the SWMP Phase 2, and provides recommendations for Phase 3. The following sections outline the geology and hydrogeology in the Chippenham study area. From this analysis,

- Potential groundwater flooding mechanisms are identified;
- Evidence for groundwater flooding is discussed;
- Areas susceptible to groundwater flooding are recognised; and
- Recommendations are provided for further investigation.

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

The two branches of the Hampshire Avon (East and West) both rise in the Vale of Pewsey, north of Salisbury, and the river flows southwards through Salisbury centre. The Hampshire Avon has a catchment area of 1750 km^2, and the predominantly Chalk catchment of the River Avon to just below the confluence with the Bourne has an area of 1267 km^2.

Within and around Salisbury, there is the confluence of five main river systems: Avon, Nadder, Wylye, Bourne and Ebble, plus other minor watercourses (Figure 1).

The River Wylye rises in the Upper Greensand and flows over the Chalk, entering the Salisbury study area at South Newton, before flowing onto Wilton. The River Wylye is gauged at South Newton and has an area of 448 km^2.

At Wilton the River Wylye flows into the River Nadder, whose source is in Jurassic strata west of Salisbury, near Tisbury. The River Nadder at Wilton has a catchment area of 216 km^2, and is gauged by a crump weir upstream of Bulls Bridge.

The River Avon flows through Fighelden, and then south through Durrington, Amesbury and onto Salisbury. The River Avon is gauged by a weir at Amesbury, where it has catchment of 326 km^2.

A short distance downstream from the confluence of the Nadder with the Avon, the Avon is joined by the River Bourne, which rises in the Upper Greensand and drains a sub catchment mainly across Chalk, north-northeast from Salisbury. The River Bourne is gauged at Laverstock, and has a catchment area of 165 km^2.

A short distance downstream from Salisbury City centre the River Ebble joins the River Avon at Bodenham, which has a flow gauge at Nunton Bridge and a catchment of 107 km^2.

After the confluence with the River Ebble, the River Avon flows south through the towns of Downton, Fordingbridge and Ringwood.

The lower Avon, south of Salisbury, is characterised by a complex network of artificially controlled channels, and is fed by a number of small tributaries. At Christchurch the Avon joins the River Stour before discharging into the English Channel at Christchurch Harbour and Bay.

2.2 Geology

Figures 1 and 2 provide bedrock and superficial geological information, respectively, for the City of Salisbury and the surrounding area from the British Geological Survey (BGS) 1:50,000 scale geological series (Sheet 298). Figure 3 provides a generalised geological cross section for the study area showing the superficial deposits; these are used to improve the conceptual understanding of the area. The cross section for bedrock geology from Entec 2009 is presented in Appendix 1. Furthermore, 126 borehole logs and 130 water wells were identified from the BGS to provide local data; the boreholes and water well locations for the Salisbury area are shown in Figure 1.

2.2.1 Bedrock Geology

The bedrock geology (Figure 2) of the Salisbury area comprises mainly of Chalk, with a small area of Palaeogene deposits southeast of Salisbury.

The Wittering Formation is part of the Bracklesham Group of Palaeogene age. It is mainly brownish grey laminated clays; sands with clay bands; clayey sands; and beds of glauconitic sands. The Wittering Formation is of little interest to the current study, as there is only a small outcrop within the Salisbury study area (Alderbury).

The London Clay underlies the Wittering Formation and outcrops in the extreme south-eastern corner of the area around Salisbury along the axis of the Alderbury – Mottisfont Syncline. It comprises of grey or brown (olive green when unweathered), commonly micaceous silty clay, known to become more sandy and pebbly towards its base. It outcrops on the gentle dip slope behind the minor Reading Formation escarpment. The London Clay is approximately 35-50 m thick in the study area.

Reading Formation of the Lambeth Group of Palaeogene age outcrops to the southeast of Salisbury City centre and underlies the London Clay. The Reading Formation comprises greyish-green clayey sand with abundant sub-angular to rounded, corroded and pitted glauconitic-stained flints; and brown sandy clay with well rounded flints with pockets of orange-sand. The Reading Formation unconformably overlies the Culver Chalk and the Portsdown Chalk. Above its basal bed, the Reading Formation is lithologically highly variable and comprises mottled red-yellowish or lilac-brown silts and clays with occasional fine-medium and coarse-grained red cross-bedded ferruginous sands with clay intraclasts and small well rounded flint pebbles. The thickness of the Reading Formation in the Salisbury area is between 15 and 20 m.

Portsdown Chalk Formation forms the top of the Cretaceous period geology in the Salisbury area. The Portsdown Chalk only outcrops to the south of Salisbury, immediately north of the Palaeogene outcrop in the Dean syncline. It consists of white flinty chalk with common marl seams, the base of which is derived from the Portsdown Marl (Mortimore, 1986, Bristow et al., 1997). The Portsdown Chalk in the Salisbury area is either very thin (less than 10 m) or absent due to erosion prior to the deposition of the Reading Formation and London Clay.

The Culver Chalk Formation is composed of soft white chalks with a significant number of very strongly developed nodular and semi-tabular flints, but without significant marl seams. The Culver Chalk has a thickness of between 35 and 45 m in the Salisbury area, with it generally forming the face and crest of the secondary chalk escarpment.

Newhaven Chalk Formation has extensive outcrops to the east of Salisbury, forming much of the sloping ground on and immediately below the face of the secondary Chalk escarpment. The Newhaven Chalk is composed of soft to medium-hard, blocky smooth white chalks with a large number of marl seams and flint bands. It has a thickness of between 55 to 70 m, with the marl bands ranging in thickness of up to between 20 and 70 mm thick through to a few millimetres.

Seaford Chalk Formation outcrops over large areas to the north and west of Salisbury. The Seaford Chalk is composed primarily of soft smooth blocky white chalk with numerous seams of large nodular and semi-tabular flint, with thin harder nodular chalk near the base. The flints towards the base of the Seaford Chalk are often highly carious whereas higher in the sequence the flints are black and bluish-black mottled-grey with a thin white cortex, commonly enclosing shell fragments. Some of the large flint bands form almost continuous seams and in places create local topographic features, for example the Seven Sisters Flint (Mortimore, 1986). Topographically, the Seaford Chalk forms characteristic smooth convex slopes of the major ridges between the River Ebble, Nadder, Wylye, Avon and Bourne, and the rounded quite steep sided valley sides, underlying much of the Chalk dip slope and broad interfluves between the primary escarpment and the break of slope beneath the secondary Chalk escarpment. The Seaford Chalk has a thickness of between 60 to 70 m.

Stockbridge Rock Member is a thin marl band within the Seaford Chalk, comprising of an intensely hard partially compressed chalk. The Stockbridge Rock Member occurs widely between Salisbury and Winchester; however, to the west of Salisbury, it appears sporadic and intermittent, and has not been found north of Tidworth nor within the outcrops to the west.

Lewes Nodular Chalk Formation consists of interbedded hard to very hard nodular chalks and hardgrounds with soft to medium-hard grainy chalks and marls. The nodular chalks are typically lumpy and iron-stained - marking sponges. Flints are typically black or bluish black with a thick white cortex, with sheet flints common. The 'Chalk Rock' is found at its base (Bromley and Gale, 1982). In the Salisbury area, the Lewes Nodular Chalk Formation forms the highest steep slopes at the top of the primary Chalk scarp, together with dip slopes within the major interfluves, for example in the Vale of Wardour to the southwest, and the Vale of Broad Chalke to the south. Of key interest to the current study are those outcrops found in the north and northwest where the River Wyle and River Avon cut through the generally south-eastwards dipping succession. The Lewes Nodular formation has a thickness of between 40 and 45 m in the Salisbury area.

The New Pit Chalk Formation and Holywell Nodular Chalk Formation underlie the Lewes Nodular Chalk Formation, although they do not outcrop in the study area.

2.2.2 Structural Geology

The regional dip of the Chalk strata is shallow and towards the southeast, with east-west trending gentle folds superimposed on this regional dip. The larger anticlinal structures include the Vale of Wardour, Wylye Valley and the Vale of Pewsey.

Structurally, Salisbury sits within the Wessex Basin, which comprises a system of post-Variscan extensional sedimentary basins and 'highs' that covered much of southern England, south of the London Platform and Mendip Hills, during Permian to Mesozoic times (Hopson et al., 2006). A number of major faults are recognised in the Salisbury area, notably associated with the primary Chalk scarp and with the Mere Fault complex within the River Nadder valley.

The Mere Fault is present along the Nadder valley north of the Upper Greensand ridge to the west of the catchment, diverting under the flood plain of the River Nadder, before running parallel to the River Nadder just South of Salisbury. The Mere Fault is a single, southerly dipping, steeply inclined or vertical reverse fault, down throwing to the north. The throw is variable, but the maximum throw is estimated to be around 100 m (Hopson et al., 2006).

Uplift along the Wealden Axis since the deposition of early Palaeogene deposits associated with the Alpine Orogeny, is represented by a gap in the geological sequence in the Quaternary in the Salisbury area.

2.2.3 Superficial Geology

The superficial geology of the Salisbury area consists of Alluvium, River Terrace Deposits, Head, Valley Gravel Deposits and Clay-with-Flints.

Peat deposits in the Salisbury area are seen as a result of deposition within historic marsh and meadows, such as the Harnham Water Meadows. The thickness of peat is typically between 1 and 2 metres, and the distribution of the deposits is patchy.

The Alluvium forms the bed and flood plain of the River Avon and its tributaries through the centre of Salisbury. It comprises of brown and grey clay, silt, sand and gravel, locally rich in organic material. It varies in thickness, approximately 1 metre thick, although in places it has a greater thickness.

The River Terrace Deposits are associated with the historic position of the River Avon and its tributaries, and comprise brown gravels and flinty gravels locally with head and organic rich silts and clays. The River Terrace Deposits have a thickness of up to 5 m in the Salisbury area.

Head deposits have a variable geology, comprise of sand, with clay and gravels. They have a thickness of up to 5 m.

Along the valleys of the River Avon and its tributaries are pockets of Valley Gravel Deposits or Colluvium, mainly brown claying silts and sands. Valley Gravel Deposits (occasionally referred to as Gravelly Head) have a thickness of up to 5 m.

The Clay-with-Flints is essentially a reworked deposit with modification of the original Palaeogene cover and solution of the underlying Chalk. The Clay-with-Flints are characteristically composed of orange-brown or reddish-brown clays and sandy clays containing large amounts of flint nodules and pebbles. Towards its base, the matrix of the deposit becomes stiff, waxy and fissured, and dark brown in colour. Very gritty hard coarse sandstone pebbles and small rounded sarsens (pebbles of very hard fine-grained sandstone) are found locally, in particular on the high ground around Salisbury. Furthermore, on several hilltops around Salisbury, the Clay-with-Flints deposit also contains a gravelly admixture of sub-angular to sub-rounded, worn, stained, and rolled flint fragments that are almost certainly derived from river deposits. The thickness of the Clay-with-Flint deposits ranges from 1 to 10 m in the Salisbury area.

2.3 Hydrogeology

The hydrogeological significance of the various geological units within the study area is provided in Table 1. The range of permeability likely to be encountered for each geological unit is also incorporated in Table 1.

Table 2: Geological Units in the study area and their hydrogeological significance

Geological Units		Expected Permeability Based on geological data	Hydrogeological Significance
Superficial Geology	Peat	Low	Predominantly an aquitard
	Alluvium	Low to Moderate	Variable but classified as secondary aquifer
	River Terrace Deposits (Sand & Gravel)	Moderate to High	Secondary A aquifer
	Head	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
	Valley Gravel Deposits	Moderate to High	Secondary aquifer
	Clay with Flints	Low to Moderate	Variable (probably an aquitard but may locally form a secondary aquifer)
Bedrock Geology	Wittering Formation	Low to Moderate	Variable – generally regarded as an aquitard
	London Clay Formation	Low	Aquiclude
	Reading Formation	Low to Moderate	Secondary aquifer

	Newhaven Chalk Formation	Moderate to High	Principal aquifer
	Seaford Chalk Formation	Moderate to High	Principal aquifer
	Lewes Nodular Chalk Formation	Moderate to High	Principal aquifer

'Principal Aquifer' - layers that have high permeability. They may support water supply and/or river base flow on a strategic scale (EA website, 2010).
'Secondary Aquifer (A)' - permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers (EA website, 2010).

2.3.1 Bedrock Hydrogeology

According to the Environment Agency's 2006 CAMS assessment for the Hampshire Avon, the Chalk streams of the Upper Avon catchment are generally well connected to the underlying aquifers, providing baseflow to the river system. Several hydrogeological assessments of the Chalk catchments upstream from Salisbury have been undertaken, including Avon and Dorset Water Authority (1973) assessment of the Upper Wylye; Halcrow (1992) groundwater model of the Salisbury Plain, through to Entec (2005) Hampshire Avon Conceptual Model and Entec (2009) Wessex Basin Groundwater Modelling Study.

The Wittering Formation comprises of laminated clays with thin beds of fine sand or silt; interfingering with sands with local clay laminae. As a result, overall transmissvity is low, and although groundwater moves and is stored within more permeable sand lenses and layers, groundwater movement is generally very slow.

London Clay Formation - a stiff low permeability silty clay outcropping to the southeast of Salisbury - acts as an aquiclude and does not permit groundwater flow, and is thereby classified as unproductive strata. The London Clay locally confines the Chalk groundwater, although some leakage may occur through the London Clay.

Reading Formation comprises of fine to medium grained sands with varying proportions of silt and clay, underlying the London Clay. The Reading Formation typically forms a minor or secondary aquifer, with moderate storativity and transmissivity, in hydraulic continuity with the Chalk beneath and providing additional storage to the Chalk aquifer.

The Chalk is designated a major / principal aquifer. The Chalk has a number of generic hydrogeological characteristics, more pronounced in some lithostratigraphical horizons than others. Notably, preferential movement of groundwater occurs through dissolution enhanced fissures and fractures in the Chalk. Semi-karstic features in the Chalk, such as swallow holes, are observed in the catchments above Salisbury. These fissures and swallow holes provide a mechanism for rapid rainfall-recharge into the Chalk aquifer, high transmissivities and rapid release of storage.

Groundwater flow occurs in confined Chalk fractures, enlarged by dissolution. Flint bands, hard and soft grounds can focus groundwater movement within these dissolution features. The extent of fracture development depends upon depth of burial, although the active groundwater movement zone is generally within 60 m of the surface (Buckley et al., 1998).

One of the findings and assertions from Entec (2009) is that in response to the variable lithologies of the Chalk, particularly with respect to marl layers and preferential flow paths, the Chalk acts as a series of aquifer units, with water table / piezometric head levels differing between these main layers. Springs and flows are commonly associated with hard bands and marl layers, notably the Plenus Marls, Melbourn Rock, Chalk Rock and Stockbridge Rock. This is presented in Appendix 1. Further, although these Chalk units have some hydraulic connectivity such that recharge storage builds up over the winter, release of this storage is strongly affected by these marls and hardbands. Groundwater flooding and groundwater induced flooding occurs when the water table rises, and is released typically at the intersection of these marls and hard chalk layers with the ground surface. There may be a delay in the build up of storage in response to winter recharge, or sustained heavy rainfall; however, the release of groundwater via the preferential pathways above or through these marl bands or hard chalk layers and associated springs may mean substantive river flows through Salisbury for considerable periods after the rainfall itself.

Chalk porosity varies between about 5% and 45% and depends on stratigraphy (Bloomfield et al., 1995). For example, the Upper Chalk of southern England has an average porosity of 39%, the Middle Chalk 28% and the Lower Chalk 23 % (Bloomfield et al., 1995). In the Upper Chalk at Twyford, porosity of the Seaford Chalk is in the range 38–50% and in the underlying Lewes Nodular Chalk between 35 and 40% (Stuart et al., 2008).

Relative high transmissivities are reported for the Chalk of Salisbury Plain (MacDonald and Allen, 2001), who identify a median transmissivity of 1,600 m2/d and a median storage coefficient of 0.01.

2.3.2 Superficial Hydrogeology

Alluvium and River Terrace Gravel deposits along the course of the River Avon and its tributaries are classed as Secondary Aquifer by the Environment Agency. The Valley Gravel Deposits, Clay-with-Flints and Head Deposits are also included in the Secondary Aquifer classification.

Because all of the superficial deposits in the Salisbury area have a broad range of grain size, the sands and gravels allow effective groundwater movement and groundwater yields, therefore forming secondary aquifer units. However, the clays and silts retard groundwater flow, forming aquitards. Some localised perching of the water table within these deposits with small springs and seepage faces are likely in the superficial deposits of Salisbury area. These aquifer units tend to be small and localised, with a small storage capacity. Springs flow after sustained and heavy rainfall – usually in the winter, filling up these aquifer units to overflowing.

Furthermore, the Alluvium is in hydraulic connectivity with the River Avon and its respective tributaries; and the River Terrace Deposits have the potential to be hydraulically connected with the flood plains of the River Avon and its tributaries. The groundwater level in the Alluvium, therefore, will be a reflection of the water level of the River Avon, and the amount of sustained and heavy rainfall.

2.3.3 Bedrock Groundwater Levels

The Environment Agency does not monitor groundwater levels within Salisbury City but do operate a network of groundwater monitoring boreholes in the surrounding area. As a consequence, limited groundwater level information is available for this area. Groundwater level data were also requested from the water supply company, Wessex Water.

Water level information has been obtained from a number of borehole drilling logs held by the British Geological Survey. Observation borehole monitoring show water table levels in the Chalk to have a considerable annual fluctuation range. For example, the Environment Agency monitor groundwater in an observation borehole at Tilshead, and historic data shows winter water table levels to exceed 98 m aOD and summer water tables as low as 80 m aOD. Such that the range in groundwater between summer and winter may exceed 18 to 20 metres in the upper catchment of the Avon and its tributaries. In Salisbury City centre, the range in Chalk groundwater levels is expected to be less, as the river relates water level in the aquifer.

Appendix 1 illustrates the modelled depth to water table from the ground surface, and shows the areas vulnerable to elevated groundwater levels and most vulnerable to the water table reaching the ground surface and groundwater issuing as springs. This has been used to highlight those areas with potential for elevated groundwater levels on Figure 5.

2.3.4 Superficial Geology Groundwater Levels

The Environment Agency does not specifically monitor groundwater levels in the superficial deposits of the Salisbury City area. However, borehole logs have been collated from the BGS and a number of these provide some details of groundwater levels. The boreholes were drilled in different years and so groundwater contours cannot be constructed, although comments on groundwater levels can provide an indication of depth to groundwater.

The BGS borehole logs indicate that there may be some localised perching of the water table in the Alluvium and River Terrace Deposits; partly controlled by the water level in the River Avon and its tributaries. The groundwater table has generally a greater depth in the bedrock geology aquifers. It is stressed, however, that this is based on the limited available data.

The presence of marsh and water meadows on the Alluvium, such as found at Harnham Water Meadows, indicates that there is some perching of the water table in this area, and the water table is very close to the ground surface. Shallow water tables are reported elsewhere on the Alluvium, including historic records indicating that Salisbury Cathedral was built in the 1200's with very shallow foundations (4 feet) as a result of the water table close to the surface.

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

Groundwater to surface water interactions are primarily within the Alluvium and River Terrace Deposits. This has been partly restrained by the historic modification of surface water courses, notably the navigational section of the River Avon and culverting of its minor tributaries through the built up environment.

Because the headwaters of the River Avon and its tributaries are spring fed, their base flow during the summer months tend to decline in response to the release of significant volumes of natural groundwater storage in the Chalk aquifer, and minor contributions of groundwater storage release from superficial deposit aquifers present in the area. However, they may also be low owing to limited hydraulic connectivity with the superficial geology aquifers resulting from the river channel modifications. Robust groundwater level data – both spatially and temporally - for the Chalk and superficial geology aquifers within Salisbury are required to gain an understanding of the relationship between surface water and groundwater.

2.3.6 Abstractions and Discharges

The Hampshire Avon catchment is subdivided into four Water Resources Management Units (WRMU) comprising the Lower Avon (Unit 1); the Upper Avon (Unit 2) comprising the Eastern Avon, Western Avon, Nine Mile River and the upper Avon down to Salisbury; the Wylye (Unit 3) consisting of the majority of the River Wylye and its tributaries including the River Till and the

Chitterne Brook; and the Bourne (Unit 4) covering the catchment of this tributary of the Hampshire Avon.

WRMU 1 is classified under CAMS as over-abstracted. WRMU 2 has been assessed as over-licensed; WRMU 3 has been assessed as over-abstracted; and WRMU 4 has a classification under CAMS as over-licensed.

Wessex Water supplies the majority of their water from groundwater sources including the Chalk of the Hampshire Avon catchment. According to Environment Agency (2006), 89.2% of consumptive abstraction licences in the Hampshire Avon catchment are used for public water supply purposes.

Considerable volumes of groundwater are abstracted from the Hampshire Avon abstractions, such that a proportion of the yield is exported to their North resource zone and supplies parts of Wiltshire and Somerset including Bath, Trowbridge and Yeovil (Environment Agency, July 2009).

Figure 4 shows Source Protection Zones are delineated by the Environment Agency for three major groundwater abstractions in the Salisbury City area.

In addition to the major licensed abstractions primarily operated by Wessex Water, there are a small number of minor groundwater abstractions from the superficial and respective Chalk formations used for domestic, minor agricultural, industrial and ground source heating purposes. This abstraction will only have a minor impact on the water balance.

2.3.7 Artificial Groundwater Recharge

Water mains leakage data for Salisbury and the surrounding area were requested from Wessex Water. Unfortunately the water company does not assess leakage estimates at this level of detail. In principle, it would be possible to estimate leakage in the Salisbury City area by apportioning total leakage for the Wessex Water 'East' Resource Zone area based on population estimates; although this approach might be limited by the sizeable proportion of this resource zone area being rural rather than built up. This has not been undertaken, but the method could be used in future investigations if a water balance assessment is required.

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

Based on the current hydrogeological conceptual understanding, there is potential for groundwater flooding in the Salisbury area. There are four key groundwater flooding mechanisms that may exist:

- **Water table elevation in the Chalk aquifer rising to above the ground surface:** groundwater flooding during periods of elevated groundwater levels results in water table rising above the ground surface, via springs and seepages; such that the flooded area is a representation of the groundwater table. Areas that may be vulnerable to this type of flood are identified in Figure 5. Substantial areas were affected by this direct groundwater flooding during the flood events of the autumn/winter 2000/2001, and the floods of winter 1959 and 1915 can be attributed to this mechanism.
- **Water table in the Chalk aquifer induced groundwater floods**: water table rises in the Chalk aquifer in the catchments of the River Avon and its tributaries upstream from Salisbury can result in the flowing of ephemeral springs and streams, some of which rarely flow, resulting in greater river flows through the City, causing floods. These high groundwater levels also lead to reduced rainfall infiltration and increased rapid runoff to surface water courses. It is believed that this is a key mechanism behind the 1990 fluvial flood event, and will also have contributed to flood events in other years including 2000/2001.
- **Superficial aquifers along the River Avon and its tributaries**: flooding may be associated with Alluvium deposits and the sand and gravel River Terrace Gravels deposits where they are in hydraulic continuity with surface water courses. Stream levels may rise following high rainfall events but still remain “in-bank”, and this can trigger a rise in groundwater levels in the associated superficial deposits. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars, which have been constructed within the superficial deposits. Within the UK, houses with cellars / basements were largely built within the Victorian era and into the early 1900s. Therefore, the developed areas with properties of this period are more likely to comprise properties with cellars / basements.
- **Superficial aquifers in various locations:** a second mechanism for groundwater flooding is associated with River Terrace Deposits (gravel and sand) and sand lenses within the Valley Deposits, Clay-with-Flints and Head deposits along the River Avon and its tributaries flowing through Salisbury City and surrounding area that occurs where they are not hydraulically connected to surface water courses. Perched groundwater tables can exist within these deposits, developed through a combination of natural rainfall recharge and artificial recharge e.g. leaking water mains. The properties at risk from this type of groundwater flooding are probably limited to those with basements / cellars; and in close proximity to the course of the River Avon and its tributaries within Salisbury.
- **Made ground in various locations:** a final mechanism for groundwater flooding may occur where the ground has been artificially modified to a significant degree. If this ‘made ground’ is of substantial thickness and permeability, then a shallow perched water table may exist. This could potentially result in or enhance groundwater flooding of properties with basements, or may equally be considered a drainage issue. Areas mapped by the

BGS as containing made ground deposits are found both on the superficial deposits and directly on the bedrock and may either form a continuous aquifer with respective aquifer horizons, or provide a low permeability cap constraining recharge to and seepage from such horizons, depending on the composition of the made ground.

3.2 Evidence of Groundwater Flooding

The reported historic flood incidents, including those reported as groundwater flooding, are shown on Figure 5. The groundwater flooding incidents are scattered along the River Bourne, in Wilton to the west, and near Salisbury Cathedral and Britford in the south east. There were 19 incidents during December 2000; 3 incidents in December 1995; 3 incidents in January 2003; others occurred in 1990, 1994, 2002 and 2001.

The Environment Agency has a groundwater flood warning system in the Salisbury area and further details are provided in Table 2. The Clarendon monitoring point is closest to Salisbury. The others are west or north of the study area. However, they are still relevant to the current study; high groundwater levels at these upstream locations can lead to increased spring flows and reduced rainfall infiltration, resulting in increased river flows and fluvial flood risk within the City.

Table 2: Environment Agency Groundwater Level Warning System

Location	Site ID	Potential Flood Watch Level (m AOD)	Potential Flood Warning Level (m AOD)
Clarendon	9115	67	70
Everleigh	9114	125	127.5
Idmiston	9109	69	71
Fonthill	9106	Unconfirmed	115

3.3 Groundwater Flooding Susceptible

3.3.1 Environment Agency Groundwater Model

Outputs from the Environment Agency's regional groundwater model have been used to identify those areas where there is potential for elevated groundwater levels (Figure 5). The data indicate that, as expected, the elevated (<4 m below ground surface) groundwater levels are likely to occur where Alluvium, Head and River Terrace Deposits are present at surface; notably along the River Avon and its tributaries that flow through Salisbury. All of the recorded groundwater flooding incidents occur within the area defined by the regional groundwater model.

In addition to the above, the Environment Agency / Council has defined a 1 in 20 year groundwater flooding zone (Figure 5). There are no historic flood incidents recorded as groundwater flooding in this zone, although this does not necessarily mean that groundwater flooding has not occurred.

3.3.2 Environment Agency Groundwater Model

Guidance on protecting properties from groundwater flooding has been produced by the Environment Agency, and this is provided in Appendix 2.

4 Water Framework Directive and Infiltration SUDS

The Water Framework Directive approach to implementing its various environmental objectives is based on River Basin Management Plans (RBMP). These documents were published by the Environment Agency in December 2009 and they outline measures that are required by all sectors impacting the water environment. The South West RBMP is considered within the current study since infiltration Sustainable Drainage Systems (SUDS) has the potential to impact the water quality and water quantity status of aquifers.

4.1 Current Quantity and Quality Status

The current quality assessment for the Upper Avon, the Nadder and the Till is 'good', and other tributary catchments have a moderate classification, apart from the River Bourne, which has a WFD classification as poor.

It is also noted the Harnham Water Meadow – a Sites of Special Scientific Interest (SSSI) – lies east of Salisbury City centre, at the confluence of the River Nadder with the River Avon. This is integral to the River Avon flood plain, and the relatively shallow water table in the Alluvium.

4.2 Infiltration SUDS Suitability

Improper use of infiltration SUDS could lead to contamination of the superficial or bedrock geology aquifers, leading to deterioration in aquifer quality status or groundwater flooding / drainage issues. However, correct use of infiltration SUDS is likely to help improve aquifer quality status and reduce overall flood risk.

Environment Agency guidance on infiltration SUDS is available on their website at: http://www.environment-agency.gov.uk/business/sectors/36998.aspx. This should be considered by developers and their contractors, and by Wiltshire Council when approving or rejecting planning applications.

The areas with the potential for elevated groundwater level conditions (<4 m below ground level) are shown on Figure 5. The areas that may be suitable for infiltration SUDS exist where groundwater levels are at significant depth. Therefore, any development within the areas defined as having the potential for elevated groundwater levels will require careful consideration with respect to use of infiltration SUDS.

As many of the permeable superficial deposits are River Terrace Deposits associated with surface water courses in the area, it will be important to understand the degree of hydraulic continuity between groundwater and surface water. Maximum likely groundwater levels should be assessed, to confirm that soakaways will continue to function even during prolonged wet conditions.

Consideration should also be given to the impact of increased infiltration SUDS on properties further down gradient. An increase in infiltration / groundwater recharge will lead to an increase in groundwater levels, thereby increasing the susceptibility to groundwater flooding at a down gradient location. This type of analysis is beyond the scope of the current report, although sensitivity analysis could be undertaken using the regional groundwater model.

The expected permeability assessment shown on Figure 4 is based on the BGS bedrock and superficial geology (Figures 1 and 2). The unconfined Chalk away from surface water courses may prove suitable for infiltration SUDS because of its preferential fissure drainage and deeper water table. Terrace Gravel and Head deposits away from the flood plain may also be suitable, although the clay and silt layers and lenses may limit their drainage capacity.

It will also be important to consider the potential development of solution features in the Chalk caused by infiltration SUDS. Soakaways should be located at an appropriate distance from buildings to reduce the risk of subsidence issues.

It is emphasised that this is a high level assessment and only forms an approximate guide to infiltration SUDS suitability; a site investigation is required to confirm local conditions.

Infiltration SUDS should be located away from areas of historic landfill and areas of known contamination or risk of contamination, where possible, to ensure that the drainage does not re-mobilise latent contamination or exacerbate the risk to groundwater quality and possible receptors, such as abstractors, springs and rivers. A preliminary groundwater risk assessment should be included with the planning application to include consideration of historic landfill and contamination.

Restrictions on the use of infiltration SUDS apply to those areas within Source Protection Zones (SPZ). Developers must ensure that their proposed drainage designs comply with the available Environment Agency guidance. Figure 4 shows the areas covered by respective zones of the SPZ in Salisbury, and this affects significant areas of the City and surrounding area.

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

- The superficial deposits, primarily the River Terrace Deposits, may form a small perched aquifer, or may be in good hydraulic continuity with the Chalk bedrock, which is a principal aquifer. The Environment Agency and City Council do not currently monitor groundwater levels in the superficial deposits.
- A number of potential groundwater flooding mechanisms have been identified. Of significance are those associated with the respective Chalk aquifer horizons, the overlying River Terrace Deposits and Alluvium, and their hydraulic continuity with surface water courses. Properties at most risk are those with basements / cellars.
- The flow in the upper catchments of the spring fed River Avon and its tributaries are also susceptible to groundwater table elevation, and may result in groundwater induced fluvial flooding in Salisbury. Higher groundwater levels lead to increased base flow to rivers. They may also prevent infiltration of rainfall, resulting in rapid runoff to rivers i.e. the surface of the aquifer can effectively become impermeable.
- Groundwater is a key source of flooding within the Salisbury area, and there are numerous reported historic flood incidents; the majority of these were recorded in December 2001. They occurred within the areas identified by the regional groundwater model as having the potential for elevated groundwater levels (<4 m below ground level).

5.2 Recommendations

The following recommendations are made based on the findings of the current report:

- The areas identified as having the potential for elevated groundwater levels should be compared with those areas identified as being susceptible to other sources of flooding e.g. fluvial and pluvial. An integrated understanding of flood risk will be gained through this exercise;
- Further evaluation of flood events could be undertaken using the regional groundwater model to help gain an integrated understanding of the mechanisms behind the significant historic flood events in the Salisbury area. For example, a number of the 'fluvial' flood events are likely to have been triggered by groundwater conditions. Although flood maps indicate areas susceptible to fluvial, pluvial and groundwater flooding, they do not show areas susceptible to groundwater induced flooding, such as floods derived from spring flows in the upper catchment consequent with elevated groundwater table levels. There is value in distinguishing these areas to refine flood risk, warning and response.
- The impact of infiltration SUDS on water quality and quantity with respect to the Water Framework Directive should be considered further within future investigations, including those undertaken by developers;
- Sets of monitoring boreholes could be installed in the Alluvium, River Terrace Deposits and the Chalk at key locations, and fitted with automatic level recording equipment for a period of one year and water quality sampling undertaken. The data would allow for an improved understanding of hydraulic relationships between different aquifers (and hydraulic continuity with the surface water courses where river stage data is available). At

this point a review of the monitoring network should be undertaken and an update on groundwater flooding / infiltration SUDS guidance provided;

- The proposed monitoring boreholes may assist the Environment Agency with water quality and quantity assessments for the next River Basin Management Plan. They may also be useful for flood warning and response. Therefore, site selection should be agreed with the Environment Agency and the necessity for water quality monitoring agreed; and
- The existing regional groundwater model could be used as a tool for assessing the impact of infiltration SUDS on the aquifer or for modelling water management options.

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