Salisbury Surface Water Management Plan

Intermediate Assessment of Groundwater Flooding Susceptibility

Phase 2

November 2011

Prepared for

Wiltshire Council

Where everybody matters

Revision Schedule

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

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Abbreviations

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

Glossary

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

1 Introduction

1.1 Groundwater Flooding

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

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

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

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

1.2 The Current Report

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

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

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

2 Topography, Geology and Hydrogeology

2.1 Topography and Hydrology

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

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

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

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

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

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

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

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

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

2.2 Geology

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

2.2.1 Bedrock Geology

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

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

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

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

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

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

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

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

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

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

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

2.2.2 Structural Geology

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

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

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

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

2.2.3 Superficial Geology

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

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

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

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

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

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

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

2.3 Hydrogeology

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

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

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

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

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

2.3.1 Bedrock Hydrogeology

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

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

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

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

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

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

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

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

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

2.3.2 Superficial Hydrogeology

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

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

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

2.3.3 Bedrock Groundwater Levels

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

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

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

2.3.4 Superficial Geology Groundwater Levels

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

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

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

2.3.5 Hydraulic Relationships

Surface Water / Groundwater Interactions

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

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

2.3.6 Abstractions and Discharges

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

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

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

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

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

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

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

2.3.7 Artificial Groundwater Recharge

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

3 Assessment of Groundwater Flooding Susceptibility

3.1 Groundwater Flooding Mechanisms

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

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

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

3.2 Evidence of Groundwater Flooding

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

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

Table 2: Environment Agency Groundwater Level Warning System

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

3.3 Groundwater Flooding Susceptible

3.3.1 Environment Agency Groundwater Model

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

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

3.3.2 Environment Agency Groundwater Model

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

4 Water Framework Directive and Infiltration SUDS

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

4.1 Current Quantity and Quality Status

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

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

4.2 Infiltration SUDS Suitability

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

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

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

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

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

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

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

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

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

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

5 Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be drawn from the current study:

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

5.2 Recommendations

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

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

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

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

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