THE GLAVEN RIVER CATCHMENT
Links between geodiversity and landscape

- A resource for educational and outreach work -

Tim Holt-Wilson
Norfolk Geodiversity Partnership

CONTENTS

1.0 INTRODUCTION

The River Glaven is partly a chalk river, of which there are more in England than any other country in the world. Chalk rivers are fed from groundwater sources in chalk bedrock, producing clear waters. Many of them have 'winterbourne' stretches in their headwaters, with intermittent or absent flow in summer. They have characteristic plant communities, and their gravelly beds, clear waters and rich invertebrate life support important populations of brown trout, salmon and other fish. The Stiffkey is a notable example of a chalk river in north Norfolk, and is classified as one between Edgefield Bridge (TG085363) and Glandford Bridge (TG045415).

This report explains the links between geodiversity and the biological and cultural character of the river catchment. It provides a digest of information for education and interpretive outreach about this precious natural resource. Some specialist words are marked in blue and appear in the Glossary (section 5).

2.0 LANDSCAPE PORTRAIT

2.1 Topography and geology

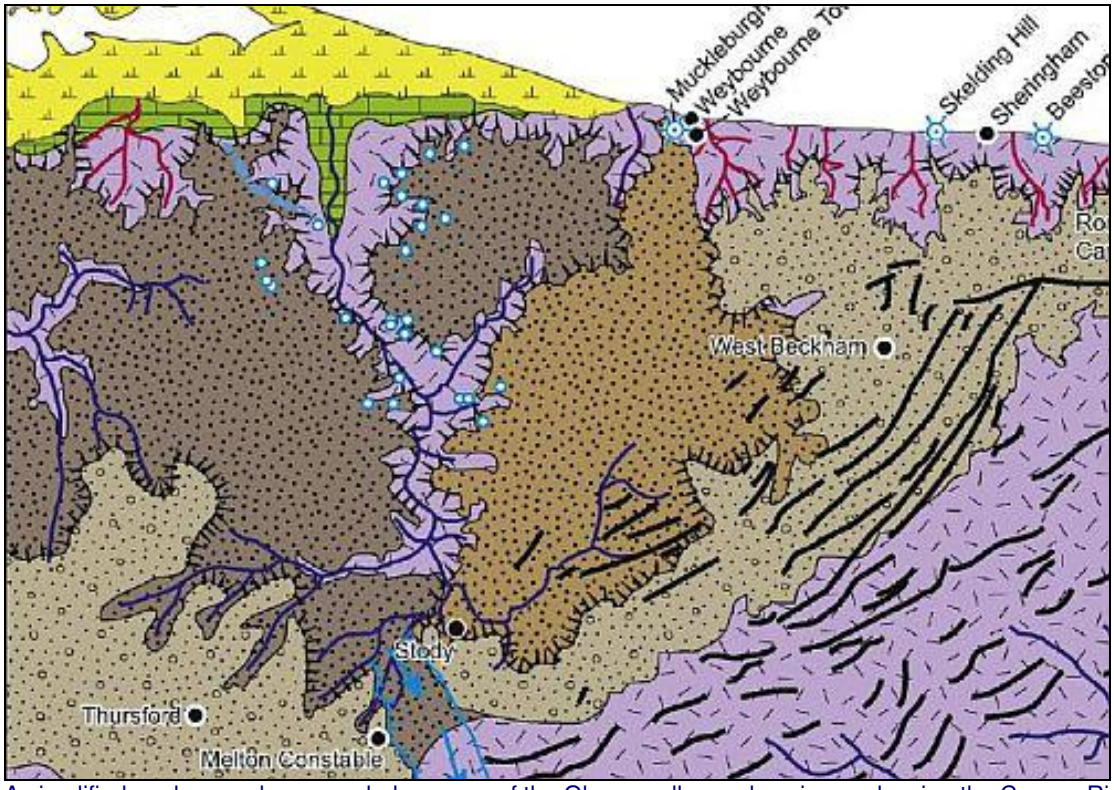
The River Glaven is a river in north Norfolk with a length of 17 km (11 miles). Its catchment drains an area of some 115 sq km, with its headwaters in the uplands of the Cromer Ridge. It is fed by several tributaries, including the Thornage Beck and Water Lane Beck, among other spring-fed sources; there are no tributaries in the lower reaches where it flows directly over chalk bedrock.

The Glaven falls some 75 m (246 ft) from its headwaters at Baconsthorpe to where it meets the sea at Cley-next-the-Sea. This represents a mean fall of approximately 4.4 m (14½ ft) per km. The gradient is steeper in the section above Hunworth, at 6.4 m per km; thus shallower (3 m per km) down-river from this point.

The bedrock of the area is Cretaceous Chalk. It is overlain by complex layers of superficial deposits of Pleistocene age. These include glacial tills of the Sheringham Cliffs Formation and glaciofluvial sands and gravels of the Briton's Lane Formation dating from the later phases of the Anglian glaciation, c.430,000 years ago. The tills were laid down beneath an ice sheet while the sands and gravels were deposited by its meltwaters. Because the ice

sheet was eroding a land surface of chalk, the character of the till in the Glaven catchment is rich in chalk and flint, from which it was given the informal name Marly Drift. The Pleistocene deposits are overlain by a variety of more recent Holocene deposits, including alluvium and peat. While peat is a natural accumulation of plant matter, much alluvium has accumulated on the valley floor due to the impact of forest clearance and farming, as silt is washed into the valley from bare soils.

The drainage pattern of the catchment is unusual, having a sharp elbow at Hunworth, where the river turns from a south-westerly to a northerly direction. This pattern reflects the geological history of the area. The story begins some 430,000 years ago during the Anglian glaciation. The first stage occurred when a major ice sheet was withdrawing from north-east Norfolk in a north-westerly direction. As it retreated, it had a temporary still-stand and deposited a ridge of outwash sands and gravels as a moraine along the ice front – this is now the Cromer Ridge landform. The Ridge is oriented north-east / south-west between Aylmerton and Edgefield, and the headwaters of the Glaven above Hunworth share this orientation. When ice sheet later withdrew to a still-stand in the Holt area (stage 2), a south-west flowing valley was excavated parallel to the ice front by meltwaters; the water found its outlet to the south through a valley at Briston (the Briston Gap), and thence into the River Bure system. Later (stage 3), the ice sheet withdrew further north-westwards and the gravel plateaux of Kelling Heath and Salthouse Heath were deposited as outwash plains, along with other gravel mound features in the valley and the sand and gravel spreads around Holt. The river's two major tributary streams are likely to have originated then; they have the same north-east / south-west orientation as the retreating ice front. The north-south trending middle and lower reaches of the main Glaven valley between Hunworth and Cley-next-the-Sea may have been excavated at this time, by a meltwater river beneath or emerging at the ice front and sending its waters southwards to the Briston Gap. The landform of the Blakeney Esker is thought to have formed beneath this same ice sheet as it retreated further north-westwards.



A simplified geology and geomorphology map of the Glaven valley and environs, showing the Cromer Ridge gravels (pale brown), Kelling outwash plain (mid brown), Salthouse outwash plain (dark brown), till plain (purple), Briston Gap (near Melton Constable) (blue lines). Black lines represent moraine ridges. Blue circles represent kames.
Image courtesy JR Lee et al, Proceedings of the Geologists' Association 124, 2013; Figure 2b.

Because the ice sheet was moving over and eroding the chalk bedrock, the character of the sands, gravels and tills which it deposited have a strongly chalky character. The Marly Drift

deposited by this ice sheet has given an alkaline, chalky character to the waters of the Glaven. For this reason, some 10.9 km (6½ miles) out of a total length of 17 km (11 miles) are classified as a chalk river, although chalk only outcrops (discontinuously) along the valley sides for some 4 km (2½ miles) downstream of Bayfield Hall.

2.2 Water in the catchment

The chalk bedrock is the most important aquifer in north Norfolk, holding massive quantities of water in its fissures, joints and pores. Rainwater percolates downwards to recharge the aquifer at different rates, according to the thickness of any overlying superficial deposits. Percolation is slowest through layers of glacial till capping the interfluves if they have a high clay content; in some parts of Norfolk the water underneath the till has been estimated to be over 10,000 years old. The Glaven catchment, however, has generally good aquifer recharge, as its chalk-rich tills, glaciofluvial sands and periglacial silts are quite permeable. A steady flow of groundwater is released into the valleys through springs and seeps, and also directly into the river bed. Due to the influence of the superficial deposits, the chemistry of the water is slightly more acidic than a pure chalk stream, particularly upstream of Hunworth.

The geomorphological integrity of the River Glaven and its dynamic relationship to its floodplain have been compromised by human activity over many centuries. The channel has been diverted, straightened and deepened in places; dams, weirs and mills have been installed. The mills are no longer used, so their relict structures may impede natural river functioning. The chemistry of the water has been altered by pesticides and fertilisers used in farming, and by excess nutrients such as phosphorus from sewage. The chalk aquifer and river flows have been depleted by pumped abstraction for homes, businesses and farms. Silt from agricultural run-off has entered the river, impeding flow and shrouding stretches of the riverbed in places, so impeding fish from spawning. These changes to the river's water and natural dynamics have led inevitably to impoverished biodiversity and a need to protect water quality. The condition of groundwaters is regularly monitored at observation boreholes at Holt Lowes, Stody, and Brinton, and the quality of groundwater at the Glandford public water supply borehole is particularly protected. The quantity of river water is assessed at a gauging station at Wiveton Bridge.

2.3 Soils

Soil types in the catchment are strongly influenced by the glacial deposits. The headwaters are sourced principally in acidic soils developed on sandy glaciofluvial and silty wind-blown deposits of periglacial origin. Downriver from Thornage, the soil types become more calcareous as the Marly Drift glacial till deposits predominate over the glaciofluvial sands, although sandy influences are still evident in the Glandford area. The valley is floored with peaty soils and river alluvium, and also marine alluvium (old saltmarsh deposits) in its lower reaches.

2.4 Geodiversity in the landscape

In terms of its geodiversity, the Glaven valley can be divided into three thematic sections:

2.4.1 From the headwaters to Hunworth

The headwaters of the River Glaven lie on high ground draining the backslope of the Cromer Ridge in the parishes of Baconsthorpe and Bodham. The soils are sandy, and are derived from the underlying sands and gravels of the Briton's Lane Formation which compose the body of the Ridge. The header valleys are floored with poorly draining head deposits, which give rise to springs and wet flushes in Baconsthorpe Wood and supply the moat at Baconsthorpe Castle. Other tributary sources include Pond Hills in Hempstead. Coniferous plantations are often developed on the sandiest soils, while swampy alder carr woodland developed on shallow peat occupies the valley floor.

The moat and pond at Baconsthorpe Castle are supplied with spring water.

The present Hempstead mill was built in 1830 to harness the waters of the Glaven, but from the start there were doubts about the reliability of the supply. This necessitated bringing water from several sources, including the mill dam and an upper pond, Selbrigg Pond, New Decoy Pond and Horsepit Pond. Selbrigg Pond was created for this purpose in 1810, and has recently been subject of an ecological restoration and dam strengthening project.

Holt and High Kelling stand on the southern skirts of the Kelling glacial outwash plain, which rises to a highpoint (78 m / 256 ft OD) at Kelling Heath. This area of sands and gravels was deposited as a southward sloping plateau, and the River Glaven flows along its southern margin at about 45 m / 148 ft OD. The valley in this area is quite steep-sided, and was excavated by meltwaters flowing towards the Briston Gap. Holt Lowes is a Site of Special Scientific Interest (SSSI) designated for its biodiversity. Areas of heathland underlain by coarse 'cannon-shot' gravels' on the plateau (the outwash plain) contrast with flushed slopes along the valley side that give rise to diverse mire plant communities, some acidic and some calcareous. The calcareous waters here emerge lower down on the slopes and relate to the Marly Drift geology rather than to chalk bedrock - the upper surface of the Chalk bedrock in this area lies some 50 m (164 ft) deep below the plateau surface.

Holt Lowes SSSI. Coarse cannon-shot gravels (left) form the southern edge of the Kelling glacial outwash plain underlie the heathland at this site. Water emerges in the valley (right) creating a mosaic of flushed wetland habitats.

From the 1880s until the 1950s, Holt obtained its water supply from springs rising from the glacial deposits at the Spout Hills, an area of common land west of the town. A cluster of wet flushes, rivulets and small dry valleys here are testimony to the power of local groundwater and variations in flow over millennia. The town's water supply is now piped from the Glandford borehole, but water used to be stored in a reservoir then pumped to a brick water tower, now demolished. Spout Hills is a Norfolk County Wildlife site designated for its dry grassland and wetland biodiversity interest.

Spout Hills, Holt. Natural springs here provided the town's water supply until the 1950s.

2.4.2 From Edgefield to Glandford

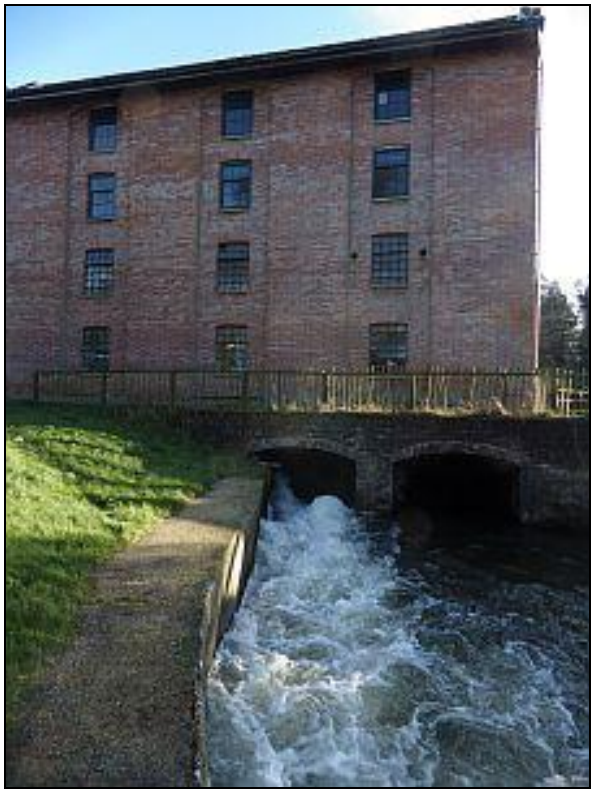
Just downstream from the Lowes, below Edgefield Bridge, the river becomes a characteristic chalk river, as calcareous groundwater starts feeding into the river bed from below. At Hunworth, the Glaven turns to flow northwards at the southernmost margins of the Kelling outwash plain. It receives the water of the Thornage Beck at Beck Farm, Stody. This stream has its headwaters in the uplands of Marly Drift round Gunthorpe and Briningham, which imparts a lime-rich character to the waters which it brings to the Glaven valley.

The valley floor broadens out appreciably north of Hunworth. 18th century maps show that the river used to have a natural meandering pattern over the floodplain. Stretches of the river were altered in the 19th and 20th centuries by straightening and deepening the river channel to speed up drainage, with consequent effects on river dynamics and biodiversity. River restoration work has been undertaken in recent years to restore more natural integrity to river functioning. The River Glaven Conservation Group (RGCG) and the Stody Estate have reinstated pools, riffles and meanders in two stretches of the river between Hunworth and Letheringsett, including a 400-metre reach known as Hunworth Meadows (near Beck Farm). The channel was narrowed in places to promote variable flow within it, and the river has been reconnected with its floodplain by removing marginal embankments to facilitate natural flooding. A further 1 km has been enhanced near Thornage Common. Restoration work has also been carried out by the RGCG at Bayfield Lake. This is not a natural lake, and was created as an ornamental feature in the early 19th century. Over the years it has been filling up with silt, so a suction-dredger has been used to remove some of the mud. Some of the lake bed has been sampled with a corer and will provide scientific information about changes in the Glaven valley over the last 200 years.

Looking east over the River Glaven at Hunworth. The uplands on the left mark the southern skirts of the Kelling glacial outwash plain. The river here has a natural meandering planform. The waters of the Stody Beck join the river from the right in an artificially straightened channel.

Water Lane Beck enters the Glaven valley at Letheringsett. Its catchment drains the plateau land south of Salthouse Heath and Kelling Heath, and includes several ponds developed on peaty soils where water emerges from the drift. The north-east / south-west orientation of this tributary valley suggests it is likely to have been initiated by meltwaters draining from an ice sheet still-stand at the Salthouse Heath outwash plain.

In past centuries, the power of the river was harnessed by four watermills between Hunworth and Glandford: Hunworth, Thornage, Letheringsett and Glandford. Each of these provided obstacles to the natural functioning of the river and obstacles to the passage of migrating fish. At Thornage in the early 19th the water was diverted into a mill pond constructed on the valley side then directed through an undershot wheel. This meant that the old course of the river was abandoned and the floodplain became deprived of water. At Letheringsett, the river supplied motive power and water to a mill (still working today) and a brewery through an array of leats, channels, dams and sluices at various levels; these can



Letheringsett Mill, showing two mill races. The one on the right houses the water wheel, the one on the left is a bypass used when the wheel is not in operation.

be seen today and exemplify the complex water management structures which altered the natural flow of the Glaven. Similar structures can be seen at Bayfield, where a lake was created in the 19th century and the river was partly diverted through a bypass tunnel. Both Letheringsett Mill and Bayfield Lake are affected by siltation problems. The channel structures pose difficulties for migratory fish.

The water environment in the Glaven valley is of high biodiversity conservation value. The river has a gravelly bed, which provides breeding habitat for native populations of brown trout, brook lamprey and white-clawed crayfish - it may hold the biggest remaining river population of the latter in southern England. The valley also includes a variety of ditches, ponds and artificial lakes, as at Edgefield and Bayfield. These provides habitat for wetland and aquatic species characteristic of chalk-rich waters, including water crowfoot and a notable variety of stoneworts. Glaven Farm Meadow, between Thornage and Letheringsett, is a County Wildlife Site on the floodplain designated for its diverse flora. In other parts of the catchment, a scattering of farm ponds and marl pits may also provide valuable watery habitat, for example for eels and rare crucian carp. Clean, unpolluted water is essential to maintaining this ecological value, which is why potential sources of pollution such as nitrates and phosphates are monitored by the Environment Agency. Water from Holt sewage works discharges into the river at Letheringsett, and makes a substantial contribution to downstream river levels, so its quality is strictly monitored; unfortunately phosphates are not stripped prior to discharge.

The ridge of the Blakeney Esker, seen here at Wiveton Downs SSSI.

The Glaven valley north of Letheringsett is one of the most interesting parts of the UK for studying lowland glacial landforms. There are many relict features along the valley here, including an assortment of distinctive rounded hills, scarps and bluffs formed from sands and gravels of the Briton's Lane Formation. These are often capped by woodland, which tends to mask their landform. The knolls are thought to be the remains of kames deposited beneath the ice; examples include Candlestick Hill, Banham's Hill and Oulton Hill. Some linear features are though to be kame terraces; examples include Horse Hill in Bayfield Park and Pereer's Hills. A meandering ridge of coarse gravel between Glandford and Blakeney is the known as the Blakeney Esker. Almost all its length has been designated as Wiveton Downs SSSI, and is thought to represent the esker deposit of Anglian age. The geology of these glacial landforms can be seen in several old quarries, most notably the gravel pit at Letheringsett Road, Glandford (a geological SSSI) and the quarry near the south-eastern end of Wiveton Downs SSSI. Another SSSI at Hurdle Lane (Letheringsett) has interesting exposures of the contorted glacial tills, sands and gravels which underlie the flanks of the Glaven valley in this area.

2.4.3 From Glandford to Cley

The Glaven valley widens out downstream of Glandford. It is no longer classified as a chalk river from this point. Although chalk bedrock outcrops along the valley sides from here northwards it is overlain by thin layers of chalky and sandy drift. The floodplain is floored by layers of river and marine alluvium. Near the ford at Glandford the alluvium is 3.6 m (12 ft) deep overlying Marly Drift and Chalk; further north, it is over 8 m (26 ft) deep at Cley Bridge. The chalk is close to the surface at Cley, about 2 m (6½ ft) down, giving the village's well water a very alkaline character.

The Glaven valley was tidal as far as Glandford in Tudor times. There were prosperous seaports at Wiveton and Cley, trading wool with the continent until the river silted up in the 17th century, perhaps due to the effects of saltmarsh reclamation at the mouth of the estuary. The old bridge at Wiveton was once the lowest crossing point on the Glaven.

The Glaven floodplain at Wiveton Bridge, looking south. 500 years ago this would have been tidal marshland.

The Glaven becomes a tidal channel at Cley-next-the-Sea, and its freshwater mingles with saltwater in the saltmarsh zone north of the sea wall. There are two sluices which prevent brackish water from flowing upstream. While maintaining the lower Glaven's freshwater character, these sluices impair the ability of migratory fish such as sea trout, lamprey and eel to enter the river from the sea.

2.5 Future scenario

Rising sea levels due to human-induced global warming may well see tidal influence extending up the Glaven valley once more. Norfolk County Council estimates that sea levels are likely to rise by up to 0.88 m this century, so in theory the river could become tidal as far upstream as Bayfield Lake (located just below the 10 m contour). If so, the river will be grading to a rising base level, which could raise freshwater levels upstream in the catchment. Set against this, all future scenarios suggest that climate change is likely to lead to lower groundwater and river flows in summer. To add to the uncertainty, unstable weather patterns are likely to lead to episodes of more intense rainfall alternating with drought, all of which have implications for river, floodplain and water management, and biodiversity in the catchment. The Glaven valley is clearly still evolving.

3.0 FEATURES TO VISIT

The following natural and cultural features have potential to communicate the contribution of geodiversity to the natural and cultural character of the River Glaven and its catchment. For details see section 4 below.

3.1 Letheringsett Mill

An active water mill offering guided tours and producing flour for local retail. The mill was restored during the 1980s, and the waterwheel and driving mechanism survive in working order. Issues regarding water management in the valley and impact on geodiversity and biodiversity can be explored, as several leats and sluices can be seen on site. An old brewery which used river water for brewing as well as motive power is sited nearby.

A 19th century sluice feeding Letheringsett brewey.

3.2 Holt Lowes

This is an open access area which includes the pine woods of Holt Country Park (managed by N Norfolk DC) and the heathland and wetland areas of Holt Lowes SSSI. It has on-site car park and toilet facilities, and a wooden viewing tower offering views at tree-top height over the heath area. Features of the site include exposures of distinctive 'cannon-shot' gravels which form the distal end of the Kelling glacial outwash plain, and interesting ecological variations linked with the geology of the valley. Dry heathland habitat contrasts with acid mire and calcareous wet flushes along the lower valley side. The River Glaven can be seen in a straightened, slightly embanked channel.

3.3 Natural Surroundings, Bayfield

The Natural Surroundings Wildflower Centre at Bayfield has a programme of walks and workshops for the general public and caters for educational field trips. It is a good place to explore topics including a) water management issues associated with the creation of Bayfield Lake, b) geological history of the valley, including glacial depositional landforms; c) ecology of the river and spring-fed fenland; d) the physics of hydraulic rams. Facilities are geared up for biodiversity-related educational work, such as pond and river dipping and bird watching.

The River Glaven at Bayfield Bridge. The building on the left houses a Victorian hydraulic ram machine which once supplied Bayfield Hall.

3.4 River restoration

The Hunworth Meadows site at Stody offers an opportunity to see the results of recent river restoration work, involving re-meandering and enhanced floodplain connectivity. The site can be seen from the road, and a grandstand view can be had from an adjacent railway embankment (rough, steep ground). Visits can be arranged through the River Glaven Conservation Group and the Stody Estate. It may also be possible to arrange a visit to Little Thornage Meadows one mile away.

3.5 Blakeney Esker

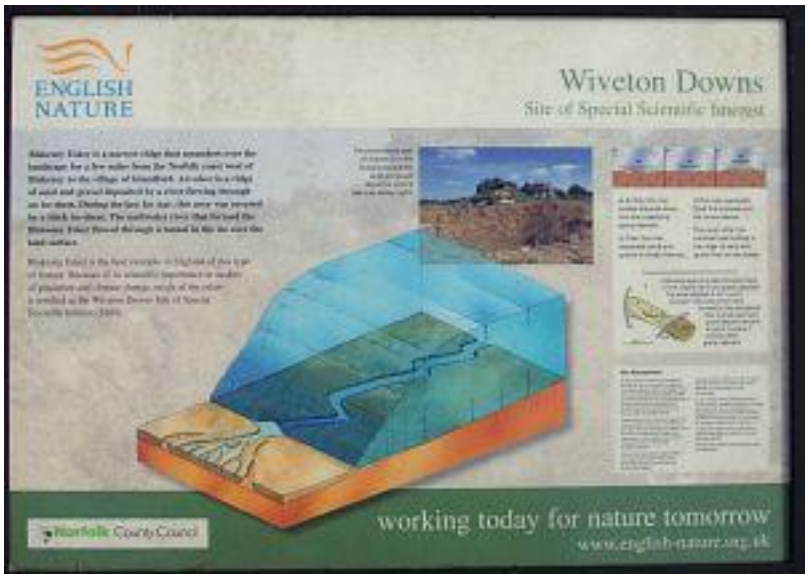
The best example of an esker in lowland England, illustrating glacio-fluvial processes associated with the formation of the Glaven valley. The site comprises the public access area of Wiveton Downs at its south-eastern end, with quarry exposures of 'cannon-shot' gravels and interpretive panels; a middle section which can be viewed from Saxlingham Road; a north-western section that can be explored by footpath, with a quarry at Morston Downs displaying cannon-shot' gravels (can be viewed over a fence).

3.6 Spout Hills, Holt

Close to the centre of the town, Spout Hills is an attractive public area in a small valley which once supplied Holt's water. The site includes ponds fed by flowing spring water and a storage cistern, providing a visible introduction to the links between water and human settlement. A series of springs, wet flushes and rivulets enable links to be made between water and local wildlife habitat. The valley is fretted with spring-sapping scarps and hollows, showing how the local landscape has been shaped by emergent groundwater.

3.7 Holt Hall Environmental and Learning Centre

The Centre offers a mix of residential and day school geography courses related to the River Glaven from Key Stage 2 to A level. At KS2 the 'River Explorers' course records changes in the river from its headwaters to the sea. A more advanced course called the 'River Glaven' is offered for KS2/3, including a river restoration topic. Two relevant courses are offered at A Level. 'Rivers and Management' explores in-depth aspects of river management, and 'Water Quality' investigates biotic and abiotic data.



An interpretive panel at Wiveton Downs, explaining the formation of the Blakeney esker.

4.0 LOCAL DETAILS

Supporting in-depth information about environmental features of the River Glaven catchment.

Geology and soils

Geology

Area underlain by Cretaceous Chalk bedrock. Chalky tills ('Marly Drift') of the Sheringham Cliffs Formation (Anglian glaciation) occupy higher ground, thickly overlain by glaciofluvial sands and gravels of the Briton's Lane Formation (late Anglian outwash). (NB The SCF was then mapped as the Lowestoft Formation.) Related to story of late Anglian ice retreat – see below. Chalk is discontinuously exposed along the valley sides downstream of Glandford.
See: British Geological Survey 2002: *Cromer. England and Wales sheet 131. Solid and Drift Geology,* and associated Brief Sheet Explanation booklet.
In BGS boreholes TG03NE38 (Heath House, Holt) and TG03NE1 (Heath Farm, Holt) located at c.63 m OD chalk bedrock was encountered at 46 m and 51 m depth respectively. They demonstrate the thickness of Anglian glacial till and outwash deposits composing the southern edge of the outwash plain at Holt. The floodplain here is at approx 43 m OD, so the chalk may lie locally at up to 30 m below the valley floor.

Soils

Soil types in the catchment are strongly influenced by the glacial deposits. The headwaters are sourced principally in acidic soils of the 541 2 Wick 2 and 541 t Wick 3 Associations (on glaciofluvial, aeolian and till deposits with loamy or sandy texture) and 551g Newport 4 (on glaciofluvial drift, with sandy acidic character). Downriver from Thornage, the soil types become more calcareous, with 343 g Newmarket 2 (on chalky drift) and 581 f Barrow (on chalky till and drift, loamy), although acidic influences are evident in the Glandford area (Newport 4). The valley is floored with 871c Hanworth soils (aeolian drift with peat upstream of Hunworth, and 861b Isleham 2 (on glaciofluvial drift and peat) downstream from there.

Geomorphology

One of the most interesting areas of Britain. Complex story relating to retreat of late Anglian ice sheet which emplaced the Cromer Ridge moraine and deposited a variety of depositional landforms (kames, kame terraces) in the valley.
The Kelling outwash plain includes the plateau round Holt. The Salthouse outwash plain includes the plateau between Salthouse Heath and Glandford.
Lee, JR et al (2013): *A polyphase glacitectonic model for ice-marginal retreat and terminal*

moraine development: the Middle Pleistocene British Ice Sheet, northern Norfolk, UK; Proc Geol Assoc 124.
Sparks, B and West, RG (1964): *The Drift Landforms around Holt, Norfolk*; Trans Inst Brit Geog #35.
Pawley, S. (2006): *Quaternary glaciations of north and west Norfolk*; Unpublished Ph.D. Thesis. University of London, 453pp.
"There are no tributaries in the lower part, whereas in the upper part there is no main stream." See Whitaker 1921: The water supply of Norfolk; HMSO, p.8

Biodiversity
Crayfish.
"Over the 18th-19th September, volunteers from the RGCG, Environment Agency, UCL and the Norfolk Non-native Species Initiative were involved in the third Glaven white-clawed crayfish transfer. As usual all volunteers were by guided by Martin Pugh of Essex WT. Unfortunately non-native American signal crayfish are present in the Glaven catchment and greatly threaten the river's native white-clawed ones. The Glaven probably holds the biggest remaining river population of white-clawed crayfish in southern England".
See http://www.riverglaven.co.uk/2013/09/glaven-crayfish-transfer-iii/
In 2012 a small number of signal crayfish were discovered in the main River Glaven below Letheringsett Mill. In 2009 a population of signal crayfish were discovered in some small ponds (Lawn Farm ponds) at the top of Watering Lane, an important tributary of the Glaven in the Kelling-Letheringsett area. That year 50 crayfish moved to the Gunthorpe stream, giving them a safer place to reside in the Glaven catchment.
http://www.riverglaven.co.uk/2012/09/glaven-to-stiffkey-crayfish-swap/ and
http://www.riverglaven.co.uk/2012/06/elimination-of-signal-crayfish/
See also
http://www.norfolkbiodiversity.org/actionplans/speciesactionplans/whiteclawedcrayfish.aspx
Brook lamprey.
"Brook lamprey are found in the Glaven in large numbers. It is likely that river and sea lamprey were common in the Glaven before the sluice gates were installed at Cley". See http://www.riverglaven.co.uk/2013/06/searching-for-the-brook-lamprey/
Rare beetles.
The Great Silver Water Beetle (Hydrophilus piceus) at Manor Farm Ponds, Briston, Carl Sayer found a single specimen. The Manor Farm ponds are spring-fed marl pits set in agricultural land at the headwaters of the Glaven and Bure rivers. See http://www.riverglaven.co.uk/2012/05/the-rare-great-silver-water-beetle/
Water vole, otter, brook lamprey, bullhead, three-spined stickleback, brown trout. White-clawed crayfish. http://www.riverglaven.co.uk/2012/04/hunworth-invertebrate-survey-2012/

Letheringsett brewery
NHER 6522 An important 18th and 19th century brewery and maltings complex. The surviving buildings stand around a courtyard and include a malthouse, a building containing two malt kilns, a tun house, cart sheds and Glaven Cottage (the brewer's house). Sections of the brewhouse remain, although most of it was demolished following a fire in 1936. The complex had a waterwheel which was located in a tunnel passing under the malthouse (installed 1784) and the cart sheds. The brick and iron road bridge on the Holt to King's Lynn road was built as part of the complex in 1818. The Lily Pond (NHER 44223) was originally dug for use by the brewery, but also provided water to Letheringsett Hall. It was fed by a hydraulic ram (NHER 17280) in Letheringsett Park. -
http://www.heritage.norfolk.gov.uk/record-details?MNF6522
Brewery owned by William Hardy – much detail in his wife's diaries, including dispute with Letheringsett watermill – See http://maryhardysdiary.co.uk/diary-volumes/2-beer-supply-water-power-and-a-death/

Letheringsett hydraulic ram
NHER 17280 Modern hydraulic ram c.1905 located in Letheringsett Park (NHER 44219) and once fed a pond that provided water for the Hall (NHER 6521). TG 0609 3886. Two 2-inch

Easton Amos and Andrews rams.

Water mills
The River Glaven had 16 mills throughout its length at the time of Domesday.
"In Domesday Holt is said to have had five watermills and this is not surprising as the parish is bounded by the river for a long distance. I can trace four of them. One of them is what is called Hempstead Mill, which is actually in the parish of Holt and is a rebuilding early last century". Basil Cozens-Hardy

Hempstead mill
The present building was built by Richard John Gurney in 1830 and at that time was known as Holt Mill. The original watercourse, along which the parish boundary runs, was moved southwards some 40 yards slightly up the hill towards Holt in order to better accommodate the mill. The Glaven, which used to be called Hempstead Beck, was effectively dammed by the mill thereby forming the large lake that is still above the mill today. The stream draining from the pond originally ran to the left of the mill until it was diverted when the mill was built. At the time locals used to say, "Mr. Gurney, he built a barn where there weren't enough corn to put in it and a mill where there weren't enough water to turn the wheel." In about 1905 the wheel was removed and replaced by a turbine, this being a more efficient way of using the limited amount of available water. At the beginning of 20th century, when the turbine was fitted, there were 5 sources of water - mill dam, upper pond (swept away in the 1912 floods) Old Decoy (Selbrigg Pond), New Decoy and Horsepit Pond.Horsepit was originally the farm horse pond for Red House Farm, fed by runoff water from the farm and its buildings but the Gurney's added a sluice in order to supplement the mill dam. See http://www.norfolkmills.co.uk/Watermills/hempstead.html
Letheringsett Mill
A working water mill built 1802 on a site dating back to Tudor times, and can be visited. See www.letheringsettwatermill.co.uk. NB Mike Thurlow (owner died May 2013). Much history at http://www.norfolkmills.co.uk/Watermills/letheringsett.html
Complex water management system for breastshot working. This could lead to local disputes when water from mill leats and ponds broke through the artificial banks and flooded neighbouring land.
Significant levels of siltation are affecting the operation of Letheringsett watermill. See North Norfolk CAMS Technical Document.
NHER 6525 Letheringsett Mill is a restored 19th century watermill. A mill stood on the site in 1720, but it burnt down and was rebuilt by 1754. The 1754 building also burnt down and the present building was erected in 1802. It was restored during the 1980s.The waterwheel and driving mechanism survive. - http://www.heritage.norfolk.gov.uk/record-details?MNF6525
Glandford watermill
Built c.1907 using flint from local gravel pits. Mentioned in the 17th century. In 1824, the miller, William Cooke wrote a letter stating that at times, the tides at his mill used to pass through the water wheel into the mill dam beyond. This happened virtually daily until 1823 and in earlier times it is probable that in times of high tides, sea water came in as far as Bayfield. By the time the mill was sold in 1969 the wheel had gone and the mill was used as a store. However, it was subsequently sympathetically converted into a residence and in 1971 a fish farming business was run here by Robin Combe of Bayfield Fish Farm; lost £15,000 - £20,000 of rainbow trout due to heavy rain and flooding. See http://www.norfolkmills.co.uk/Watermills/glandford.html
NHER 6170 Glandford Watermill. A post medieval watermill that has probably been converted into a house. The mill is shown on Faden's map of 1797. Appears to have been rebuilt as house, though two arched sluices remain. Millpond at present (1998) dry. - http://www.heritage.norfolk.gov.uk/record-details?MNF6170
Hunworth Water Mill
NHER 6530. TG 0664 3560. A watermill and miller's house in one. Set to the left, the mill dates to about 1760 and is two storeys high with a large weatherboarded loft projection on posts. It has two sluices over the River Glaven at the front and three at the rear. The mill is the only example in Norfolk where the power to the millstones was delivered from above. - http://www.heritage.norfolk.gov.uk/record-details?MNF6530

Hunworth watermill is quite an old building dating from c.1750. The site is even older and goes back to at least Saxon times with milling dues having been paid since the time of Edward the Confessor. When sold in 1974 the machinery was intact. The wheel was 14 feet in diameter and 4 feet 6 inches wide and was constructed of wood with cast iron hubs. The drive to the stones was from above, which was a very rare configuration.
See http://www.norfolkmills.co.uk/Watermills/hunworth.html
Thornage Watermill
NHER 6527 A late 18th century or early 19th century red brick watermill, three storeys high with an attic and a roof of pantiles. In 1986 the building stood derelict, and in the east end some of the original machinery was still present. This included the undershot wheel.
- See http://www.heritage.norfolk.gov.uk/record-details?MNF6527
"The course of the Glaven was altered in order to construct the mill in an area able to hold the mill dam without flooding the surrounding area and in order to be more accessible to heavy transport." - http://www.norfolkmills.co.uk/Watermills/thornage.html

Bayfield Lake
Palaeolimnology project w/ Carl Sayer Collection of sediment cores from lakes to reconstruct long-term (100s-1000s of years) changes in their ecology - 1963 peak in caesium concentrations which represents the global peak in atomic weapons testing; also onset of the Industrial Revolution (around 1850) by the first occurrence of "soot" particles; before this later date more or less undisturbed and very high quality aquatic environments. Further details pending. http://www.riverglaven.co.uk/2012/11/the-secret-history-of-bayfield-lake/
Birds at Bayfield Lake - http://www.riverglaven.co.uk/2013/04/water-birds-return-to-bayfield-lake/
Lake created in C19th. River water partly diverted into tunnel, to re-emerge beyond dam (currently back in operation 2014). Dam with weir and sluice leading to two channels at lake's outfall. Hydraulic ram c.1890 supplying Bayfield Hall.

Holt Hall Environmental and Learning Centre
Offers Geography courses related to the River Glaven from KS2 to A level, including:
KS2 River Explorers
Observe, measure and record how a river changes as it winds its way to the sea. Spend the day visiting different sites from the source to the mouth of the River Glaven. Links are made to the history of its valley and the effects of human intervention. Links with QCA Unit 14. Also courses on rocks and soils.
KS2/3 The River Glaven
Changes in channel characteristics are considered as we travel from the source to the mouth of the River Glaven. Width, depth, velocity, wetted perimeter and bankful measurements are taken to allow detailed analyses of river processes. Students are also encouraged to make careful field sketches of the river and surrounding landscape. Speed investigations and invertebrate sampling are optional and it is possible to visit a site of extensive river restoration where students are able to observe management techniques.
A Level Rivers and Management
Width, depth, velocity, wetted perimeter and bankfull measurements are taken to allow detailed analyses of river processes. In addition, students consider the impact of new fishing lakes, visit a site of extensive river restoration, learn about vital channel realignment and reflect on the flood management strategy for the future.
A Level Water Quality
Is human activity influencing water quality in the River Glaven? Freshwater invertebrates are sampled and a collection of abiotic data provide students with experience in a wide range of techniques including titration and use of digital sensors. Data collection and analysis mirrors the Environment Agency General Quality Assessment (GQA) system.
See http://www.holthall.norfolkedunet.gov.uk/index.html

Meander straightening
See Faden's map for C18th river profile.

Public water supply
Major PWS abstraction takes place at Glandford (Anglia Water).

Hydrogeology
Groundwater beneath the chalky boulder clay on the interfluves is characteristically about 10,000 years old, and has high HCO_3 concentrations. In contrast, modern valley zone Chalk groundwaters contain high concentrations of NO_3 (up to 120mgl^{-1}), SO_4 (up to 130mgl^{-1}) and Cl (up to 100mgl^{-1}) contributed by contamination, mainly from an agricultural sources. The Chalk aquifer in the interfluve areas experiences minor recharge, whereas the Chalk in the valley zone receives direct, modern recharge water. At the fluvial margin, glacial sands and gravels control the storage and release of water, transferred laterally through the glacial tills, to the high-transmissivity Chalk in the valley zone. See Hiscock, K 1993: *The influence of pre-Devensian glacial deposits on the hydrogeochemistry of the Chalk aquifer system of north Norfolk*, UK; Journ Hydrol 144
Recharge rates to the Chalk aquifer at the edge of the till are greater than the effective rainfall (rainfall minus actual evapotranspiration) because of the contribution of large volumes of runoff from the till sheet. This water characterises the modern (post-1960s), high-nitrate, groundwaters of the main Chalk valleys with potentially short travel times from recharge to discharge. The arable land on the till sheet has had field drains installed and these contribute to the bulk of the runoff; as a consequence nitrate concentrations in the runoff are high;
• One consequence of the redistribution of recharge by the till is that boreholes close to the edge of the till sheet are likely to pump a greater proportion of modern recharge than previously believed and these are likely to produce water with higher nitrate concentrations;
• the Chalk groundwaters at the edge of the till sheet are vulnerable to pollution because of the potentially high recharge rates (due to runoff recharge) and the relatively shallow depth to the water table. As a consequence, travel times through the unsaturated zone may be short.
See Marks et al 2004: *Chalk Recharge Beneath Thick Till Deposits in East Anglia*; Groundwater Systems & Water Quality Programme Internal Report IR/04/179; BGS
Chalk transmissivity is low under the Cromer Ridge, and is lowest downriver e.g. near Glandford, where the Chalk is closer to the surface. Groundwater flows northwards down the head gradients to the coast and into the valleys.
Non chalk aquifer takes place in the headwaters of the Glaven, in the glacial deposits.

Water management
Source Protection Zones are designated to protect groundwater. There is one downstream of Letheringsett to protect the Glandford borehole. See *North Norfolk Catchment Abstraction Management Strategy, Conceptualisation Report*; Environment Agency 2005
Groundwater Vulnerability Zones are designated to characterise vulnerability to pollution applied to the ground surface; this is related to soil properties (transmissivity). The sandy soils of the Cromer Ridge and the outwash plains are highly vulnerable; the tills west of the Glaven are intermediate vulnerability.
Nitrate Vulnerability Zones are designated to protect waters from agricultural nitrate pollution. The Cromer Ridge area of the catchment is designated NVZ for both ground and surface waters, and the rest of the catchment for groundwater.
Groundwater observation boreholes are situated at Holt Lowes, Stody, and Brinton.
Groundwater management takes place using Groundwater Management Units.
Groundwater catchments and geographical river catchments do not readily correspond. The Glaven GWMU is 102.3 sq km in size.

River restoration work
Project completed at Hunworth, 2010, on the Stody Estate land, on a 400-metre reach which, at sometime in the distant past, had been straightened and moved to the edge of the floodplain, probably for the purposes of milling. The project involved restoring the river's natural form by putting back pools, riffles, and meanders, narrowing the river and reconnecting it with its flood plain. Surrounding land in HLS. See
http://www.wildtrout.org/content/river-glaven-hunworth

See also Cinderella Project report for work in 2006 at
http://www.wildtrout.org/sites/default/files/library/Glaven.pdf
Hunworth meadows.
In 2008 cattle grazing recommenced at Hunworth (after a long absence) as part of a river-meadow restoration project enacted by the RGCG and the Stody Estate. In 2010 floodbanks were removed from the riverside to permit flooding of the meadows and then in 2011, to complete the restoration process, the river was re-meandered. See
http://www.riverglaven.co.uk/2012/12/remembering-the-meadows-summer-2012/
Little Thornage meadows (near Thornage Common and on CWS 1097 Glaven Farm Meadows)
First River Glaven Conservation Group project, to improve fish spawning in 2006. Funded by the Cinderella Chalk Rivers Project (NE/EA). "To restore and enhance one km of in-river habitat and increase biodiversity for brown trout, brook lamprey, bullhead and white-clawed crayfish; to enhance the ecological and geomorphological functioning of the river and re-connect the river and floodplain by removing a section of raised floodbank; to develop an experience base for the group in relation to further restoration projects and to establish a demonstration site to show the techniques to other interested parties". See
http://riverglaven.files.wordpress.com/2012/01/autumn-2007.pdf
Further river narrowing by the River Glaven Conservation Group using faggots of alder wood at Little Thornage meadows Jan 2013 – see
http://www.riverglaven.co.uk/2013/01/volunteer-work-day-at-little-thornage/

Bayfield Lake.
"The lake was dug for ornamental purposes in the late eighteenth century and since this time it has slowly been filling up with river-borne mud. Since June 2012 until last month a suction-dredger has been removing mud from the lake as part of a river-floodplain restoration project".
http://www.riverglaven.co.uk/2012/11/the-secret-history-of-bayfield-lake/
Thornage Beck.
April 2012 demonstration was given by Nigel Holmes on how to restore riffles and pools to small straightened channels, in this case the tiny Gunthorpe Stream (aka the Thornage Beck), close to Brinton Hall. See http://www.riverglaven.co.uk/2012/05/restoring-habitat-diversity-in-the-gunthorpe-stream/
Academic research on the Glaven.
Clilverd, HM et al [2010]: *Ecohydrology of an embanked lowland UK river meadows and the effects of embankment removal;* Studied soil moisture and fertility of disconnected floodplain re. studying it on a reconnected floodplain.
See also: Clilverd, HM et al 2013: *River–floodplain hydrology of an embanked lowland Chalk river and initial response to embankment removal*; Hydrological Sciences Journal, 58 (3), 627–650.

County Wildlife Sites
CWS 1094 Hunworth Common (Stody)
TG 068356 This site is part of a group of small semi-natural, broadleaved woodlands which lie north of the River Glaven. Access via footpath, partly open access area.
CWS 1097 Glaven Farm Meadows (Thornage/Holt)
Grid Reference: TG 059382. This site is an area of marshy grassland in the valley of the River Glaven. Along the ditches the vegetation is much taller with canary grass (Phalaris arundinacea) meadowsweet (Filipendula ulmaria) and water mint (Mentha aquatica). Where springs occur, blunt-flowered rush becomes common mixed with fen bedstraw (Galium uliginosum) and greater bird's-foot trefoil (Lotus corniculatus). The River Glaven has diverse marginal and aquatic vegetation. Within the channel is fennel pondweed, (Potamogeton pectinatus) with mats of water-crowfoot (Ranunculus spp.). No public access to all area, though Thornage Common is open access area and part of the site (strip alongside the road).
CWS 2006 Spout Common (Holt)
TG 074386 This site comprises grassland and scrub with some areas of more mature woodland around the edges. Springs seep from the valley sides feeding a small stream which flows into the River Glaven; these create wet flushes along the sides and in the

valley bottom. The fen meadows have calcareous flushes with orchids. Public access.
Glandford Mill Meadow (Letheringsett with Glandford)
TG 046415 Situated at Glandford Mill, adjacent to the mill pond and the River Glaven. It comprises an area of unimproved species rich marshy neutral grassland with tall fen vegetation surrounding a dyke and pond. No public access

SSSIs
Holt Lowes
TG 088374 This is an area of dry sandy heathland that grades into flushed slopes along the valley of the River Glaven. There is an excellent example of mixed valley mire in a small tributary valley that bisects the heath. The feeder stream emerges from underlying chalk and these alkaline waters contrast strongly with acidic, nutrient-poor areas on the valley-sides below the heathland. The mixed mire communities are diverse and reflect the variations in alkalinity and nutrient availability in the drainage waters. Several uncommon plants and animals are present, including some at their only known East Anglian locality. Areas of nutrient-rich fen on the valley-floor of the Glaven resemble some of the Broadland Fens. An acidic mire community in the tributary valley receives drainage waters from the surrounding heathland on glacial drifts. Plants characteristic of these wet, acidic conditions include several species of Bog Moss Sphagnum spp., Cross-leaved Heath Erica tetralix, Round-leaved Sundew Drosera rotundifolia, Common Butterwort Pinguicula vulgaris, Common cotton-grass Eriophorum angustifolium and Heath Rush Juncus squarrosus. There is a narrow zone of calcareous mire along the axis of the tributary stream but this community is better developed on flushed slopes above the River Glaven. A typically diverse calcareous fen vegetation has developed.
Unit 1 Fen, marsh and swamp
Unit 2 Dwarf shrub heath
See http://www.sssi.naturalengland.org.uk/citation/citation_photo/1002710.pdf
"The Lowes is an area of heathland of around 120 acres (0.49 km2) to the south of Holt set aside by the Inclosure Act of 1807. The poor of Holt had grazing rights for an animal and also had the right to take wood and gorse from the land for their own use. It is likely that the land was never used by the poor of Holt as the land was not wholly suitable. The Lowes was used for military training during World War I. It is open to the public along with Holt Country Park. The Lowes has long been recognized as an important area for wildlife, with records going back to the 18th Century. It was declared an SSSI in 1954 and for a while managed as a nature reserve by the Norfolk Wildlife Trust, which continues to act as Managing Agents for the Trustees. As on all lowland heaths, there is a constant need for management to prevent the encroachment of trees. Recent work has concentrated on clearing a large part of the mixed valley mire, an area of Sphagnum bog that supports plants like Sundews and several species of Dragonfly, including one, the Keeled Skimmer, found nowhere else in East Anglia". See http://en.wikipedia.org/wiki/Holt,_Norfolk
Glandford Hurdle Lane Pit
TG 054416 Exposures in this pit on the east side of the Glaven Valley demonstrate a complex set of Pleistocene glacigenic deposits, ranging from till, through lacustrine calcareous silts to sands and coarse gravels, the last showing tunnel-flow as well as open-flow bedding. In addition to the sedimentological interest of the sections, the site is adjacent to the outwash plain of Salthouse Heath, the kames and terraces of the Glaven Valley and the esker of Wiveton Downs. Both the sediments and landforms locally need to be considered together in order to interpret and understand the glacial history of the area. This is a working quarry.
http://www.sssi.naturalengland.org.uk/citation/citation_photo/1002247.pdf
Glandford Letheringstett Road Pit
TG 043 411 This site is important, in conjunction with the exposures at Bilsey Hill, Hurdle Lane, and Wiveton Downs, for showing the composition of the North Norfolk Pleistocene till plain and its associated kames, kame terraces and esker. Several mounds of gravel and till occur within the Glaven Valley. Their interest centres on whether they are depositional in origin, forming kames, or are the residual product of erosion of a formerly more extensive gravel spread. Study of the internal sedimentary structure of these mounds will be critical to resolving the debate. Only one of the mounds, in the section at Letheringsett Road, has such exposures.

http://www.sssi.naturalengland.org.uk/citation/citation_photo/1005462.pdf
Wiveton Downs
TG 023433 Wiveton Downs (known to geologists as the Blakeney Esker) is a classic landform of outstanding importance for teaching, research and demonstration purposes. Its genesis as an esker or crevasse-fill deposit has long been the subject of debate and research. Its overall morphology is particularly clear, showing a sharp ridge form, while its internal structures are demonstrated in several gravel pits.
Exposures of sands and gravels show bedding indicative of both tunnel- and open-flow conditions, as well as facies variation between the high-energy flow of the central area of the ridge and lower energy domains of the marginal zone. The relationship of the ridge feature to the surrounding till plain can also be seen both morphologically and sedimentologically: flowing water cut into the till before the gravels were deposited. Wiveton Downs is part of a suite of landforms comprising, in addition to the till plain, various kames, kame terraces, outwash plains and a tunnel valley. It is unusual to find such a wide range of features, most of which have exposures, in such close proximity particularly in southern England.
http://www.sssi.naturalengland.org.uk/citation/citation_photo/1002122.pdf

Baconsthorpe Castle
NHER 6561 Remains of Baconsthorpe Castle and Baconsthorpe Hall. 15th century flint-faced fortified manor house and tower surrounded by a moat (Baconsthorpe Castle) built by the Heydon family. An outer gatehouse (Baconsthorpe Hall) outside the moat was added in 1560. - http://www.heritage.norfolk.gov.uk/record-details?mnf6561

Selbrigg Pond
"The pond was dug by hand around 1810 as a header reserve for Hempstead Mill. The mill was suffering from insufficient water despite 4 other smaller ponds having been made between the mill and Selbrigg Pond. The Tithe map of 1840 shows a pond around 9 acres in size with streams from Bodham and Baconsthorpe entering the pond. Indeed the pond stretched back to 'Selbrigg Road' In Lower Bodham. The parish boundary between Hempstead and Bodham runs through the pond, presumably along the original line of the streams. Subsequently to the original pond being dug, a duck decoy was incorporated - a funnel shaped area that was netted as a way of catching ducks. Furthermore, a boat house was subsequently built mid-way along the Northern bank, little now remains".
"It would seem likely that the pond was dug on where the streams from Baconsthorpe and Bodham meet, hence the parish boundary running through the pond, and the Tithe map may have reflected the boggy nature of the land rather than the exact extent of the pond.
See http://www.selbrigg.com/History/Origins.html
Work plans to renew retaining wall and sluice 2013, and ongoing work to restore the Pond. The restoration of the pond to be managed by Norfolk Rivers Trust as part of the 9 Chalk Rivers project, and will include clearing trees, dredging silt. See
http://www.selbrigg.com/blog.html
Work 2014 and 2015 will involve dredging, preserving the reed beds, fen and wet woodland around the margins. The pond, which feeds the River Glaven, is spring-fed and has remarkably good water quality, making it an outstanding site for insects, birds and fish. See http://www.norfolkriverstrust.org/2013/11/selbrigg-pond-restoration.html

Holt Country Park
Walks in pine forested land adjacent to Holt Lowes SSSI. Includes car park and facilities; £1.50 daily parking charge. Managed by N Norfolk DC. See
http://www.northnorfolk.org/community/2261.asp

Bayfield Natural Surroundings Wildflower Centre
Eight acres of grounds, a wildlife-themed garden, woodland and riverside walks. Facilities incl shop and café. Natural history educational facilities include pond dipping, captive red squirrels and harvest mice., bird hides, herb garden, woodlands, orchard, sundial, flower meadow, river platform, bird boxes; nature tours available. Plant shop, toilets and cafe. Important area of managed spring-fed fen. The Centre is part of Bayfield Estate, which includes Pleistocene geomorphological features. Programme of walks and workshops.

Adjacent to Bayfield Lake showing water management system associated with the lake; also a hydraulic ram. See http://www.naturalsurroundings.org.uk/ Contact: Dr Andrew Cannon

Holt town water supply

Holt water tower. The town's water was pumped from the common land at Spout Hills to the water tower in Shirehall Plain. The tower was made from bricks, built in 1885 and was 56 ft (17 m) high. It held around 150,000 gallons of water and the water level inside the tank could be read from the ground. The tower was demolished in the 1950s.

Spout Hills. 14 acres (57,000 m2) of green space, which once provided the town of Holt with all of its water needs. An old reservoir still exists but the pumping station was dismantled in the 1950s. A working party is currently restoring and conserving the hills for future generations by removing scrub, keeping the pastures clear and managing the woodlands which have grown up over the last 50 years. -

http://en.wikipedia.org/wiki/Holt,_Norfolk

"At Holt, Letheringsett, and Hempton there are more or less copious springs. That at Holt rises on the west side of the town, at the junction of marls and brickearths with overlying sandy and gravelly beds, all belonging to the Glacial period." The water simply flows from the surface, through the porous strata, until arrested and thrown out by the marly and clayey beds beneath. It was remarked of this spring (in 1829) that it 'affords, in summer and winter, in drought or in wet seasons, an equable stream of very soft and very pure water' (Chambers, History of Norfolk). See also below, p. 54." See Whitaker 1921: The water supply of Norfolk; HMSO, p.28

"According to the Memoir on the Geology of the country around Holt (1884), from which these notes are taken, the water-supply had been mostly obtained from the spring called the Spouts that issues to the south-west of the town at a spot called Spout Hill, at the junction of the Glacial sands and gravels with the brick-earth and marl beneath. This has been advertised as "the purest water in England," and as an Artesian Well; it is, however, an ordinary landspring.

From this spring most of the inhabitants have been supplied, the water being carried to various houses in the town by tub-carts and buckets.

The copiousness of the spring is no doubt due to its receiving the drainage of a considerable tract, although the direction and extent of its numerous sources cannot be determined from any surface-evidence. The irregularities and local inclination of the beds might allow the waters that fall on the brow of Kelling Heath on the north, to flow southward in devious subterranean courses to help to swell the Holt spring. Issuing as the spring does from immediately beneath the town of Holt, it is of course particularly liable to contamination from the leakage of cess-pits, &c, in the town ; and this is reported to have been the case. There were few private wells, but there were two pumps about 50 feet deep which helped to supply the houses. Now, however, the supply is largely from well". Ditto

Lakes and ponds

The Glaven catchment contains several lakes and ponds. There are around 9 sizeable lakes (over 1 hectare) situated adjacent to the river, most of which date to the late 18th and early 19th centuries when they were dug for ornamental purposes (in the grounds of country estates), or as mill ponds. Bayfield Hall Lake and Selbrigg Pond are good examples. Smaller ponds also abound in the catchment with marl pits being common. Other pond origins include horse-watering pits, duck decoy ponds and ponds dug more recently for angling and conservation purposes. Glaven lakes contain a range of fish species, common species being roach, rudd, perch, pike and eel. Some of the smaller ponds also contain fishes and just a few of these have populations of Crucian Carp, a recently established Norfolk Biodiversity Action Plan (BAP) species.

Most of the Glaven lakes are high quality ecosystems with clear waters and abundant beds of submerged aquatic plants. Stoneworts (Characeae), a group of plants of conservation concern, occur in some of the lakes with at least 5 recorded species; Chara vulgaris, Chara globularis, Chara contraria, Chara hispida and Nitella flexilis.

As a consequence the Holt to Melton Constable region (largely the Glaven catchment) has been designated as an Important Stonewort Area by the UK plant charity Plantlife International. Other common plant species that occur in Glaven lakes and ponds include:

- Curled Pondweed (Potamogeton crispus)
- Fennel-leaved Pondweed (Potamogeton pectinatus)
- Least Pondweed (Potamogeton pusillus)
- Broad-leaved Pondweed (Potamogeton natans)
- Horned Pondweed (Zannichellia palustris)
- Pond Water-crowfoot (Ranunculus aquatilis)
- Rigid Hornwort (Ceratophyllum demersum)
- Soft Hornwort (Ceratophyllum submersum)
- Ivy-leaved Duckweed (Lemna trisulca)
- Common Duckweed (Lemna minor)
- Marestail (Hippurus vulgaris)
- Amphibious Bistort (Persicaria amphibia)

In particular Soft Hornwort is rare in the British Isles. North Norfolk, including the Glaven catchment, seems to be a key area for this plant.
See http://www.riverglaven.co.uk/river-glaven-wildlife/lakes-and-ponds/

Glandford
Originally 'Gleam-ford' meaning 'merriment' re. rustic sports and pastimes carried out at the ford in Saxon times. See Ekwall. Glaven is a back-formation from this name.
Borehole geology at the ford: TG04SW73 borehole 1: approx 3.7 m (12 ft) of clayey alluvium over 3.7 m (12 ft) clayey chalk [till] over bedded chalk.
The chalk river ends at this point. See: *The State of England's Chalk Rivers – A Report by the UK Biodiversity Action Plan Steering Group for Chalk Rivers;* Environment Agency, 2004; Figure 1.

Glandford Water Treatment Works
Anglia Water PWS borehole located here. Issues with nitrate pollution – see report Anglia Water 2010: Final Business Plan -Part B4: Quality Enhancements – Water Service; Strategic Management Consultants, at:
www.anglianwater.co.uk/_assets/.../SMC_AW_FBP09_B4_W_v1.3.pdf
"The data indicated a rising trend in nitrate levels. It was unclear whether this was still rising at the same rate or whether possible nitrate/fertiliser use control methods were leading to a plateau in the effect. Anglian Water confirmed that the pattern was due to the drought. Since production of this data it had rained and the trend was now rising again. Anglian Water confirmed that it considered that the borehole was at high risk due to the presence of arable farming and diffuse pollution hazards within the catchment."
"Anglian Water considered three options:
Option 1 - satellite borehole with RGF treatment to provide more water for blending
Option 2 – ion exchange plant to reduce nitrate levels by treatment
Option 3 – East Beckham to Glandford Blend scheme.
By analysis the ion exchange treatment option delivered the highest reward for the company. … A further option 4 - catchment management – had a much lower benefit score as well as cost, but only had a low probability of delivering the required risk reduction. It was therefore considered not satisfactory by itself".
Phosphates not stripped from sewage discharge at Letheringsett. - Andrew Cannon, pers comm.

Wiveton port
"Norfolk and the parishes of Wiveton, Cley and Blakeney enjoyed vast wealth as the collective 'Blakeney Haven' became one of the greatest ports in England. Wool trade prospered with the Low Countries, monies channeled into great church building projects. Cley and Wiveton silted up in the 17th Century, allowed to do so as grazing became more profitable than the wool trade, their churches now stranded far behind the tideline.".
http://www.ournorfolk.org.uk/the-built-heritage/redundant-ports-glaven-churches-wedding-flowers/
See Hooton, J (1996): *The Glaven Ports: A Maritime History of Blakeney, Cley and Wiveton in North Norfolk*; Blakeney History Group
Wharf area with continental pottery finds identified near churchyard. "This was the old wharfage area before the creek was filled in, and that an iron ring for tying boats remains.

The area is marked as Mill Hard on a map of 1586" - See http://www.heritage.norfolk.gov.uk/record-details?MNF15323
Research by the Blakeney Area Historical Society – see http://www.history-blakeney-area.org.uk/glaven-historian.asp
Wiveton Bridge is NHER 6141. Stone and brick bridge of about 1500. Later repairs to abutments. - See http://www.heritage.norfolk.gov.uk/record-details?MNF6141

Geology in the lower reaches
BGS borehole data
TG04SW57 Church Lane, Cley – 8 ft drift over Chalk? over Chalk at 12ft
TG04SW64 Town Yard, Cley – Chalk at 5 ft
TG04SW20 Cley Bridge – 2 m made ground, 6 m silty clay, 8.1 m blacker ditto, 9 m sand & gravel, 11.5 m silty clay, 12.6 m peat, 14 m downwards gravel.
TG04SW42 Hilldrop Cottage at Leatherpool Lane, Wiveton – 10 ft drift, then Chalk to 90 ft
TG04SW73 Borehole No. 1 at Glandford ford - topsoil 3 ft, clayey alluvium 3-15 ft, clayey chalk [Marly Drift] 15-27 ft, chalk 27 ft +

Coastal ecology
The river discharges into the intertidal areas of the Freshes Marshes (Norfolk Coast SSSI, cSAC, RAMSAR), and contributes freshwater to these coastal habitats, although ecology of such inputs is not fully understood. See CAMS conceptualisation report p.40.

Tidal influences and barriers
Faden shows [saltmarsh] upstream as far as Glandford bridge. Norfolk mills suggests once as far as Bayfield? If so, prob in Mediaeval high water – "in earlier times it is probable that in times of high tides, sea water came in as far as Bayfield" - http://www.norfolkmills.co.uk/Watermills/glandford.html
"Brook lamprey are found in the Glaven in large numbers. It is likely that river and sea lamprey were common in the Glaven before the sluice gates were installed at Cley". See http://www.riverglaven.co.uk/2013/06/searching-for-the-brook-lamprey/
"The lower reaches are stocked with trout. The middle and upper reaches have a population of native brown trout, and eels are present throughout the whole course. The Cley sluice is a barrier to fish such as sea trout moving upstream and there is no fish pass. The calculated score was 5 due to the presence of breeding salmonids (trout). The fish community under benchmark flow conditions was not judged to be significantly different". See EA CAMS Technical Document. Ros Wright is doing a PhD on fish passage up the river.

Global warming impacts
See Norfolk Climate Change Strategy [2009] and also Local Climate Impacts Profile at http://www.norfolkambition.gov.uk/consumption/groups/public/documents/article/ncc095340.pdf -

- Increased winter rainfall, combined with a likely increase in the quantity of rainfall from intense events in winter, will result in a greater risk of flooding.
- Acute temperature events such as heat waves are extremely likely to increase. The longest summer heat wave duration is likely to grow by up to 10 days over the 21st century.
- ☐Summers are also likely to be drier. Future summer average daily rainfall is likely to significantly decrease. In partnership with this summer dry periods are likely to ncrease in duration, more likely than not increasing by up to 10 days.
- Sea levels are likely to rise by up to 0.88m, rising at rates faster than present (IPCC, 2007), having a major impact on coastal erosion and coastal flooding. Recent scientific findings find this estimation to be very conservative.

Re. impact of climate change on groundwater and river flows, "almost all scenarios suggest lower summer flows" - see Prudhomme et al 2012 at http://nora.nerc.ac.uk/15039/

5.0 RESOURCES

5.1 BOOKS, MAPS AND REPORTS

- Moorlock, BSP, et al: *Geology of the Wells-next-the-Sea District*; British Geological Survey, 2008.
- Purseglove, J: *Taming the Flood: History and Natural History of Rivers and Wetlands*; Oxford University Press, 1988.
- *The State of England's Chalk Rivers – A report by the UK Biodiversity Action Plan for Chalk Rivers*; Environment Agency, 2004.
- Sparks, B and West, RG (1964): *The Drift Landforms around Holt, Norfolk*; Transactions of the Institute of British Geographers, 35.

5.2 GLOSSARY

Alluvium	Unconsolidated, water-lain sediments of terrestrial origin deposited in a non-marine setting, for example a floodplain or an estuary.
Anglian	A major glacial period during the middle Pleistocene Epoch, about 450,000 years ago. Norfolk was covered by ice sheets from the north and north-west, one of which extended as far south as Hornchurch in Essex. When it retreated it left behind thick deposits of till or 'boulder clay', and also beds of outwash sands and gravels deposited by meltwater.
Aquifer	A water-bearing geological formation.
Biodiversity	The variety / diversity of life forms; the totality of genes, species, and ecosystems of a region.
Catchment	The land area from which a river or stream gathers its water.
Cretaceous	A period of Earth history between 145 and 65 million years ago; it followed the Jurassic period. It was characterised by widespread shallow shelf seas in which calcareous planktonic organisms were abundant; their remains were deposited to form chalk and the silica mineral flint.
Esker	A linear accumulation of glaciofluvial sediment, deposited subglacially in a meltwater stream channel beneath a glacier or when the stream emerges at the ice front.
Geodiversity	The natural range (diversity) of geological features (rocks, minerals, fossils, structures), geomorphological features (landforms and processes), soil and hydrological features that shape the landscape. It is the non-biological aspect of nature.
Glaciofluvial	Referring to meltwater streams associated with ice sheets and glaciers and the deposits and landforms they produce.
Head	Mixed superficial deposits of periglacial origin on slopes, mobilised by solifluction (qv).
Kame	A hummock of glaciofluvial sediment deposited on an outwash plain. Kame terraces are ridges of glaciofluvial sediment deposited between a glacier and the valley sides.
Outwash	The meltwater emerging from a glacier or ice sheet. It transports and then deposits sand, gravel and silt, to form outwash plains and aprons along the ice front.
Periglacial	In the vicinity of a glacial environment, with conditions dominated by freeze-thaw processes.
Pleistocene	An Epoch of Earth history, between about 2.5 million and 10,000 years ago. Its ending corresponds with the end of the last glacial period (the Devensian Stage). It is characterised by cyclical shifts in the Earth's climate between cold (glacial) and warm (interglacial) periods, driven by variations in planetary orbit round the sun.
Saltmarsh	An area of marshy ground periodically inundated with seawater, and often having creeks and pools of salt or brackish water; it has characteristic salt-resistant vegetation.

Solifluction	The slow movement of an active layer of waterlogged sediment down-slope, over impermeable material such as permanently frozen ground (permafrost). It occurs in periglacial environments where surface layers melt in summer.
Till	Unsorted, unstratified material deposited directly by glacial ice; sometimes called boulder clay.

Written by Tim Holt-Wilson
Norfolk Geodiversity Partnership
timholtwilson@onetel.com
Version 1, February 2014

The Norfolk Geodiversity Partnership is a forum for conserving Norfolk's Earth heritage
https://sites.google.com/site/norfolkgeodiversity/