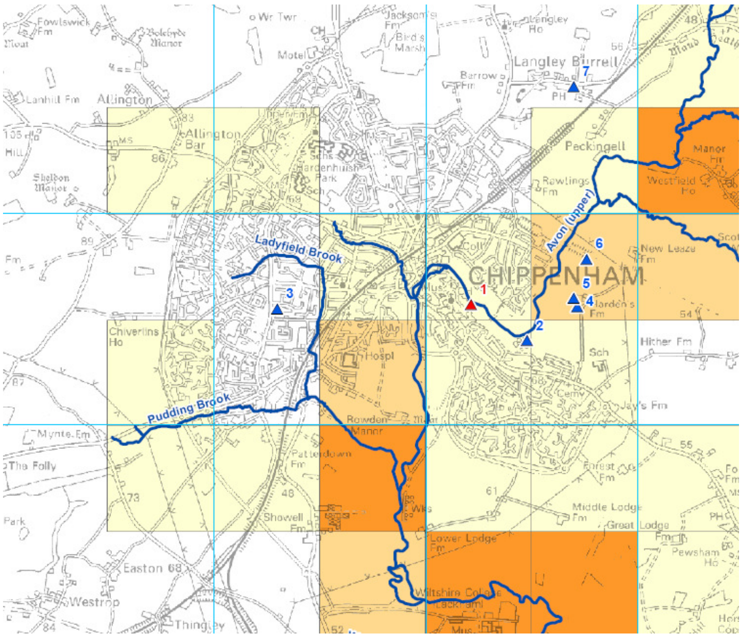
URS

Scott Wilson

Chippenham Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 1 & 2
November 2011



Prepared for

Wiltshire Council
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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

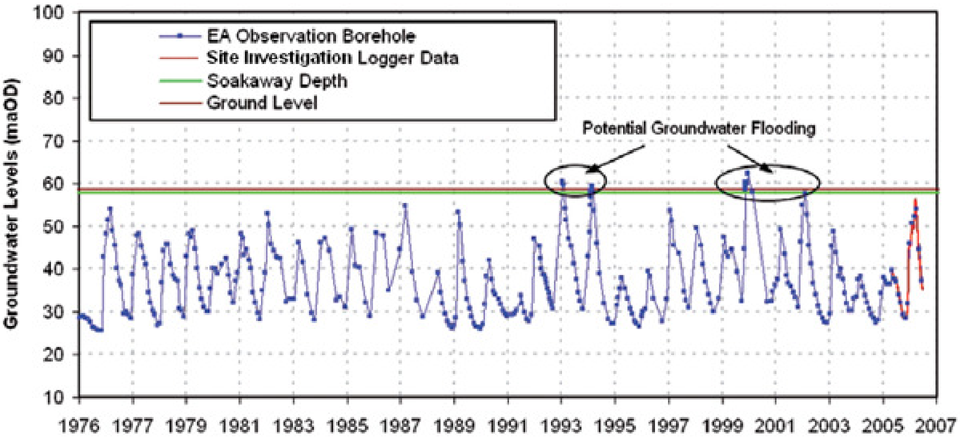
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data 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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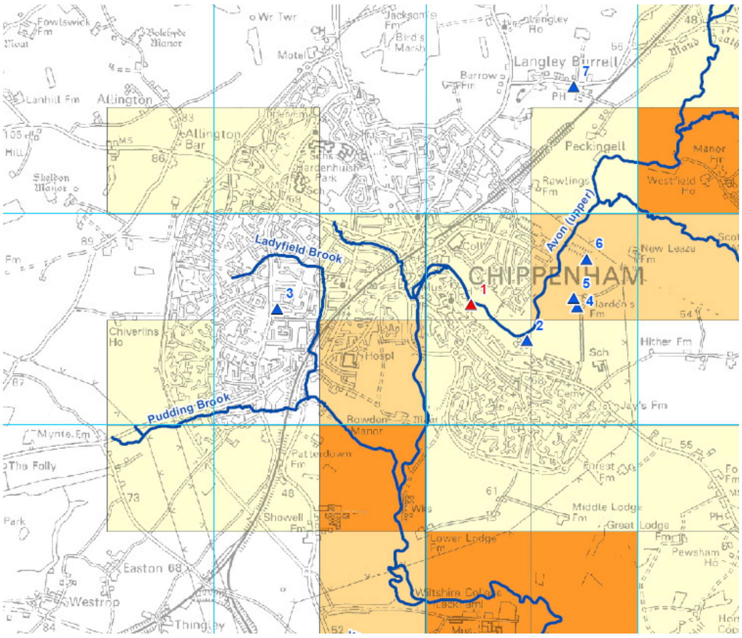
Chippenham Surface Water Management Plan

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

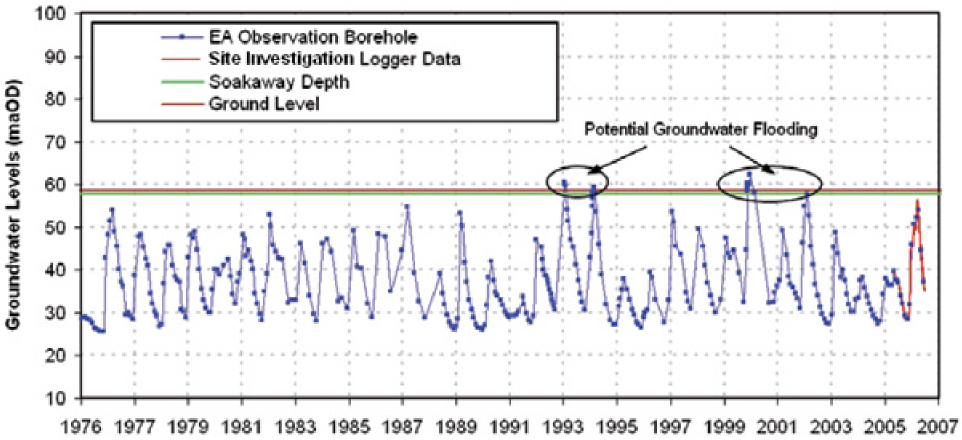
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data 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

- DEFRA, March 2010. Surface Water Management Plan Technical Guidance.
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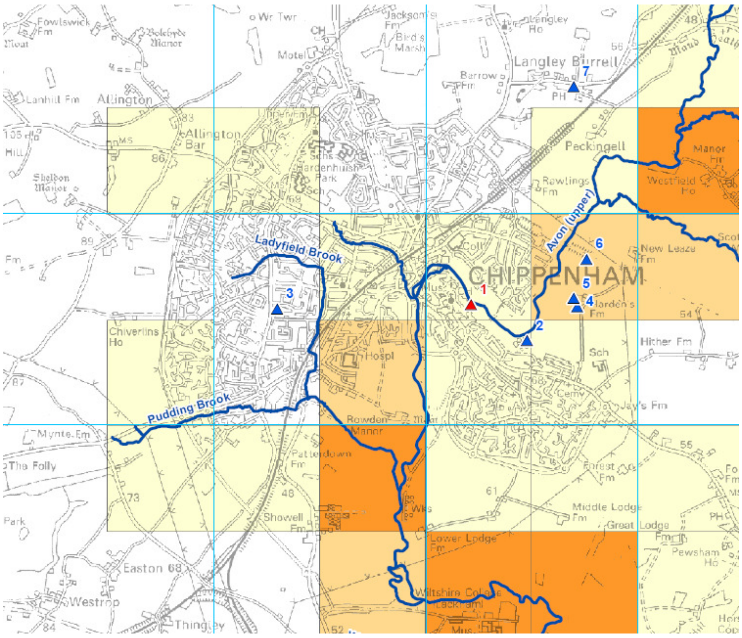
- Scott Wilson, October 2007. North Wiltshire District Council, Strategic Flood Risk Assessment Level 1 Report - Final Report.

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

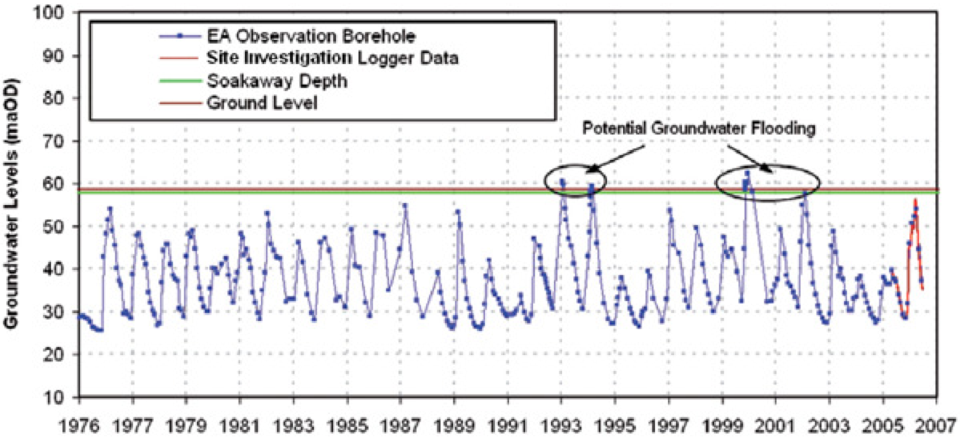
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data 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.

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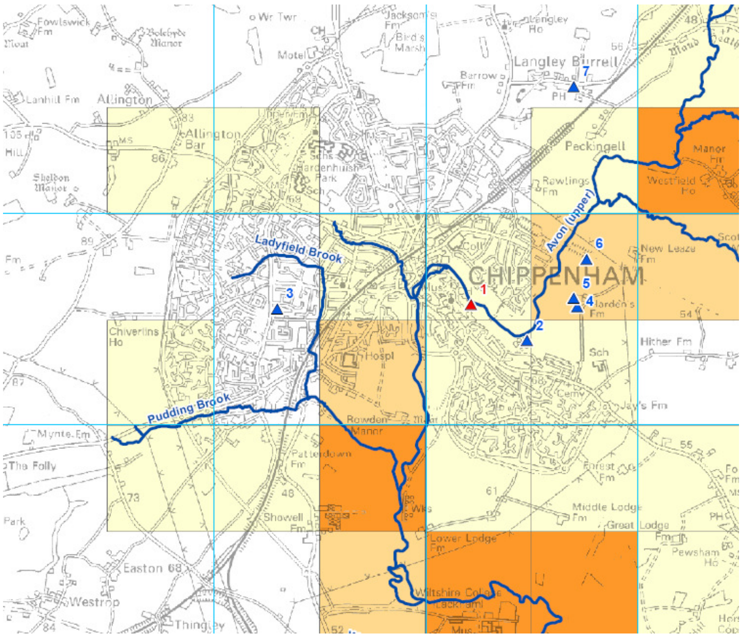
Chippenham Surface Water Management Plan

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

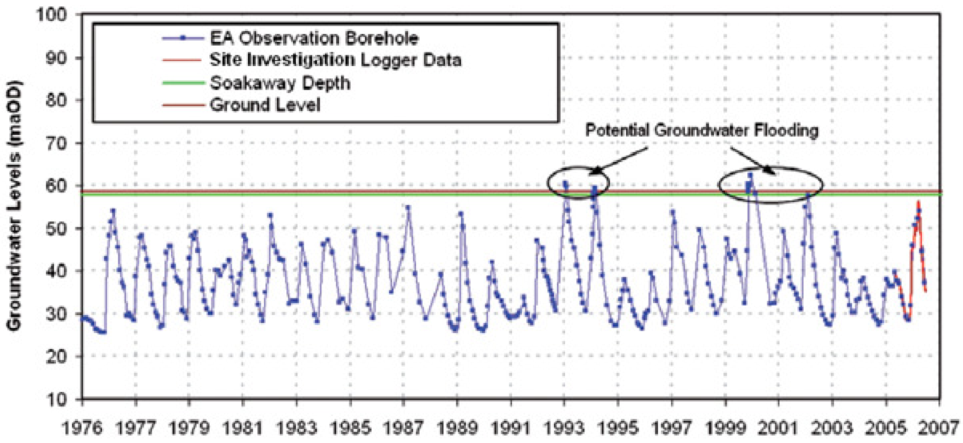
Groundwater flow direction, depth to groundwater, topography and the degree of artificial influence in the subsurface (e.g. leaking water mains or groundwater abstractions) play an important role when considering the susceptibility of an area to groundwater flooding. Unfortunately groundwater level data 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).
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- 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.
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