Hydrology and its implications for the Bronze Age landscape

A CASE STUDY FROM THE SUSSEX COASTAL PLAIN AND ADJOINING DOWNLAND BLOCK

By David Dunkin

This article focuses on the significance of hydrological factors in the contextualisation of a Bronze Age landscape. The former presence or absence of water is crucially linked to the inhabitation pattern of Bronze Age communities. This is especially relevant in southern lowland England in the later Bronze Age period, due to the emergence of a bounded agricultural landscape containing structural evidence of fields, droveways, burnt mounds, cremation cemeteries and roundhouses (Yates 2007). The study focuses on one such enclave (Dunkin 2012) and comprises the East/West Sussex Coastal Plain and abutting downland block (Figs. 1 and 2). The integration of hydrological and archaeological data has been enabled by 20 years of developer-funded archaeology and has provided evidence of this Bronze Age infrastructure. Furthermore, recent research by the author has identified that dated burnt mounds, accumulations of burnt or fire-crazed stones, ash, and charcoal, may be important markers in the landscape of previous hydrological regimes.

INTRODUCTION

The single most important factor that underpins the 'watery' aspect of this study is the comparative levels of the Bronze Age and the present-day water table. In the study area, and Southern England in general, the most prolific water source is the chalk aquifer. The research undertaken here aims to demonstrate that abstraction has created a significant reduction in the water table within the core areas of later Bronze Age activity. In particular, this work looks at evidence for the contraction of the riverine system across the Sussex Coastal Plain in the modern era, and the implications for change since the Bronze Age. Furthermore, the possibility that stream heads and spring activity occurred higher up on the downland block, within, for example, some present day dry valleys, is crucially important to understanding prehistoric settlement patterns and farming regimes on the downland chalk and coastal plain.

THE STUDY AREA

THE COASTAL PLAIN

The Sussex Coastal Plain, which extends into East Hampshire, is a flat region bounded along its northern edge by chalk downland and by the English Channel to the south. The lower coastal plain, in the central portion of the study area, rises to *c.* 15m OD at its contact with the upper coastal plain. The plain extends from its eastern-most limit, the Black Rock raised beach in Brighton, East Sussex, where the downland chalk (hereafter 'the chalk') meets the sea, to the Solent river terraces near Fareham, Hampshire, approximately eight kilometres to the west of Langstone Harbour, a distance of about 70 kilometres (Fig. 2). This region encompasses a major landform. The plain itself reaches a maximum width of around 16 kilometres close to its centre, from the rising ground north of Chichester to Selsey, on the southern tip of the Manhood Peninsula. The southern edge of the downland block is characterised by a gentle dip slope which is broken by its contact with the upper coastal plain at approximately 40m OD. The upper coastal plain therefore lies between *c.* 15m and 40m OD. The Chichester Syncline, which runs east to west across the study area and along the southern line of the dip slope, has important hydrological consequences and is discussed in a separate section below.

The southern edge of the upper coastal plain is dissected by what are now mainly dry valleys. These formed under periglacial conditions during the Pleistocene and were cut to the lower sea levels of that epoch. They connect with a series of streams on the lower coastal plain, known locally as rifes (Aldiss 2002, 51) and are the main southerly-flowing drainage channels from the downland block to

Fig. 1. The Bremere Rife at Sidlesham, West Sussex, looking north to the downland block: a typical riparian scene of the study area (Photo: D. Dunkin).

the north. The interception of this resource by the water companies is of great relevance to this study. Some of the streams drain into the River Arun, but the majority flow directly south into the sea. Much of the region would have been characterised by former marsh and braided streams, with tongues of wetland stretching inland, separated by areas of higher dry ground. Superficially, prior to drainage, parts of the area would have had similarities with a smaller version of the East Anglian Fens. The rife system itself forms a dendritic system. The superficial geology map (BGS 317/332) indicates that the alluvial spread associated with the rife system is much more extensive than the present-day limits of the streams. Furthermore, it is probable that the coastal region of the project area at the time was characterised by coastal estuarine and saltmarsh habitats (Roberts 2007), with hinterland areas dominated by fen, fen carr and alder carr environments.

The lower coastal plain is characterised by brickearth soils, a partly windblown loess deposited in the cold, dry periglacial conditions which prevailed in the last cold stage of the Devensian glaciation around 12,000 years ago. It has been suggested that much of the variable brickearth soils on the coastal plain derive from terrestrial processes. It has long been held that the deposit may also

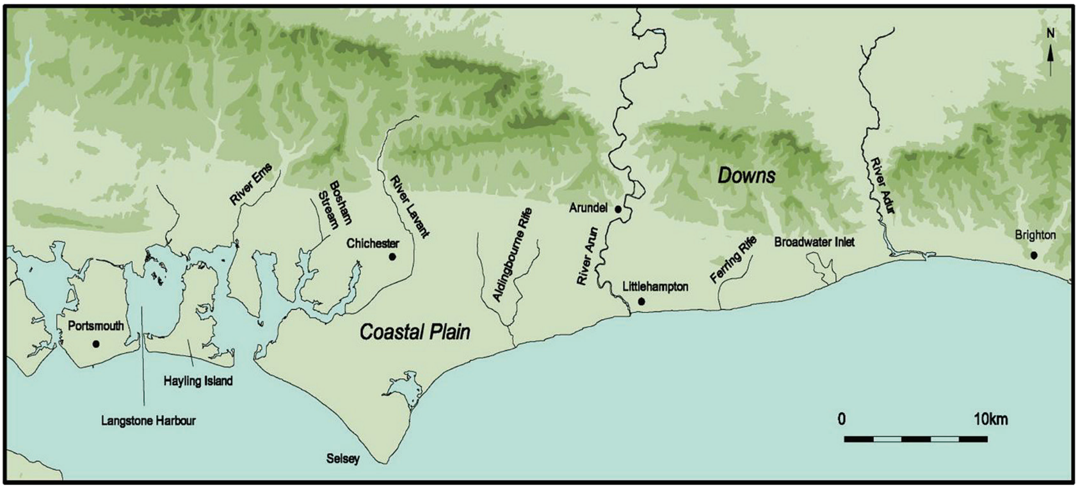

Fig. 2. Map of the study area.

occur as a fine-grained wash and sheet run-off from the Downs which has undergone decalcification by long exposure to weathering processes (Gallois 1965). It is described as an unfossiliferous brown loam (Bone 1985). Significantly, these soils are very fertile (Catt 1978) and have been sought by modern horticulturalists. Consequently, the coastal plain previously sustained the pre-eminent glasshouse crops industry in England. Recent work, however, has shown conclusively that the brickearth soils were especially targeted by Late Bronze Age and Roman farming communities across the region.

In contrast, the upper coastal plain is covered with 'head' deposits which accumulated by solifluction and hillwash under periglacial conditions. These soils contain an admixture of reworked Tertiary deposits including clay-with-flints (Hodgson *et al* 1967). They are typically composed of red-brown to yellow-brown gravelly, silty, sandy clay and commonly contain variable proportions and sizes of coarser material known as diamicton, usually flint nodules (Hodgson 1967). Although most of this zone has undergone less commercial archaeology, the settlement pattern on these heavier soils does appear to be less prolific, and therefore differs from the known archaeology on the chalk and the lower coastal plain. The west of the region is also characterised by a series of intermittent streams. The Ems, Bosham Stream and the Lavant, a true winterbourne, are all important drainage systems for the south-facing chalk (Fig. 2). These valleys connect downland and coastal communities in the locality of Chichester Harbour.

Coastal erosion

There has undoubtedly been a significant loss of the Bronze Age landscape to coastal erosion in the study area. West of Brighton, the off-shore ramp is considerably shallower (Long 1992), so the bathymetric profile, in the face of rising sea level, would have led to far greater land loss since the Bronze Age. Furthermore, at Selsey, towards the centre of the region, the loss of land (*see* Woodcock 2003) was accentuated by the effects of longshore drift. Analyses of the occupation patterns and site distribution of the region need to take account of these processes.

THE CHALK AQUIFER

The chalk lowlands of central, southern and eastern England accommodate the most important groundwater reservoir in the United Kingdom (Downing 1998), (Fig. 3). The geological formations of the region slope eastward to the North Sea Basin and south into the Anglo-Paris Basin. Within this broad structural pattern the subsidiary London and Hampshire basins are of hydrogeological significance, as each contains a major chalk aquifer. Collectively, the southern and eastern regions of England form the most densely populated area in the British Isles and their demand for industrial, agricultural, recreational and domestic use has been unprecedented. The linear increase in demand derives from the beginnings of the Industrial Revolution (Hiscock 2005). In the 1990s, total groundwater abstraction in England and Wales was approximately 2,400 million cubic metres per year (Price 1996), and about half of this total came from the chalk (Fig. 3). Clearly this will have had an impact on the hydrology of the region.

The study area itself, therefore, lies in an area in which the present-day water source is extracted primarily, *c.* 70%, (Robins *et al* 1999) from the chalk aquifer.

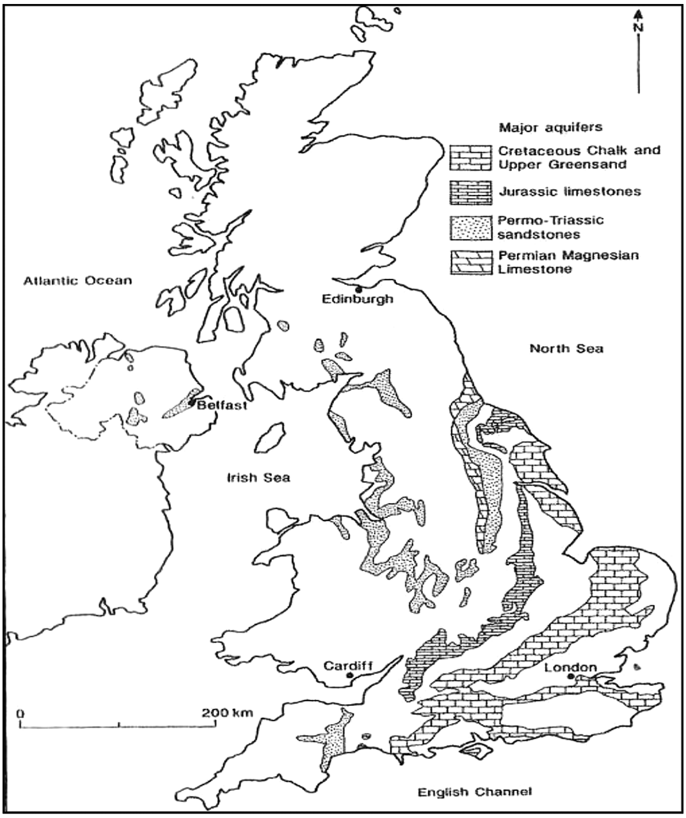

Fig 3. The principal location of the chalk aquifer in Great Britain (Hiscock 2005). CP16/027 British Geological Survey © NERC 2015. All rights reserved.

The relevance of the chalk aquifer to the study

The south-facing dip slope of the downland block drops down to the coastal plain and provides the all-important 'hydraulic gradient' within the aquifer which directs the north–south flow. Although the chalk outcrop itself is virtually devoid of surface drainage (Headworth and Fox, 1985), it is the surface outcrop of the aquifer, effectively the spring line along the dip slope, that gives rise to the hydrological character of the region. Thus, the positions of the springs along the well-defined dip slope of the downland block vary seasonally in response to infiltration. It is some of these springs that give rise to bournes, or intermittent streams, but today the majority of the locations remain dry above ground.

The transmissivity of the chalk aquifer is greatly enhanced by the fractures and fissures which exist within the chalk, particularly in the upper levels of the sedimentary sequence. These are extremely variable within the aquifer. The fractures are caused principally by solution of the chalk, and it is normally within the river and dry valleys that the porosity and transmissivity of the chalk are greatest, making the specific yield more favourable at these locales. The valleys were generally formed by freeze/thaw conditions during the Pleistocene, and reflect lines of structural weakness. Such periglacial activity, together with surface erosion, would have caused horizontal fractures and the opening up of fissures in the upper 20–30m (Jones and Robins 1999). This led to greater water flow, which causes an increased dissolution rate of the chalk. In valley locations, run-off at times of high rainfall leads to a mixing of waters of differing chemical composition, which also increases chalk dissolution. All this facilitates greater accessibility to adequate supplies of water. Aquifer properties therefore reflect the local topography.

This is significant to the study because it shows precisely why water authorities have located pumping stations and a number of boreholes within the river and dry valleys that flow from the downland block (Fig. 4). If a station is located within a present-day dry valley, it is mooted that during its operational life it may affect water flow, above or below ground, within a significant part of

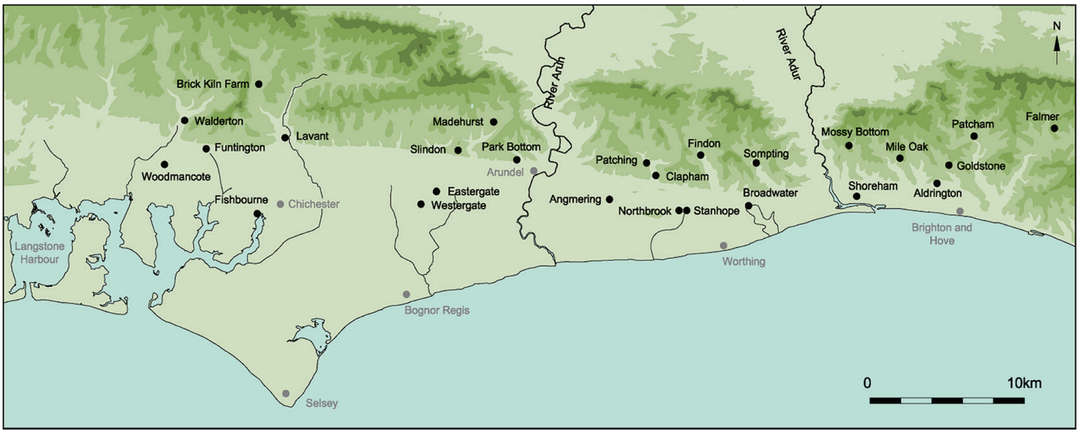

Fig. 4. Distribution of pumping stations across the study area. They are principally located on, or close to, the dip slope of the downland block (after Jones and Robins 1999).

the incised valley. If these particular valleys have associated Bronze Age archaeology, then assessing the contemporary hydrology will be of especial interest. An evaluation of specific borehole data within the study area has been undertaken.

THE IMPACT OF HYDROGEOLOGICAL FACTORS ON A BRONZE AGE LANDSCAPE

The larger rivers within the study area, in particular the Arun and the Adur, provide drainage for the Wealden area further to the north, and cut through the downland chalk. There is also substantial lateral drainage from the chalk aquifer into the rivers. The north–south dry valleys provide the main drainage relief, which derives from the aquifer and link to the rife system on the coastal plain. Relevant to Bronze Age activity, a particular geological anomaly constrains and alters the hydrology of the region: the Chichester Syncline.

THE CHICHESTER SYNCLINE

The Chichester Syncline, which runs east–west from east of Worthing in the locality of Lancing/Sompting to Portsdown Hill, East Hampshire, in the west, provides a major impediment to water discharging from the chalk aquifer (Fig. 5). This infilled trough, which is more than 100m thick in places, contains Palaeogene deposits, principally the impermeable clays of the Reading Beds and London Clay series. This linear structure forms a barrier to the south–flowing hydraulic gradient. To the west of Sompting, the boreholes and pumping stations providing the principal public water supply effectively follow the line of the dip slope and are located to the north of the Palaeogene deposits (Fig. 4). This potentially depletes the discharge of water from the aquifer crossing the line down to the coastal plain. However, what also appears to happen is that the syncline causes an east–west lateral movement of water discharging from the chalk. The water emerges at the eastern and western extremities of the syncline, and also debouches where the major river or stream valleys pass through, or from, the downland block.

Recent fieldwork has identified the occurrence of springs and an east–west stream within a wooded area three kilometres to the east of the River Arun. These locations on the upper coastal plain, close to the dip slope, have been identified as immediately adjacent to the Chichester Syncline, and specific evidence for Bronze Age archaeology, in particular burnt mounds (see below) and metalwork deposition sites, has been attributed to this zone.

The lateral movement of water is especially pronounced in the west, close to the terminal end of the Chichester Syncline. Here, a major series of 28 springs occurs between Bedhampton and Havant, south of the syncline adjacent to Portsdown Hill (Downing 1998), (Fig. 6).

THE BEDHAMPTON SPRINGS

These springs are the main water provider for Portsmouth and the largest public water supply from a spring source in the UK. The provision

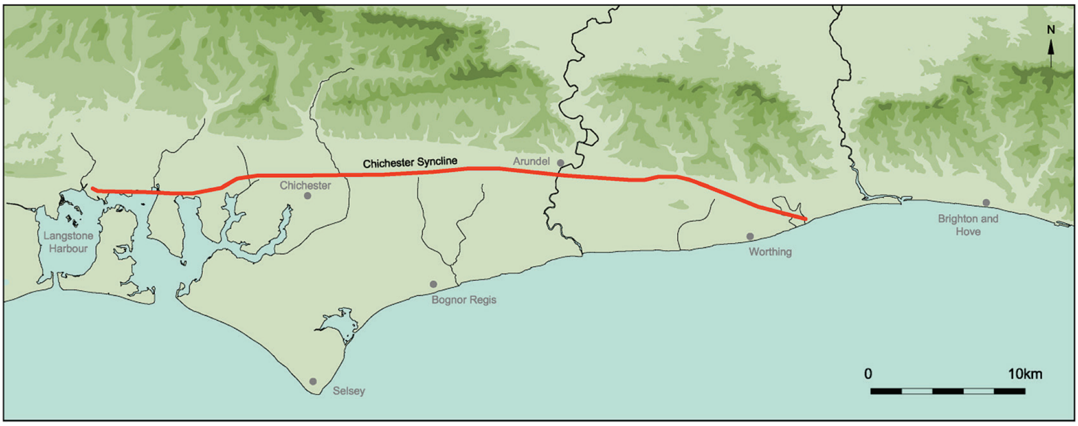

Fig. 5. The study area showing the course of the Chichester Syncline (adapted from Jones and Robins 1999).

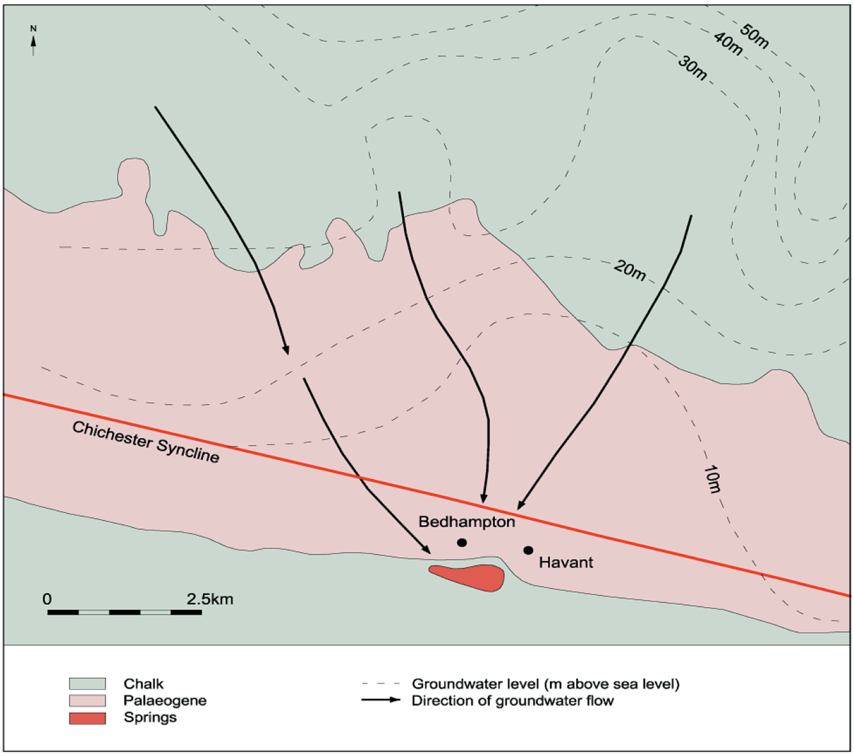

Fig. 6. The location of the springs between Havant and Bedhampton. Note the position of Chichester syncline (adapted from Downing 1998).

extends to the River Arun on the Sussex Coastal Plain. The occurrence of the springs on the south side of the syncline at Bedhampton (Fig. 6) is thought to be due to excessive fracturing and fissures in the chalk at this locale. It was this concentration of emergent groundwater that contributed to the dissolution of the chalk here and allowed it to cross the axis of the syncline (Jones and Robins 1999).

The interception of this water by the Portsmouth Water Company will have had an impact on stream flow into Langstone Harbour, immediately south of the springs. In 1999, the average flow for the entire group of springs was around 113,000 cubic metres per day (Jones and Robins 1999, 88) and from this more than 60 million litres were abstracted each day (Downing 1998). This resource has been exploited on a large scale since the mid-18th century, and the southerly freshwater flow has consequently been reduced since that time.

The transverse flow of water from the chalk aquifer has also caused major spring discharge at Fishbourne and Arundel, both of which are important public water supply sources. The springs occur here because the floodplains of the rivers Lavant and Arun cut the directional flow of the aquifer at a point where the water table comes close to the surface. They intercept the lateral movement of water impeded by the Palaeogene deposits. At Fishbourne, the springs are focused under an arch in the syncline and this may have been a factor in the siting of Fishbourne Roman Palace.

THE LAVANT

The catchment of the River Lavant, which discharges into Chichester Harbour (Fig. 7), arises high on the chalk in the vicinity of East Dean, north of Chichester. It is a true winterbourne and therefore does not have a perennial source. Its flow is controlled by, and dependent on, the relative height/levels of the water table within the chalk aquifer. This river, in particular, is an important indicator of the rise and fall through time of the potentiometric surface of the aquifer in the region. The significance of this river catchment will be assessed below.

Earlier work focused on a detailed analysis of the chemistry of the rifes between the River Arun and Chichester to the west. This study revealed that the rifes at the western end of the block, such as the Bremere Rife, contained a significant component of chalk groundwater, whereas those to the east – the Aldingbourne Rife and Binsted Rife – contained little or none (Nutbrown *et al* 1975). The western rifes are part of the drainage system of the Selsey peninsula, and the results demonstrate hydraulic continuity between the upper reaches of the River Lavant, which is the chalk component, and its braided system, the fan gravels. This suggests that the Lavant Valley directly links and connects the drainage from the chalk, despite its intermittent nature, with the streams on this part of the coastal plain.

By contrast, the lack of connection of the rifes to the south of the syncline, in the east near Arundel, with chalk-derived groundwater confirms the east–west drainage observed above. It is suggested that the impediment may be caused by a deepening of the syncline (>100m) in the vicinity of Arundel and Westergate. The repercussions could be that the development of fractures in the chalk in this zone was inhibited during glacial low sea level stands, causing low permeability (Jones and Robins 1999). This would affect the amount of water transferring to the coastal plain in this area from the chalk aquifer to streams such as the Aldingbourne Rife and the Lidsey Rife.

The Sompting area east of Worthing marks the eastern extent of the Chichester Syncline. In this locale a series of springs are located around the margins of the former Broadwater Inlet. They contributed to the existence of extensive watercress beds which were an important industry at Lyons Farm, Sompting, in the 19th and early 20th centuries. No major water course can be seen in this locality today The full depositional history of the former Teville/Broadwater Stream at the eastern margin of the syncline is not known, but has recently been identified as part of an intertidal system in the Middle Bronze Age (Pope 2009) connected with the Broadwater Inlet at Sompting. A public water supply station is located in the valley containing the former stream at Findon, and is licensed to abstract six million litres of water per day (Jones and Robins 1999). There are further pumping stations within the catchment at Broadwater and on the downland block to the north at Lychpole Farm, Sompting. The hydrology of the Sompting/Broadwater locale has therefore been greatly altered by drainage and abstraction in the modern period.

THE CHALK AQUIFER: LOOKING NORTH

Of interest to this study is the northerly directional flow of the aquifer. The crest of the Downs forms an approximate east–west water table divide, so that water flows north from this point to the escarpment. This outflow emanates from a generally well-defined perennial spring line just above the base of the Lower Chalk (Headworth and Fox 1985) and outcrops on the north-facing slope of the escarpment. The formation known as Melbourn Rock lies at the

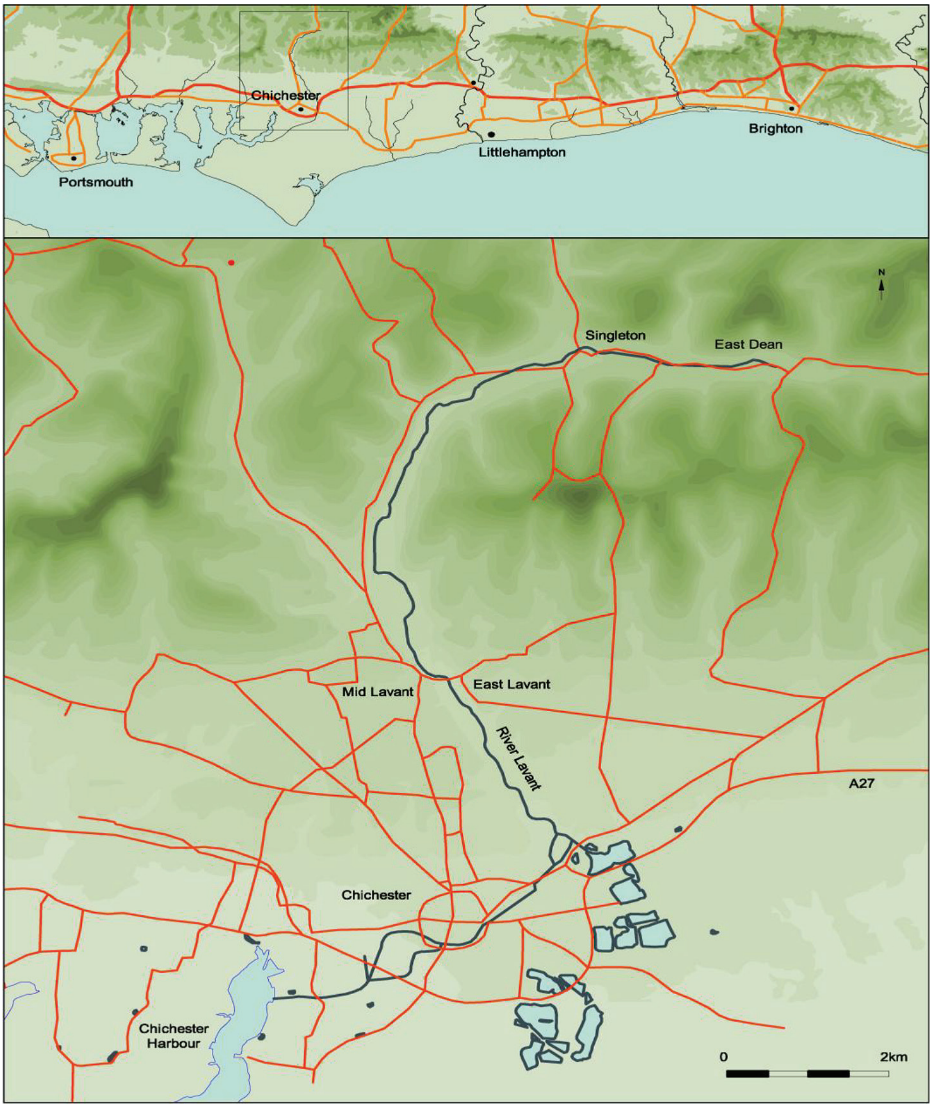

Fig. 7. The present-day course of the River Lavant and its discharge point into Chichester Harbour.

interface of the Lower and Upper/Middle Chalk sequence. This lithological unit is one of a group known as a hardground, and is particularly prone to clean-cut fractures which cause the rock to have greater permeability than the surrounding chalk. The fracturing characteristic usually occurs close to the outcrop where the unit is not deeply buried and the fracture joints remain open. The Melbourn Rock therefore has minor aquifer properties, and this has created a spring line along the axis of its outcrop.

Immediately north of the escarpment, the chalk aquifer issues forth at the interface of the Gault Clay and the Lower Greensand, and forms an important spring line (Bone 1985; Keef *et al.* 1965). These spring sources have important archaeological repercussions and are discussed below.

TERTIARY DEPOSITS AND CHALK DISSOLUTION

The acidic nature of the Tertiary cover on the chalk can, by downward washing, cause solution pipes

(Aldiss 2002, 54) and swallow holes to appear up to 2–3m deep within the study area, though in the Newhaven, East Sussex area, for example, in cliff contexts, some are much deeper. The Tertiary pipes have a non-calcareous fill of sand and clay pebbles derived from the overlaying eroded Tertiary deposits. The translocation of clay often causes the contact of the non-calcareous fill and the surrounding chalk to be lined with clay at the margins of the pipe (Gallois 1965). These holes are good access points for recharge to the chalk aquifer, facilitated by the higher porosity of the sand element of the infilled pipe.

THE CHALK AQUIFER AND THE EFFECTS OF ABSTRACTION: AN EXAMPLE FROM SOUTHERN ENGLAND

THE LONDON BASIN

London is underlain by a massive chalk aquifer. Within the syncline of the London Basin the aquifer is geologically confined by the underlying Gault Clay and is capped by Eocene Tertiary clays. This effectively creates an artesian situation, and the basin is principally drained by the Thames and its tributaries. Prior to abstraction, the potentiometric surface of the aquifer in central London was *c.* +7.5m OD in the pre-development era (Hiscock 2005). At this datum level, for example, there was sufficient 'hydraulic head' to allow the fountains at Trafalgar Square to operate by the use of boreholes under true artesian conditions.

The initial borehole sunk at Trafalgar Square in 1844 caused a fairly immediate reduction in the water table of about 30m. As a result of continuing severe over-exploitation, the water table had, by 1965, declined to more than –75m OD (Hiscock 2005). Subsequent measures have seen a basement level of around –40m OD maintained in order to alleviate the problems of flooding and saline intrusion.

As a result of the London example, it is apparent that the recharge from the chalk aquifer of the lower Thames and its immediate tributaries has been greatly reduced by the process of abstraction since the 1840s. This highlights the dramatic effects that abstraction can have on water table levels and above ground water flow.

BRONZE AGE LANDSCAPES OF THE WEST SUSSEX COASTAL PLAIN AND DOWNLAND BLOCK

Immediately to the west of the River Arun lies the dendritic formation of the Aldingbourne rife system. Now greatly reduced in extent, as seen by the alluvial spread depicted on the geology map (BGS 317/332), its former prominence may be seen in a recent exposure. A storm which took place in January 1998, prior to sea defence work being carried out on the foreshore at Bognor Regis, uncovered evidence of an ancient channel adjacent to the present day outfall of the Aldingbourne Rife (Allen *et al.* 2004). This grossly underfit river now occupies a floodplain about one kilometre wide, and the exposed Pleistocene channel, considered to be the infilled channel of the Aldingbourne Rife, was approximately 550m wide and 10m deep. A later Holocene channel cuts the western side of the palaeochannel, and the identification of two silty clay braids to the east of the feature provides supporting evidence that a significant part of the coastal plain drainage relief developed within braided river environments.

Later archaeological work at North Bersted by Archaeology South–East (Worrall and Priestley-Bell 2005) as well as a fieldwork survey by the author recorded evidence for sub-fossil oak and Bronze/Iron Age deposits associated with a former alluvial arm of the rife (Fig. 8). A number of previously unknown palaeochannels were uncovered and identified during a walkover survey (Dunkin and Jones, 2000). Furthermore, the presence of burnt mounds suggests that this location was very much wetter in the late prehistoric period. In southern England burnt mounds are primarily dated to the later Bronze Age and may be cooking sites or have other ancillary functions. They are usually positioned close to a fresh water source (Dunkin 2001). Thus, direct evidence for tributary and braided streams in present-day dry locations, associated with both the rife system and late prehistoric archaeology, has been identified within this part of the study area.

The direct transference of water from the chalk aquifer to the Aldingbourne Rife and associated streams appears to be impeded in the modern period. This is partly due, as discussed above, to the deepening of the Chichester Syncline in the vicinity of Arundel immediately to the north, acting as a barrier for waters transferring from the chalk aquifer to the rife network. Today's freshwater source for the system is thought to derive primarily from groundwater retained by the superficial deposits within the coastal plain. Recent abstraction by Southern Water directly from the Ryebank Rife at Bilsham (Christopher Pine, pers. comm.), together with public water supply abstraction and the loss of the marine influence of the Aldingbourne Rife, which would previously have caused the headwaters to backup, accounts for the modern-day contraction of the entire system.

Fig. 8. Alluvial arm of Aldingbourne Rife, North Bersted, West Sussex. (D. Dunkin.)

The production of major springs at the eastern and western ends of the Chichester Syncline also undoubtedly influenced the activities of Bronze Age communities. In the east, at Sompting, there is considerable evidence for later Bronze Age burnt mounds, metalwork deposition (Curwen 1954) and settlement (Dunkin 2000). In the west, before the 18th century interception by the Portsmouth Water Company, the Bedhampton Springs would have provided large inputs of fresh water into Langstone Harbour and adjacent areas. An extensive survey of the harbour produced a large quantity of Bronze Age evidence, including burial urns, urnfields, diagnostic flintwork, concentrations of flint-gritted pottery and settlement in the form of roundhouses. Six Bronze Age metalwork hoards were recorded, extending to the adjacent Hayling Island (Allen and Gardiner 2000, 207) on the West Sussex/Hampshire border.

Nearer to Chichester and its hinterland, the hydraulic continuity of the River Lavant and the Selsey peninsula has provided an important zonal corridor of Bronze Age archaeology. This has been confirmed by the extensive archaeological work undertaken on the recently completed 'managed re-alignment' scheme at Medmerry, Selsey (Archaeology South-East, forthcoming). This work produced evidence on a large scale for later Bronze Age activity, including settlement, burial and burnt mounds. This work significantly emphasises the connection of Bronze Age communities occupying coastal and downland environments.

A recent study has shown that the outcrop of Melbourn Rock, on the north-facing scarp slope of the downland block which has produced a spring line, attracted Bronze Age activity in the form of metalwork deposition (Yates and Bradley 2010). The placing of metalwork in, or near water, particularly in the later period, is a depositional practice that is part of an established behavioural repertoire (Bradley 1990). Furthermore, the Greensand ridge which runs close to, and parallel to, the north of the South Downs escarpment was a favoured location for mesolithic communities and was used as a linear Bronze Age burial ground, for example at West Heath and Minsted (Drewett *et al.* 1988). In Sussex, the spring line at the base of the escarpment has also provided archaeological and place name evidence for settlement in the Anglo-Saxon period (Martin Bell, pers. comm).

Within the study area on the downland block to the north of Chichester, and on the coastal plain, the use of swallow holes and other access points for recharge to the chalk aquifer appears to have been adapted and used for Bronze Age purposes. The recent discovery of two pond features on Bow Hill, the summit of which is a narrow chalk plateau capped by clay with flints, may have a geological derivation. Another pond structure was identified on the coastal plain at Cobnor (Greg Priestley-Bell, pers. comm.). This and the Bow Hill examples were probably adapted for burnt mound use, and have been dated to the later Bronze Age (Mark Roberts pers. comm.). Although the configuration of the geology is different at Cobnor, it is possible that natural solution hollows and other similar features have been used for water capture by Bronze Age communities. It may be worth noting that Bow Hill and the Cobnor site are intervisible.

WELL WATER LEVELS AND BOREHOLE DATA ANALYSIS IN THE STUDY AREA: THE CHALK AQUIFER AND ITS RELATIONSHOP TO ABOVE GROUND HYDROLOGY

THE RIVER LAVANT

As discussed above, it is apparent that pumping stations and borehole wells are generally located in valley floors. The importance of the River Lavant has been stressed with regard to its sensitivity to the chalk aquifer and the effect of its drainage properties on the coastal plain. It is therefore relevant to this study that the middle reaches of its valley, in the vicinity of the villages of East and Mid Lavant, contain a significant number of water utility sites, including a sewage works, some of which have accessible data. The location of these is shown in Fig. 10. Two pumping stations, Mid Lavant and Brick Kiln Farm, have a combined water abstraction licence for 9,950 million litres per annum. This undoubtedly has a major impact on the potentiometric levels within the aquifer and the flow of the river (Fig. 9).

The station at Brick Kiln Farm, for which data is available, is located at the southern end of the Chilgrove Valley, just four kilometres from its junction with the Lavant Valley (Fig. 10). This station, which has been in operation since the mid-1970s, is operated in the summer months to conserve water supplies from the Lavant. However, the contention here is that the aquifer beneath the Chilgrove Valley is in hydraulic contact with the Lavant (Jones and Robins 1999). It is important to note that today the Chilgrove Valley is dry (Fig. 10). A number of springs occur in Mid Lavant, close to the junction of the two valleys, which support this assertion.

It is fortunate that at the head of the Chilgrove Valley there is a well/borehole at Chilgrove House. It has a continuous record of groundwater level since 1836 to the present day, about 4,000 readings to date, which may be the longest continuous record of its kind in the world (Jones and Robins 1999). Chilgrove House is situated in a recharge area on the downland chalk (Fig. 10, No 1) and from here the hydraulic gradient flows south to the Lavant catchment. The periodic flooding and/or flow of the River Lavant and the flooding of Chichester, for example, as well as drought episodes, may be gauged and are reflected in the water levels in this borehole. The Ordnance Datum for the top of the well is 77.18m OD. The borehole log which has been obtained for this study (British Geological Survey, Wallingford, Oxon.) indicates that the range within the well over 175 years has fluctuated between 33m OD and 77m+ OD. During this long period the average annual water levels within the well were in the range of 38.5m above OD (1855) to 59.3m above OD (1879) (Jones and Robins 1999).

The matching of water level data with known flood events of the Lavant indicates that flooding may occur when the level reaches *c.*65m OD. These events have been recorded throughout every decade since 1836

Fig. 9. The dried-up bed of the River Lavant at Mid Lavant (SU 857096) in September 2009. (D. Dunkin.)

Fig. 10. Pumping stations and boreholes in the Upper Lavant and Chilgrove Valleys.

and there have been almost 300 occasions where this level has been exceeded. Extremely serious flooding in Chichester and surrounding areas occurs when levels reach more than 70m OD. On 30 December 1993 the level reached 69.8m OD. On 8 January 1994, the well went artesian for only the second time in its history, i.e. above 77.18m OD. It remained at that level until 23 January 1994 (BGS data). The flow rate for the River Lavant at Graylingwell, Chichester, nine kilometres from Chilgrove House, peaked at 8.1 cubic metres per second on 10 January1994 (Taylor 1995).

Thus, the concordance of the attainment of the highest water level at Chilgrove House, 77.18m OD, and the peaking of the flow rate of the Lavant in Chichester, fell within a two-day window. This demonstrates, albeit under extreme conditions, the direct relationship that exists between the water table levels in the aquifer and the river catchment. This is further supported by the other borehole readings in the catchment (Fig. 10, 2–5). Numerous springs were also activated throughout the course of the river during this period.

WATER LEVELS IN DRY VALLEYS AND DIP SLOPE LOCATIONS IN THE STUDY AREA: DATA ANALYSIS

THE WORTHING TO ARUNDEL BLOCK

The Patching pumping station (TQ 090075; BGS Id No. 7091)

This public water supply station is situated in a dry valley (Fig. 11, 1) associated with a considerable amount of Bronze Age archaeology. Higher up on the chalk, it derives from Springhead Hill and passes 200m west of Harrow Hill (Late Bronze Age enclosure) and New Barn Down (Middle Bronze Age settlement). At 1.5km below the station, the valley contains Patching Pond which joins a stream, the Black Ditch, at the junction with the coastal plain north of Angmering, close to Highdown Hill, and thence runs into the River Arun.

The height of the wellhead is 35.44m OD and, unfortunately, only one level was available from the BGS database. However, perhaps because of the relatively lower altitude of this location on the chalk, the water table appears to be much closer to the surface. The recorded level on 8 November 1960 was 9.71m BGL. This places the height of the water table at 25.73m OD. Patching Pond, which is below 25m OD, is almost certainly spring-fed from the aquifer, and this links to the Black Ditch. Although care must be taken not to infer too much from just one level, it is likely that, prior to drainage and abstraction (the site has operated since the 1930s), the spring head from the aquifer occurred higher up the valley than today, perhaps in the vicinity of the pumping station.

Warningcamp: The Dover (TQ 058067; BGS Id No. 7094), Park Farm Arundel (TQ 004074; BGS Id No. 7094)

The levels from two wellheads/boreholes on this block of downland at Warningcamp and Park Farm (Fig. 11, 2 and 3) also indicate that the potentiometric surface of the underlying chalk aquifer is within the range (i.e. 2–5m OD). This supports the known spring discharge into the adjacent Arun Valley and coastal plain close to the two locations.

THE WALDERTON GROUP

Background

This group of four sites lies in an area which defines the groundwater levels in the Upper Ems Valley (Fig. 12). The relevance of this group is related to a case study of a burnt mound site within a linear copse known as Piglegged Row (Dunkin 2012). A radiocarbon sample from the site produced a Middle Bronze Age date. The linear copse, which is approximately 700m in length, lies within a narrow 30–40m wide present-day dry valley. The entire length of the linear wood contains surface nodular flint in a clean white state, suggesting periodic water flow. These are valley gravels (BGS 316). The dry valley connects the downland block to the north of Piglegged Row and Pitlands Farm with the western branch of the Upper Ems, a few hundred metres north of Walderton Bridge (Fig. 12). The confluence of the river with its eastern branch is at Walderton Bridge. Three water sources, which include the dry valley, thus converge close to one location.

Pitlands Farm, Upper Marden (SU 797124; BGS Id No. 4003)

This well lies in the dry valley, approximately 600m north of the north end of Piglegged Row linear copse (Fig. 12, 1). This is not a public water supply. The height of the wellhead at Pitlands Farm is 62.48m OD, and 214 readings are available for the period 1958–77. They range between 27 and 52m OD, which is 10–35m BGL. The highest reading level is 52.74m OD, recorded on 17 February 1969, which indicates that the water level was 9.74m BGL on that day. A level taken at the investigated site within Piglegged Row, *c.* 900m, was recorded at *c.* 53.50m OD. Therefore, the differential between the ground level of the linear copse almost one kilometre to the south, and the highest water level at the upper part of the aquifer, recorded at the Pitlands Farm borehole, is 0.76m. The dry valley continues to descend from this point until it reaches the West Ems *c.*400 m above the confluence of the East and West Ems (Fig. 12).

Martlett Walderton (SU 789107; BGS Id No. 4030)

This well, which is not a public water supply, is situated in the village of Walderton, about 200m from the south side of the dry valley and close to the latter's confluence with the Western Ems (Fig. 12, No. 2). The well is about one kilometre south of the Piglegged Row linear copse. The height of the

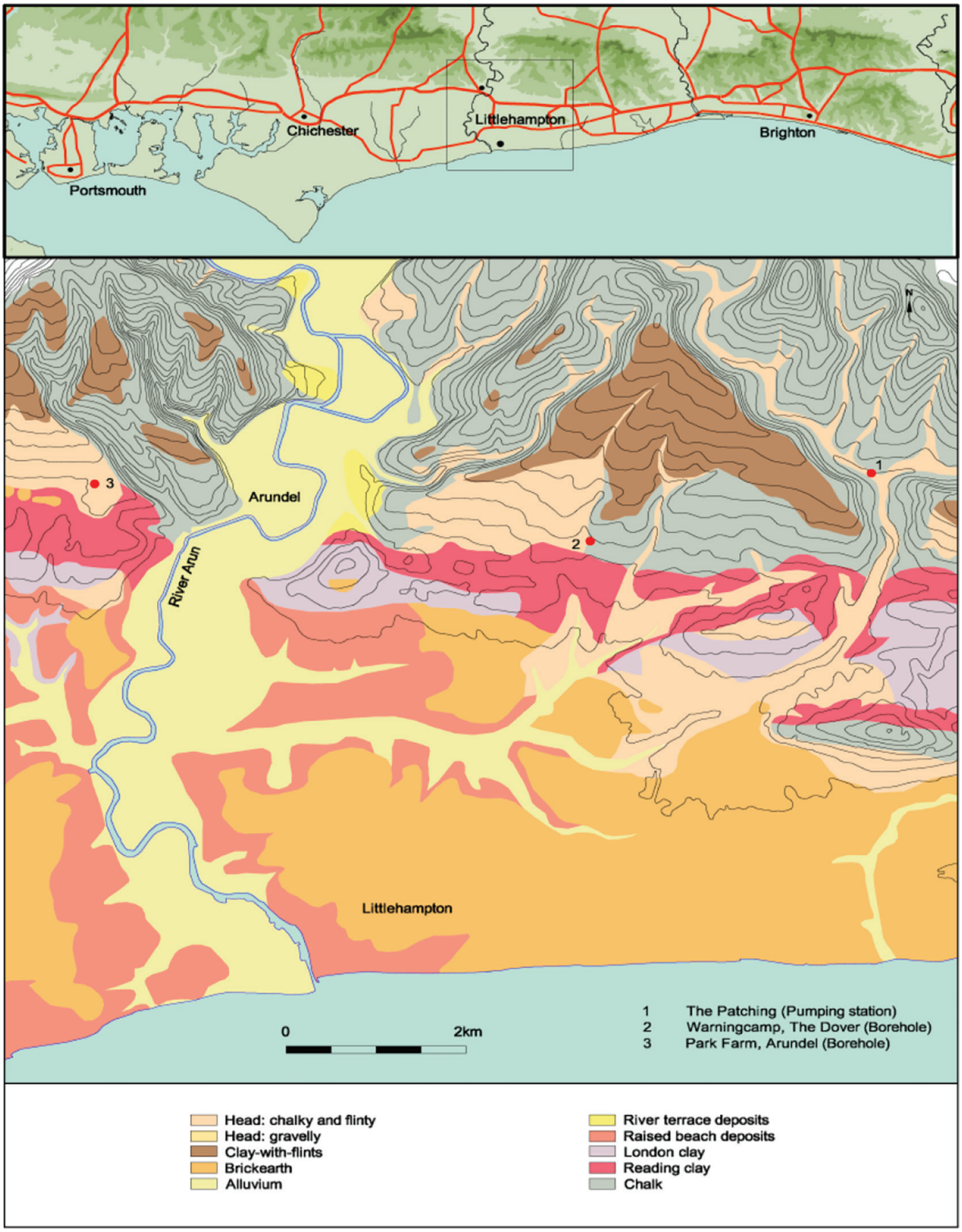

Fig. 11. The geology of the Worthing/Littlehampton area in the vicinity of the Patching Pumping Station (1)

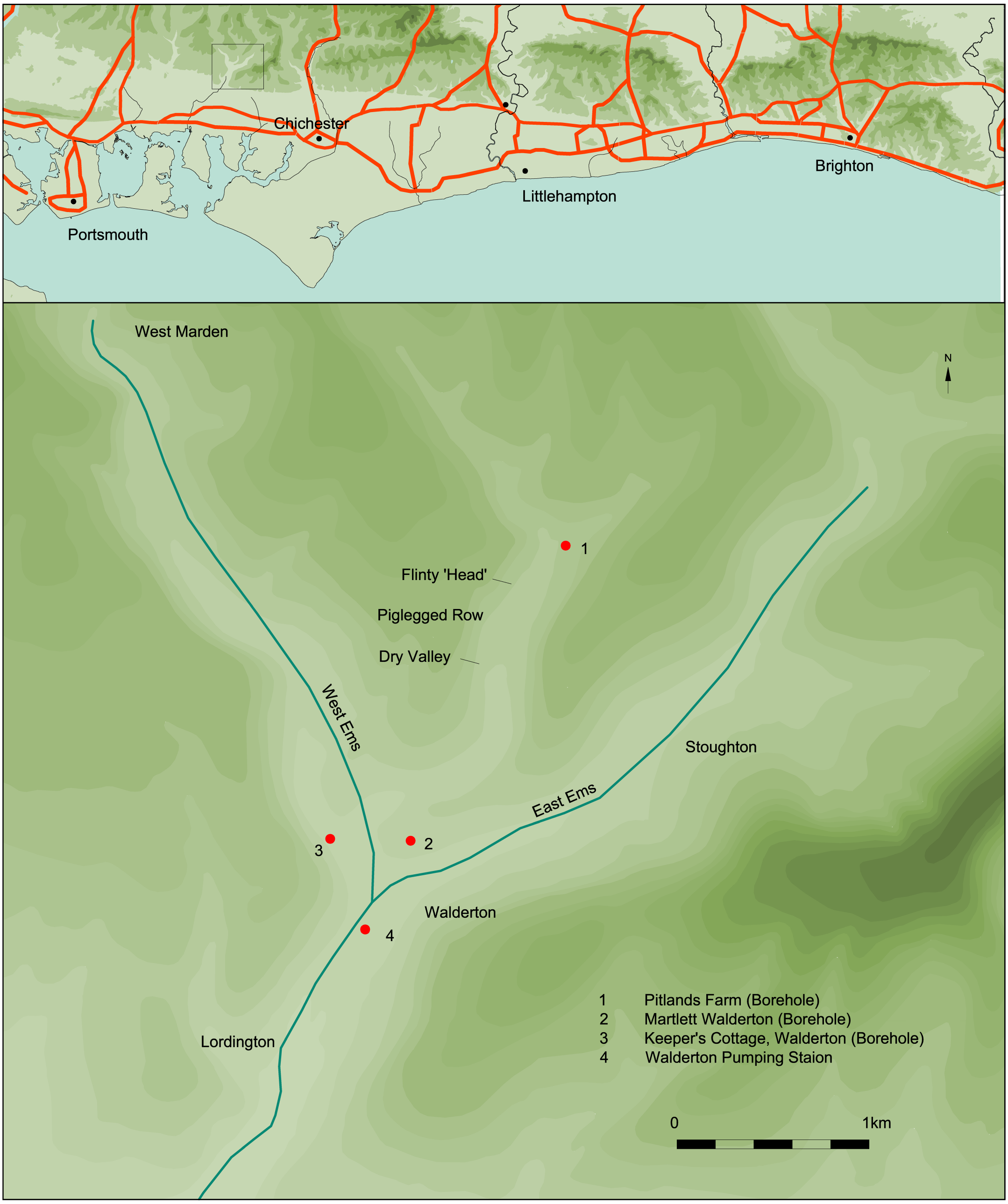

Fig. 12. The positions of boreholes and the pumping station at Walderton Bridge, West Sussex.

well is 41.17m OD, approximately 2m above the level of the adjacent dry valley (*c*. 39m OD). Ninety one readings are available for this site from the period 1969–77. They lie within the range of 27–34m OD, *c*. 7–14m BGL.

Keeper's Cottage Walderton (SU 784108; BGS Id No. 4011)

This non-utility borehole is situated on the right bank of the Western Ems, opposite the confluence of the dry valley discussed above (Fig. 12, No. 3). The height of the well is 43.m OD, about 2 m above the valley floor at this location, *c.*41m OD; 79 readings taken between 1955 and 1977 were available from the BGS and lie within the range of 25–35m OD, or *c.*8–18m BGL.

Walderton Pumping Station (SU 786103; BGS Id No. 4013)

This public water supply station is located on the left bank of the Ems, 100m south of the confluence of the East and West Ems adjacent to Walderton Bridge (Fig. 12, No. 4). The height of the wellhead is 32.21m OD. Just two readings are available from the BGS database: 1.98m BGL on 22 June 1962 and 1.15m BGL on 1 January 1976. In height OD these are 30.23m and 31.06 OD. The siting of the pumping station is due to its confluent location (Fig. 12, No. 4). The abstraction licence is 9,955 million litres per annum (Jones and Robins 1999).

Summary of the Walderton Group

It is apparent from the water levels at these four sites that there is a consistent adjustment in the height of the water table in relation to the height of each of the wellheads above Ordnance Datum. This suggests good hydraulic connectivity between the sites. For example, at the Walderton pumping station (4) the water table is within one or two metres of the surface, about 30–31m OD, and at the two nearest wells, Martlett Walderton and Keepers Cottage Walderton (Fig. 12, Nos 2 and 3), the recorded levels of the water table are within the same range: 25–35m OD.

Of special importance is the fact that the water table in the lower reaches of the dry valley at Martlett Walderton, appears to be in hydraulic contact with the Ems Valley floor. Furthermore, the closeness of the water table to the surface in the latter site (7–14m BGL) and the fact that its wellhead is only 12m below the investigated site within the Piglegged Row linear copse, may be significant. It suggests the possibility that the dry valley in its lower reaches may have had intermittent flow in the pre-modern period. The Pitlands Farm evidence supports this assertion.

At Pitlands Farm, about two kilometres north of the dry valley's confluence with the Ems, the range is much greater: 27–52m OD. Nevertheless, the valley floor of the Ems in the vicinity of Walderton Bridge is approximately 32m OD, which falls within the Pitlands Farm range. The higher levels of the aquifer at Pitlands, from the recorded data, suggest that the potential for flooding in the Ems Valley is high. In fact, the Walderton Bridge area, unsurprisingly, is nominated a high-risk flood area by the Environment Agency (Fig. 13).

What is of special relevance to this study is that the highest level in the data obtained for the Pitlands Farm well (52.74m OD) is calculated to be within one metre of the ground level at Piglegged Row dry valley copse 900m to the south (53.50m OD). This suggests that, at times of exceptionally high rainfall, the water table could rise above ground level at some point between Pitlands Farm and the dry valley's confluence with the West Ems. This is supported by the fact that the relative levels at the four sites appear to indicate good hydraulic

Fig. 13. Winter flood conditions at the junction of the East and West Ems at Walderton Bridge, 100m from the pumping station. (D. Dunkin.)

contact within the chalk aquifer in this locality. Furthermore, the abstraction of almost 10 billion litres of water per annum from the Ems below the dry valley suggests that the reduction of water table levels here would be significant in terms of former water flow in this particular dry valley. The presence of a burnt mound at Piglegged Row suggests the former presence of above-ground water in the vicinity.

SUMMARY OF HYDRAULIC DATA

It is clear from the evidence of this research that it is unlikely that the saturated zone of the chalk aquifer reached ground level in the Holocene period in the upper catchment in many of the dry valleys which proceed south from the chalk. In the upper and middle reaches of the valleys, the aquifer level is generally too far below ground level for this to have occurred. However, in some cases, there appears a critical point where ground water may occur as an intermittent water source, or issue forth as springs. This happens in the relatively lower-lying areas of some valleys as they approach the coastal plain. The potentiometric surface of the chalk aquifer gets closer to ground level with increased reduction in height of the dip slope. This may be seen clearly at Sompting, Patching and Walderton, for example, where there is definitive evidence in the modern period for the occurrence of surface water in, or close to, the lower reaches of their respective dry valleys. The occurrence of former springheads higher up valleys during the Holocene will, of course, be dependent on local topography, including such factors as relative height above OD, the inclination of the dip slope and, ultimately, the average range and level of the water table.

The responsiveness of the River Lavant to high and low rainfall levels has been demonstrated from the Chilgrove House data. Abstraction levels are again high from within this river catchment, at nearly 10 billion litres per annum, and must have an impact on the water table. The data shows the water levels to be relatively high within the central valley area. The 'flashy' nature of the Lavant indicates its volatility at times of high rainfall, and contrasts with its usual low, or no flow, regime. However, it is probable that this river once had a very different and more consistently reliable flow rate. Within the fan gravels around Chichester, recent work has revealed a number of former braided streams and palaeochannels which were part of the former Lavant system, among them Drayton Park sand and gravel quarries. At Kingsham, on the south side of Chichester, a large area of humose soils known as the Gade Complex, formed in freshwater conditions and has been identified as associated with the Lavant (Hodgson 1967).

Furthermore, at the time of the Domesday Book the Lavant had four working mills: one at Singleton in the upper reaches, another at East Lavant, and a further two at Westhampnett and Chichester (Newbury 1987). The modern river could not sustain such industry. The presence of chalk groundwater from the Lavant system in the western rifes associated with the Selsey peninsula suggests, in the light of this other evidence, that this region had a more complex and prolific drainage system than today. The peninsula also contains brickearth soils, primarily of the Parkgate Series, which are characteristically prone to waterlogging and water retention (Hodgson 1967). This emphasises the importance of former stream flow and drainage relief in the region, which would have been both attractive and challenging to recently identified agrarian later Bronze Age communities using the area (Archaeology South-East forthcoming).

The effect of the Chichester Syncline on the water table has proved relevant to this research. Firstly, the lateral east–west movement of water north of the syncline on the upper coastal plain, close to the dip slope, has revealed previously unknown wet locations. Secondly, the syncline has affected the character of the drainage relief from the downland block onto the coastal plain. A number of important springs have occurred due to the barrier effect of the syncline. At Bedhampton in the west, and at Fishbourne, very productive springheads occur on the south side of the syncline. These are important water sources for public supplies, and will accordingly denude the freshwater input into the Chichester Harbour area. The deepening of the syncline trough to the west of Arundel may be responsible for large amounts of water from the adjacent chalk aquifer debouching into the River Arun.

The Aldingbourne/Lidsey/Binsted rife system was found to have low or non-existent chalk groundwater levels (Nutbrown *et al.* 1975). In modern times, little chalk-derived groundwater crossed the syncline at this point. However, the alluvial ends of each of these stream systems pass to the north of the syncline. It is therefore reasonable to infer that in pre-modern times water would have passed directly into these streams, which are now largely dry from the aquifer, and crossed the syncline onto the coastal plain. Abstraction and lower water levels are likely to be factors here, but the conclusion is that the coastal plain would have contained more groundwater derived from drainage relief of the chalk than is implied by recent hydrological assessments.

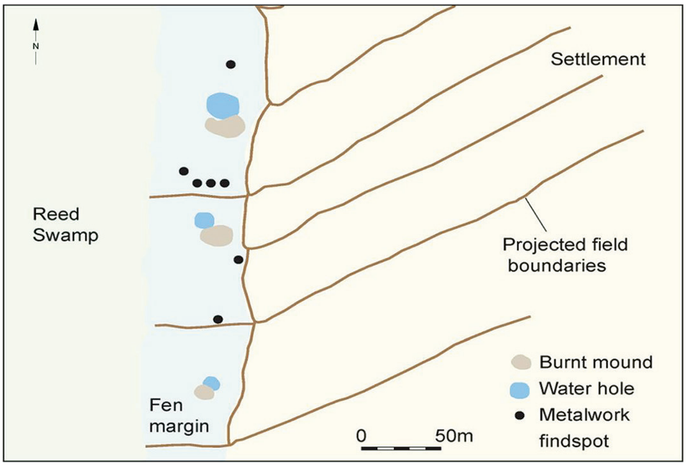

Fig. 14. The configuration of the Late Bronze Age landscape and its relationship to the fen 'edge' at Bradley Fen, Cambridgeshire (after Knight 2000).

HYDROLOGY AND THE BRONZE AGE LANDSCAPE

Recent work in the study area has established that burnt mounds are an important element of the Bronze Age landscape, particularly in the later period. Fieldwork has shown that the burnt mounds generally occupy an 'edge' location in the landscape, defined by the watercourse. Metalwork sites often lie close by, separating the burnt area from the associated settlement and field systems (Dunkin 2001). In the coastal zone of the study area this is certainly true at a number of locations, among them North Bersted, Bilsham and Drayton Park quarries, and Kingsham, near Chichester. Outside the study area, at Bradley Fen in Cambridgeshire, the structured nature of the later Bronze Age landscape exemplifies this patterning (Fig. 14), with all these elements immediately abutting the fen margin.

The votive nature of Bronze Age metalwork deposition practices is the subject of ongoing fieldwork (Dunkin *et al*. forthcoming) and a persistent pattern of placement close to watercourses and flood plains can already be confirmed and reiterated in the new work. Clearly, a hydrological perspective and assessment of landscapes containing metalwork is a crucial aspect of this work.

Water and the 'edge' location, in conjunction with soil type, play an important part in the contextualisation of the Bronze Age landscape. The position and occurrence of water are therefore important structuring components in the development of a farmscape containing roundhouses, fields, droves, hoard sites, waterholes and burnt mounds. The association of dated burnt mounds and fresh water provides clues to former hydrological regimes and their relationship to settlement pattern. At Bilsham, for example, a burnt mound dated by radiocarbon assay (Dunkin 2012) to the earlier part of the Middle Bronze Age lies approximately 250m from the present-day Ryebank Rife (Fig. 15). The BGS soil map shows that the structure is located on the edge of the alluvial spread of the stream. This provides an important dateable horizon in a Bronze Age landscape which contains these other elements. Furthermore, investigation of the Bilsham mound demonstrated that the structure had been sealed by later alluvium. Collectively, such data may assist in identifying changing climate or other factors influencing hydrological regimes in pre- or post-abandonment phases.

The example of the London Basin emphasises the effect that abstraction has on the local surface levels of a chalk aquifer. It would, for example, have had a great impact on the Lea Valley, which was an important later Bronze Age corridor connecting to the Thames (Ritchie 2008; Yates 2007). Although it is very difficult to gauge accurately, it can be demonstrated that significant changes in hydrology in local catchments can be expected. To reiterate, this has important repercussions for the contextualisation of inhabitation patterns for the Bronze Age.

The burnt mound at Piglegged Row, near Walderton, is situated in a present-day dry valley in the downland sector of the study area and

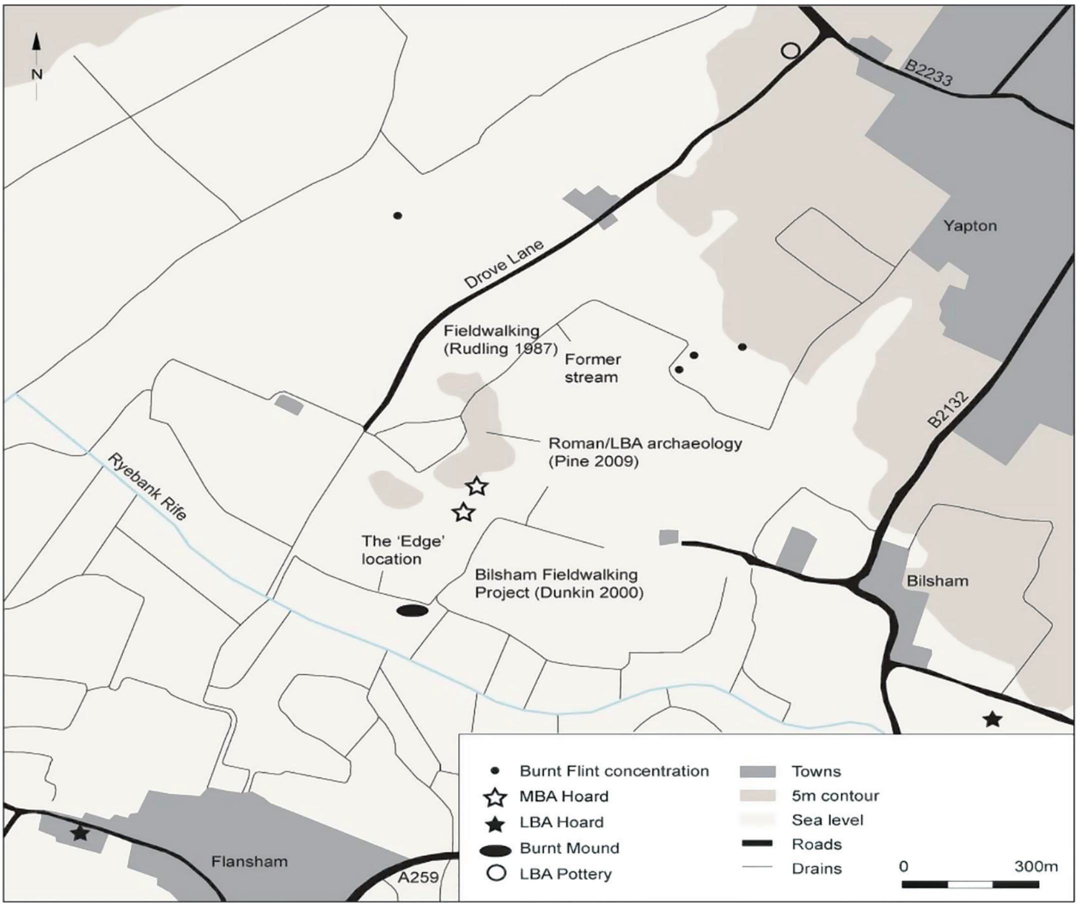

Fig. 15. The location of the Middle Bronze Age Bilsham burnt mound on the alluvial edge and its relationship to late prehistoric activity.

highlights another important aspect of this work. Dated also to the earlier part of the Middle Bronze Age by radiocarbon assay (Dunkin 2012), the presence of a burnt mound, in conjunction with the hydrological assessment, suggests the probability of above-ground water flow in the period. Today it is two kilometres from the nearest major water source, the River Ems at Walderton Bridge. The former presence of water is therefore a vital factor in the assessment of contemporary landscapes. This is especially relevant to the study of dry valleys with Bronze Age associations. Preliminary findings suggest that there may be a correlation between those dry valleys that contain Bronze Age archaeology in their upper reaches, and demonstrable water sources in the lower catchment. This study has identified locales where water flow might have occurred higher up in the catchment, and where Bronze Age occupation has been identified, for example at New Barn Down (Curwen 1934) and Harrow Hill (Holleyman 1937) both near Patching, and Park Brow, Sompting (Wolseley and Smith 1927). It has been conjectured in the larger study (Dunkin 2012) that some dry valleys may have facilitated a social corridor between downland and coastal environments. Models of transhumance can be given more weight by a fusion of archaeological and hydrological factors.

The lateral discharge of water into the River Arun caused by the Chichester syncline may have had an effect to the south of the barrier. These additional freshwater supplies may be relevant to the partitioned landscape that emerged in the later Bronze Age in the lower Arun Valley. The lower valley near Ford and Climping, for example, is grossly underfit, though this must in part relate to earlier Pleistocene processes. However, accessible abundant supplies of freshwater would have been of great value to a pastoral or agricultural society in this locale which contains settlement, fields and droveways. The stream line and springs caused by the barrier effect of the syncline on its north side within the upper coastal plain have also produced signs of Bronze Age activity. Fieldwork by the author has identified the presence and association of burnt mounds and metalwork in this zone.

Earlier work identified the existence of a significant association in the distribution of later Bronze Age coaxial field systems and the fertile brickearth soils in south-eastern lowland England (Yates 2007, Figs 9, 6 and 12, 2). This enclave of fields and fertile soils fits very well with the location of the chalk aquifer of southern England (Fig. 3). It therefore appears that, given the configuration of the archaeology and topography, an assessment of hydrology, taking account of modern day abstraction rates, is relevant to the contextualisation of Bronze Age landscapes in the chalk environments of southern England. This approach may prove useful in other landscapes and for other archaeological periods.

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