GEOLOGICAL IMPACTS ON COASTAL WETLAND LANDSCAPES: SEA-LEVEL RISE, WITH ILLUSTRATIONS FROM THE RIVER BANWELL

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SUMMARY

Field criteria were used to map the locations of seabanks on the enclosed marshes of the lower Banwell, in an area where sea levels have continued to rise. The banks appear in the cartographic record for the first time in the mid eighteenth century but are unlikely to be post-medieval in age. At this date they ranged along the banks of the tributaries of the Banwell and, along the Banwell itself, extended inland as far as Ebdon. Because of rising sea levels the banks over the course of time have been significantly raised and shortened in order to minimise risks and costs. In about 1790 the outfall on the Banwell had been moved by c. 1.5 km to a location (New Bow) much nearer the coast. As in much of Britain and mainland Europe, the seabanks of the lower Banwell area are now defensive features, rather than the wealth-creating structures built at the time of land-claim in the area. The earliest seabank and its associated outfalls have not survived as upstanding field monuments.

INTRODUCTION

The River Banwell is one of a number of tidal streams that drain the North Somerset Level (Williams 1970), once part of the extensive estuarine to freshwater marshes along the margins of the inner Bristol Channel and Severn Estuary which, through land-claim (also called reclamation) over a period of almost 2000 years, have come to be known as the Severn Estuary Levels. Engineering a seabank to exclude the tide from part of a marsh is a decisive act, and the banks themselves, together with the outfalls that must accompany them, are critical field monuments by any archaeological standard. Their construction allows a natural marsh dissected by tidal creeks and fit only for seasonal use to be permanently settled and exploited for arable or pastoral farming or for industrial development. Borrowing from military strategists, seabanks and outfalls, initially at least, are offensive structures: their purpose at the time of construction is wealth-creation. Once the dramatic change in land-use has been wrought, however, external factors may force a shift in the status of the enclosing banks. Rising water-levels—one of a number of geological factors that impact on the lowland coastal zone and human activities located there—cause seabanks built for the purpose of enclosure to become defensive structures against inroads by the sea. Strategically, their purpose has become that of wealth-protection in the context of an historic landscape.

Seabanks and outfalls are part of the present and historic landscape of the lower Banwell area, falling in the parishes of Wick St. Lawrence, Worle and Kewstoke. The purpose of this paper is to give an account of the evidence surviving in the area for these archaeologically neglected structures, and as far as possible to show how they have evolved under the impact of continuing sea-level rise. A change from an offensive to a defensive function is clearly reflected in their character in the landscape.

SEA-LEVEL RISE

Globally, mean sea level rose eustatically by about 120 m over the last c. 18,000 years due to the melting of the Devensian ice sheets (Fairbanks 1989). The rise was at first swift but about 4000 BC began to slacken significantly, although it continues today at about 2 mm/yr (Gornitz 1995), and is probably accelerating on account of anthropogenic global warming.

The actual pattern of rise measured in comparison to a fixed point on the Earth's surface at a place on the coast is the time-height curve for *relative* mean sea level (RMSL). Sea level requires careful and consistent definition (van de Plassche 1986). Its behaviour at a place (Pirazzoli and Pluet 1991) is determined not just by the global eustatic rise mentioned but by numerous local-regional meteorological, oceanographical and geological effects acting as well (Fulford *et al.* 1996). Among the geological effects significant for the Bristol Channel region is the sinking of the Earth's crust at 0.2–0.5 mm/yr as part of a complex response, detectable across southern Britain as a whole, and especially in southeast England, to the gradual shedding of the Devensian ice-load (Shennan 1989, Lambeck 1993a 1993b 1995).

The most recent, comprehensive sea-level curve for the region is given by Heyworth and Kidson (1982). Covering roughly the last 10,000 years (Holocene), it is an age-altitude plot of widely scattered, radiocarbon-dated samples from peat beds and wooden trackways, largely from the Somerset Levels and the associated coast (Fig. 1a). Heyworth and Kidson assigned to all their samples an indicative meaning of mean high water of spring tides (MHWST), and applied an arbitrary correction for peat consolidation, but only to the deepest-lying beds (<25 m below ground surface). Serious criticisms relating to the choice of sample locations and samples can be levelled at this curve (Haslett *et al.* 1998). Equally if not more important is the failure adequately to correct for the consolidation—an asymptotic process—of the highly compressible peats and, to a much lesser extent, the associated silts. (Allen 1999). The data of Bell (1995 fig. 61) and Haslett *et al.* (1998 fig. 4) indicate that peats in the Severn Estuary Levels have a compressibility of the order of 0.3–0.5 per metre of overburden; the estuarine silts are much less compressible, the data given in Hawkins *et al.* (1989 fig. 6) suggesting a factor an order of magnitude smaller. Consequently, the Heyworth-Kidson curve lies significantly lower than it should in the age-altitude graph.

Two further, major criticisms of the curve relate to the use of MHWST as a reference level. Firstly, the overall sedimentary character of a deposit formed at a particular time on a coastal marsh depends on the supply of organic matter by indigenous plants relative to the deposition of mineral silt introduced by tidal waters (Allen 1990a 1995). The likelihood is that peats did not form at MHWST on the evolving Severn Estuary Levels, but at a variable and generally higher level within the tidal frame, depending at the time on the rate of sea-level change, the distance from the sea, and on plant productivity and the survivability of sub-surface organic matter. Secondly, there is no reason to suppose that MHWST remained fixed over time relative to mean sea level. Simulation modelling suggests that the tidal range in the Bristol Channel area has increased on a millennial time scale (Austin 1991). Tide guage data reveal an expansion on the recent short term. As the mean height of high water at Avonmouth is currently increasing by about 0.55 mm/yr (Woodworth *et al.*, 1991), the higher tidal levels to which the coastal marshes are broadly adjusted are

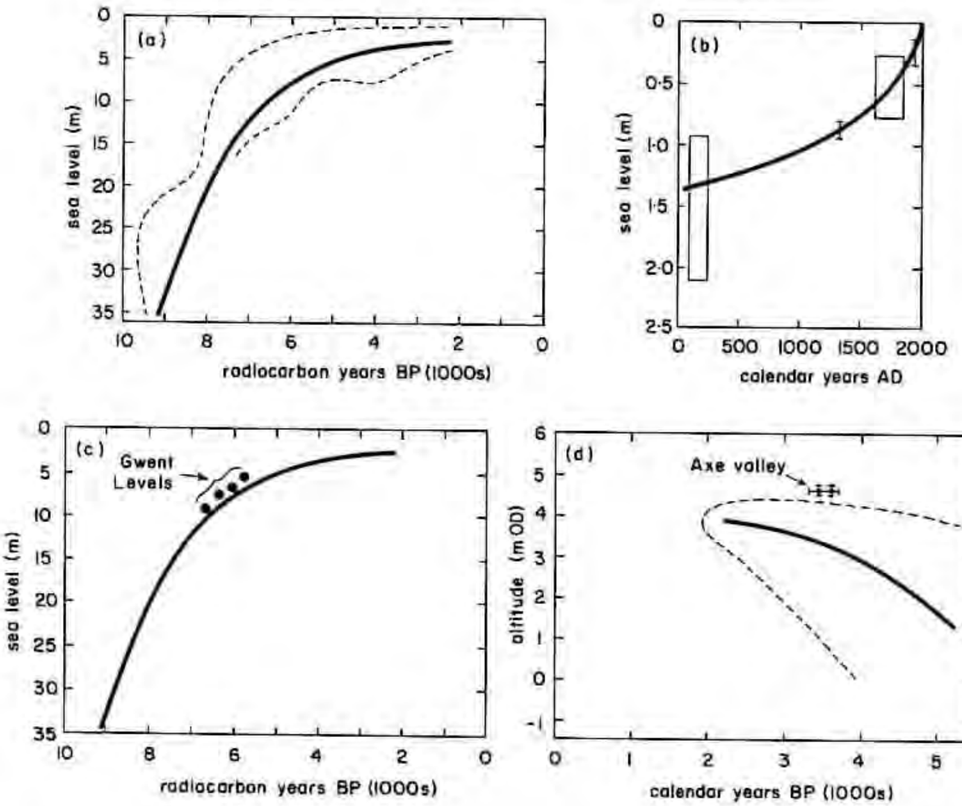

Fig. 1 Holocene age-altitude curves for the Severn Estuary–Bristol Channel area. (a) Heyworth and Kidson's (1982) curve of sea level for the Bristol Channel, relative to present-day mean high-water of spring tides (the dashed line is the approximate envelope line of the data points and their errors). (b) Allen's (1991) curve for late Holocene sea level (the high tidal levels to which salt marshes are adjusted) in the inner Severn Estuary. The constraints on the data (ranges of altitude and age) are indicated by the boxes and bars. (c) Scaife and Long's (1995) plot of the Heyworth and Kidson (1982) sea-level curve for the Bristol Channel, together with data for four basal organic deposits from the mid Holocene of the Gwent coast. (d) The age and altitude relative to Ordnance Datum of two samples from a basal peat bed in the Axe Valley, Somerset Levels, relative to Heyworth and Kidson's (1982) late Holocene data shown as the average (solid line) and envelope (dashed line) of sample points and error bars (modified after Haslett *et al.* 1998).

rising at about twice this rate. On the very short term, the sea can reach heights at a place significantly above those predicted under astronomical tidal theory. These excess heights, or positive surges, are due to meteorological effects, chiefly a combination of storm-related, low atmospheric pressure and extreme wind stress (Lennon 1963a). At Avonmouth a positive surge of about a metre is observed once every year or so, and one of about 2 metres on the average every few decades (Lennon 1963b). Historically, as Boon (1980) observes, surges have frequently brought disaster to the Severn Estuary Levels, that of January 1606/7 being widely commemorated in flood marks on parish churches on both sides of the waterway. Finally, other than demonstrating that sea level has continued to rise, the Heyworth-Kidson curve offers little help in understanding the more recent history of human interference in the area, since the peats on which the curve is based ceased to form 2000–2500 years ago.

Recent work begins to address the limitations of the Heyworth-Kidson curve. In the inner Severn Estuary, the rate of rise of the high tidal levels to which marshes are adjusted was estimated by measuring the deficit in height of dated embanked areas relative to the adjoining active marshes, on which deposition continued (Allen and Fulford 1990, Allen 1991). A marked acceleration is apparent over the early modern and modern periods (Fig. 1b). The rate of rise is *c.* 0.4 mm/yr from Roman to medieval times, about 0.8 mm/yr from then to the start of modern times, *c.* 1.5 mm/yr over the modern period up to about 1945, and 4.8 mm/yr since then. Because of spatial changes in the tidal regime, these rates are probably slightly less in the outer estuary and inner Bristol Channel. Scaife and Long (1995) dated organic materials from the outer estuary that were actually or effectively in a basal position within the Holocene sequence, thus largely eliminating the effects of consolidation. Their four index points plot about 1 m above the mean Heyworth-Kidson curve (Fig. 1c). Another study which overcomes the problem of consolidation is that by Haslett *et al.* (1998) from the Axe Valley in the Somerset Levels. Here a basal peat that dipped and thickened downslope beneath silts had an upper boundary of *constant* radiocarbon age within laboratory error. The altitude of this bed at the cessation of peat formation also plots about 1 m above the mean Heyworth-Kidson curve (Fig. 1d).

Geological Effects of Sea-Level Rise

The most obvious effect of the encroachment of the rising Holocene waters into the Bristol Channel and Severn Vale (Hawkins 1971) was to create space in which peats and silts could be deposited on mudflats and marshes at the edges of the sea. These deposits, amounting today to some 8 km^3 beneath a total outcrop of about 840 km^2 (Allen 1990b), constitute the Holocene sequence preserved beneath the Severn Estuary Levels as seen today. The sediments, of the order of 10 m thick, rest on a bedrock surface of substantial relief that carries knolls, hills and ridges and had been deeply dissected by rivers (e.g. Anderson 1968 1974, Williams 1968, Whitaker and Green 1983).

The marshes in their natural state were subject to a degree of probably seasonal human exploitation, but by the end of the Roman period there had been embanking and settlement on a large and wide scale (review in Rippon 1997), and the process of land-claim was to continue into modern times. Embankers are likely to have encountered conditions on the natural marsh that depended on the rate of sea-level rise at the time. Simulation models of salt-marsh vertical growth (Allen 1990a 1995 1997 2000, French 1993) suggest that, when the rate of sea-level rise is low, established marshes lie very close below the level of the contemporaneous highest tide and are drained by relatively small, low-density tidal creeks. With a high rate, however, the marsh has a lower relative elevation and carries larger and more densely arranged channel networks because of the increased tidal prism to be discharged on and off the wetland. In the inner Bristol Channel-Severn Estuary, according to these calculations, the decrease in the relative elevation of an established marsh could amount to many decimetres for an order of magnitude increase in the rate of sea-level rise.

Impacts After Human Interference

Land-Claim on the Lower River Banwell

The area is complex geologically (British Geological Survey Sheets 264, 279) and topographically (Fig. 2), including some natural features that would have facilitated land-claim. The Banwell flows northwestward across the North Somerset Level to enter the Severn Estuary in Woodspring Bay at the eastern end of the bold Middle Hope peninsula, at the

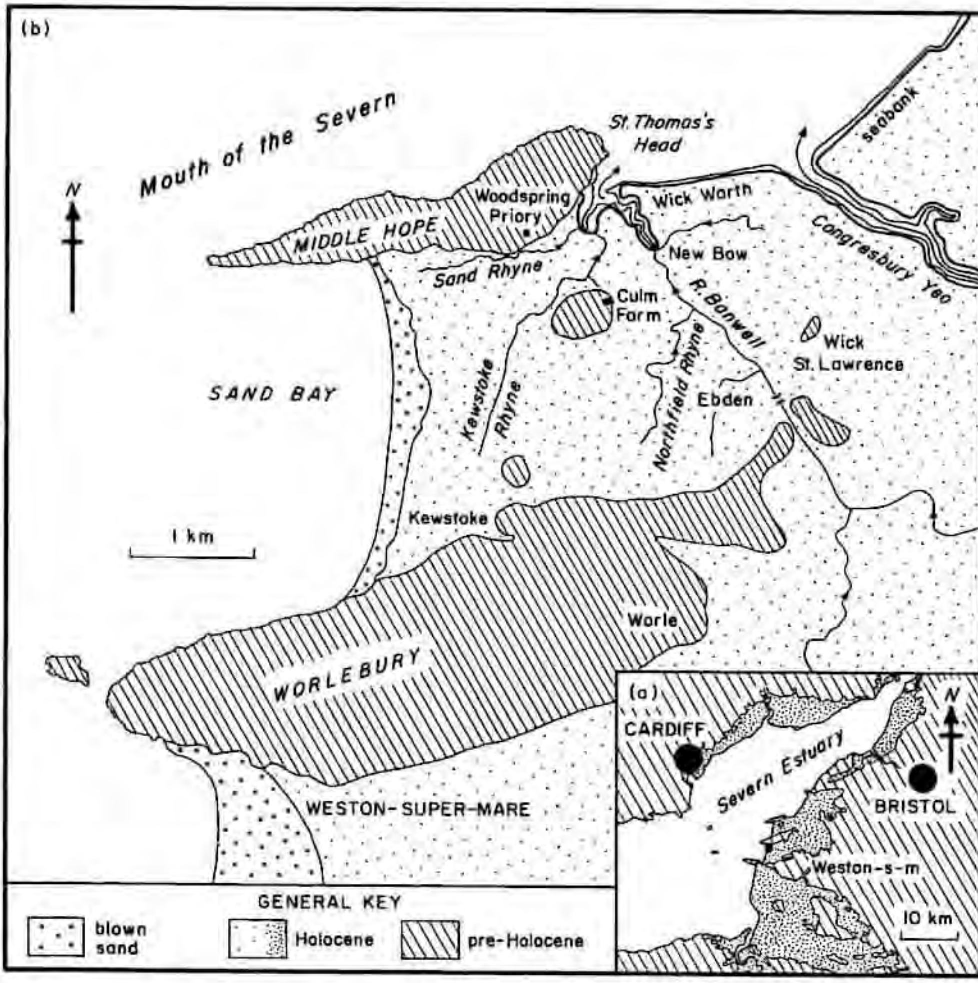

Fig. 2 The lower Banwell area, North Somerset Level. (a) General setting in the Severn Estuary Levels. (b) Outline geology and main topographic features.

foot of which lies Woodspring Priory (Tomalin and Crook 1993), founded in the early thirteenth century. On the west the enclosed marshes (altitude *c*. 6 m OD) are bounded by a low belt of blown sand up to 250 m wide that ranges along the shores of Sand Bay from Middle Hope southward to the even larger and bolder ridge of Worlebury (Fig. 2b). This bedrock ridge has a low and partly buried extension that ranges northeastward to Wick St. Lawrence; at Ebdon (formerly Ebden Green or Ebden) the feature is cut by the Banwell. Culm Farm lies on the larger of two knolls of bedrock that lie isolated in the enclosed area. The Congresbury Yeo, flowing parallel with the Banwell, forms a natural eastern limit to the marshes of interest. Williams (1970) has depicted the currently active seabanks on the coast of the North Somerset Level, but his documentary researches yielded nothing directly relevant to the lower Banwell.

The locations of seabanks were mapped in the field using criteria fully described else-

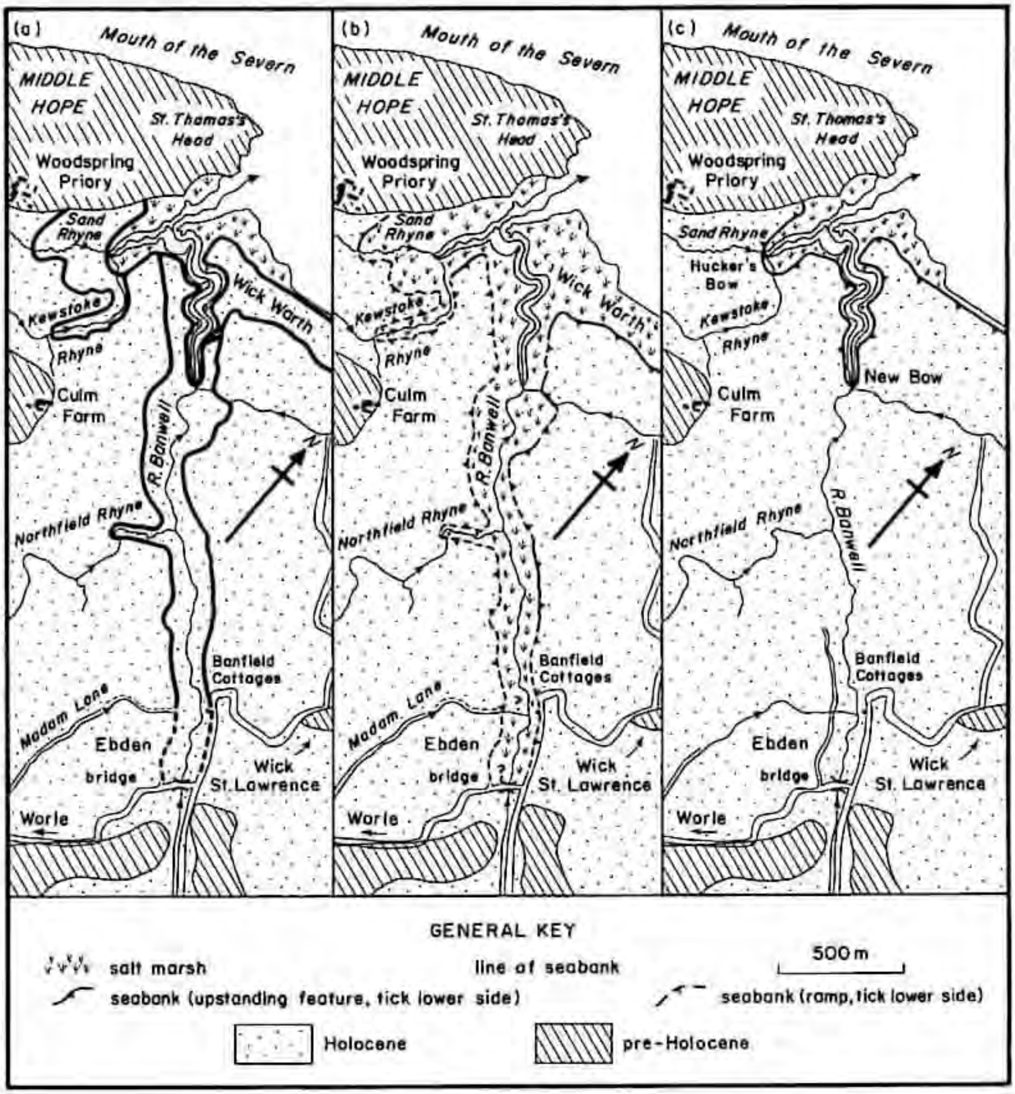

Fig. 3 Development of land-claim on the lower Banwell. (a) The locations of all seabanks identified by field survey. (b) The location and present status as earthwork features of seabanks active in the mid-late eighteenth century. (c) The location and status of seabanks and outfalls active from *c.* 1790 to the present day.

where (Allen 1993 1998) and checked against cartographic and air-photographic evidence (Fig. 3a). Where a seabank no longer survives as an upstanding earthwork, the main criterion for its former location is a systematic rise in the altitude of the ground outward from the enclosed area to the marsh that continued to be active. Typically, in reorganised fields, the rise has the form of a ramp, with in some places a slight, parallel depression where a back-ditch associated with the original bank had been infilled.

The oldest identifiable seabank in the area ranged along the banks of the lower Banwell

Plate 1 Ramp at the site of the earlier seabank, right bank of Northfield Rhyne, viewed from the northeast.

at least as far upstream as the vicinity of the bridge at Ebdon, where the river cuts the bedrock ridge (Fig. 3b). It also extended for some distance up the three tributaries—Sand Rhyne, Kewstoke Rhyne and Northfield Rhyne—entering the Banwell from the southwest. The defence along the left bank of the Banwell survives only as a ramp. This is rather shadowy within the developed area at Ebdon itself, but gradually increases in relief and clarity northwestward to about 0.5 m at Northfield Rhyne (Plate 1), maintaining that altitude difference to the general vicinity of New Bow. Turning into Kewstoke Rhyne, the defence is first seen as a short length of earth bank, but this is quickly replaced by a combined ramp and interior depression associated with soil and crop marks and the disappearance of gripps (Plate 2). A low bank survives fragmentarily near the cottages east of Woodspring Priory. On the right bank of the Banwell the defence is first evident as a slight increase in ground level southwestward across the road northwest from Ebdon bridge. It can be traced to the vicinity of New Bow partly as a ramp, reaching a maximum height of about 0.5 m, and partly as a low and much-degraded bank. The defence is a long, bold earth bank along the southern side of Wick Warth.

Where the bank may have cross the Banwell and an outfall was situated is unclear. The weakening of the ramp over the ground rising toward Ebdon, and the presence here of bedrock close to or at the surface, would logically place any outfall at the location of the narrow, hump-backed bridge, built of dressed Old Red Sandstone and Carboniferous Limestone (Plate 3), that carries the modern road from Worle to Wick St Lawrence over the Banwell. Another site for the crossing a little further downstream must, however, be considered a possibility, given the limitations of the earthwork evidence at Ebdon itself. Early maps show that a track (Madam Lane), formerly a parish boundary, reached as late as the early nineteenth century (e.g. Somerset Record Office DD/WY 121) from the Worle road

Plate 2 Extract from an air photograph of 1971 (900 × 600 m, north toward top) showing seabanks between the Banwell (B) and Kewstoke Rhyne (KR) and between Kewstoke Rhyne and Sand Rhyne (SR). WP—Woodspring Priory; HB—Hucker's Bow; single arrows—earlier bank as a soil mark (and associated ramp); double arrows—earlier bank in the form of an upstanding earthwork.

toward the Banwell opposite Banfield Cottages. The strange doubling-back of the road at Banfield Cottages may, therefore, be a feature linked to the transfer of the crossing at an outfall at the cottages to a site a little further upstream, where geological conditions were appropriate for a stone bridge at Ebdon. What can be said with certainty is that some kind of structure for controlling water existed at or near Ebdon, for a newspaper report of the local activities of the Commissioners of Sewers in 1899 refers to a meeting of dyke-reeves on the Banwell at Ebdon's Bow (Williams 1970). Where exactly this place was has not been established, but it could not at that date have been a tidewater outfall (see below); the place name may either be an historical survival or record the presence of a stank, perhaps adapted from an earlier tidal sluice, for controlling the local water table.

The age of this oldest and probably first seabank in the area is uncertain. It was surveyed along the right bank of the Banwell in 1738 (Bristol Record Office 04480) but, like other seabanks, is not shown in the Day and Master 1782 map of Somerset. The bank may be presumed, from the presence of Wick St. Lawrence village, to be at least early medieval in date. It is recorded on the 1738 map along the southern side of Wick Warth, and is a persisting landscape feature in later maps of the area up to the present (e.g. 1809, Ordnance Survey (Old Series) Sheet XX Bridgwater; 1838, SRO D/D/Rt126; 1883, Ordnance Survey Somerset X NW). The defence along the left bank is unlikely to postdate 1226, by which date an Augustinian community had transferred to the site of Woodspring Priory (Tomalin and Crook 1993).

Plate 3 The bridge at Ebdon, seen from the north.

The geological constraints on land-claim in the area would allow the banks on the two sides of the Banwell to be of different ages. Provided that the blown sand recorded along the coast from the eighteenth century onward (Harley and Dunning 1981) existed in earlier times to furnish a natural defence, the entire marsh bounded by Middle Hope, Sand Bay, Worlebury and the Banwell (*c*. 600 ha) could have been enclosed simply by connecting the one bedrock outcrop to the other by an earth bank along the riverside of some 2.5 km. The status of marshes to the northeast of the Banwell need have no bearing on this process, and their enclosure—they include several Roman-British sites (review in Rippon 1997)—could be of a different date. Only one Roman site, a settlement at the southern foot of Middlehope, is known west of the Banwell and north of Worlebury.

By about 1790 the outfall on the Banwell had been moved downstream to New Bow (B. Paine, *pers. comm*., 1998), the sluices on Kewstoke Rhyne and Sand Rhyne had been repositioned nearer the sea, and Wick Warth had been enclosed by a new bank along the northern side (Fig. 3c). These changes are shown at a small scale on the Ordnance Survey map of Bridgwater published in 1809 (Old Series, Sheet XX) and are depicted in greater detail in plans accompanying inclosure and tithe awards (1816, SRO Q/Rde 133; 1838, SRO D/D/Rt 126; 1840, SRO D/D/Rt 193) and in other maps (e.g. 1883, 1902, Ordnance Survey Somerset X NW). A bridge over the Banwell existed at Ebdon by 1782, as shown in the Day and Masters map (Harley and Dunning 1981), and was recorded again in 1803 (SRO Q/Rde 53). By 1840 the pattern of fields along the left bank of the Banwell was essentially as today (SRO D/D/Rt 192).

SIZE OF SEABANKS

Over time, the seabanks on the lower Banwell have been significantly increased in height and cross-section. As seen along the right bank, immediately to the west of Wick St.

Plate 4 The raised and strengthened (1990) earlier seabank at the western end of Wick Warth, seen from the west.

Lawrence, the earliest recorded defence is a broad ridge no more than 0.25 m high (Fig. 3b). The cross-sectional area of this feature suggests that the original structure, prior to its degradation, was similarly modest and not much taller. No other examples of the earliest bank remain visible today, but a portion about 300 m long still existed in the 1970s in the fields to the northwest of New Bow (Fig. 3b, Plate 2). Taking measurements from air photographs of the period (e.g. 39 RAF 3764 F42-0051), this flat-topped structure had a footprint (base width) estimated to be 3.1 m. The height at the time of the photography could have been as little as 0.5 m, assuming a symmetrical trapezoidal section, a flat top 1 m wide and side slopes of 20° from the horizontal. Consequently, the unit volume was about 1 cubic metre per metre of bank length (m^3/m).

In its modern form, created in 1990 (B. Paine, *pers. comm.*, 1998), the earliest bank along the southern side of Wick Warth is a much larger earthwork (Fig. 3b, Plate 4). To the north of New Bow (ST 354664), for example, it has a footprint of about 20 m, a width at the top of 5–6 m, and a height of about 3.5 m, yielding a unit volume of about 45 m^3/m.

The newer bank (Fig. 3c) was last strengthened and raised in 1990 (B. Paine, *pers. comm.*, 1998) and is also a majestic feature (Plate 5). Traced around the embayments at Hucker's Bow and New Bow, it has a height of between 2.5 and 3 m, a width at the top of about 5 m and a footprint of 15–18 m. Hence the unit volume is roughly 25–35 m^3/m.

SHORTENING OF SEABANKS

The seabanks in the area were also reduced in length over time, in parallel with the raising of their height (Fig. 3b, c). The effect in the latest eighteenth century of moving the main outfall from its presumed position at Ebdon to New Bow was to shorten the defences along

Plate 5 The newer seabank, raised and strengthened in 1990, to the northwest of New Bow, viewed toward the sluice.

the Banwell by *c*. 3300 m. Simultaneously, land along the Banwell amounting to 34 ha was added to the enclosures; by the construction of a new seabank along the coast to the east, an enclosure of 26 ha was created at Wick Warth. The shortening amounts to *c*. 900 m at Sand Rhyne and Kewstoke Rhyne, adding 12 ha to the enclosed land and shifting the outfall on Sand Rhyne to its present position at Hucker's Bow.

OUTFALLS AND DRAINAGE

Given the character of modern British salt marshes (e.g. Allen and Pye 1992), the coastal wetlands enclosed along the lower Banwell may be assumed to have carried in their natural state a number of large, tree-like networks of tidal creeks focused on the Banwell and Yeo. Four among what may be assumed to have been the larger tributary channels survive today as features deliberately incorporated into the post-enclosure drainage pattern of the area. They are Sand Rhyne, Kewstoke Rhyne and Northfield Rhyne on the left bank of the Banwell and an un-named drain that enters the Banwell from the east near New Bow (Fig. 2b). These are all recognisable as drains along curvilinear to meandering field boundaries, as opposed to the more usual rectilinear, artificial features.

None of the outfalls originally constructed where the earliest seabank crossed the Banwell and each of the four subordinate creeks mentioned above have survived the combined raising and shortening of the defences. There is little about the bridge at Ebdon (Plate 3) to suggest that it is a modified sluice or stank, despite the stylistic suggestions of comparative age (eighteenth century). The oldest surviving structure, perhaps dating from the latest eighteenth century when the newer bank was built, is the lower part of Hucker's Bow (Plate 6), constructed of dressed Carboniferous limestone. The precise character of this small and

Plate 6 Hucker's Bow viewed from the east, with Woodspring Priory in the background.

somewhat modified outfall is now difficult to ascertain. The outermost and higher parts of the structure, incorporating concrete blocks, probably date from the last decade when the associated seabank was strengthened and raised.

The present reinforced concrete and metal outfall at on the Banwell at New Bow (Fig. 3c) was built in 1990–91 to replace a much-modified earlier structure, composed of two masonry walls connected by brick culverts closed at first by timber vertical doors but later by metal flaps (B. Paine, *pers. comm.*, 1998). The new sluice is a large structure that combines a storage pond and adjustable sill on the inland side (Plate 7) with a pair of metal flap-valves serving as a pressure-controlled outlet to the sea (Plate 8). To the northwest, at the western end of Wick Warth (ST 350665), lies a good example of a small, modern outfall which combines a flap valve on the seaward side with a worm-operated penstock on the inner face (Plate 9) allowing full control over the water level in the enclosure.

Discussion

The enclosed marshes around the lower R. Banwell are typical of both the evolution of land-claim in such contexts on the Severn Estuary Levels, and of the fate in Britain of the engineered field monuments that define this decisive process.

Although the surviving evidence from the lower Banwell does not allow the process to be examined with much resolution, there can be no doubt from the information available that the seabanks have been significantly increased in size over time. This can be seen as a direct response to increasing high-water levels and it is likely that continuing consolidation of the Holocene silt-peat sequence in the area has also contributed. The earliest builders

Plate 7 New Bow (1990–91) seen from inland.

Plate 8 New Bow (1990–91) seen from seaward.

Plate 9 Small outfall (1990) at the western end of Wick Warth, viewed from the northeast.

would have designed their banks by rule of thumb, taking into account their recollection of contemporaneous water conditions, particularly those associated with storms and equinoctial tides. Today, the engineer designs on a probabilistic basis after cost-benefit analysis, using forecasts from records of measured water levels and wave heights (e.g. Bakker and Vrijling 1980). Whatever the basis for design, the top of a bank must be maintained in at least a constant relative position and also be sufficiently elevated to prevent significant wave over-spill; wave height, and the risk of overspill, grow steeply with the increase in general water depths consequent on sea-level rise and expansion of the tidal range.

Given the evidence for rising water levels (Fig. 1), particularly in recent centuries, it is not surprising to find that, over a period of many hundreds of years, there has been an accompanying five-fold increase in the height of the Banwell seabanks. This trend can be seen throughout the Severn Estuary Levels and can be matched in other British coastal lowlands and in mainland Europe (Allen, 1998). At Leverington in the Fenland, in an archaeological investigation unique for Britain, an early medieval bank originally about 1 m high was shown by excavation to have been raised three times in the course of its active life, by which time the remaining salt marsh active on its seaward side had built up by a remarkable 2 m (Hall and Coles 1994). The bank did not become redundant until land-claim was renewed in the seventeenth century. Very many, similar examples can be cited from the North Sea coast of mainland Europe (e.g. Bloemers *et al.* 1981). In Eiderstedt, Schleswig-Holstein, a seabank 1.3 m high was raised in two stages to a height of 3.3 m between the eleventh/twelfth century and the fourteenth/fifteenth century (Meier 1994). The increases between medieval and modern times, and over the modern period itself, are particularly dramatic. Mazure (1980) describes from near the mouth of the Ijssel in the central Netherlands a seabank which, between 1812 and 1963, was increased in height from 2 m to 10.5

m in three stages. Excavation showed that a bank at Aartswoud in Friesland had been raised by 4 m in several stages since the thirteenth century (van de Ven 1993). Further south, on the Westerschelde (Brand 1985), banks were about 2.75 m high in the thirteenth century but 8 m tall by the time of the calamitous 1953 storm surge: they were subsequently raised a further 3.75 m. The artificial defences now present along the North Sea coast of the Low Countries and Germany are huge structures with footprints measuring many tens of metres (e.g. Kramer 1969).

A less obvious but parallel, historical trend on the lower Banwell was that toward the shortening of seabanks with, as a consequence, the addition of more land to that already enclosed (Fig. 3b, c). This was accomplished by moving outfalls to places nearer the coast, where the tidal channels are wider and deeper. The total gain by shortening on the lower Banwell was about 4200 m, about two-thirds of the original length of the defences. Again, this particular trend finds parallels elsewhere on the Severn Estuary Levels (Allen and Rippon 1995), in southeast England (Grieve 1959, Summers 1978), and in northwest Germany (e.g. Garniel and Mierwald 1996), although the gains are generally less spectacular. No doubt as in the past, the exceptional storm surge of 1953, by revealing the weaknesses of the defences, rekindled interest in this process on the coasts of the southern North Sea.

Land-claim on the lower Banwell took place so far back in the past that the seabanks visible today are inevitably and correctly seen as defensive and wealth-protecting structures. When first built, however, they created wealth by assuring year-round land-use and settlement. Their increase in height over time has been forced by rising water levels at sea, but the shortening is largely an attempt to reduce risk and escalating costs. As the cross-sectional area of a seabank of symmetrical trapezoidal form equals $(ah+h^2/\tan\alpha)$, where a is the width of the flat top, h the height, and α the angle of the sides, the unit volume of the bank must vary as the square of the height. This gives an indication of the magnitude of the additional, locally-dug earth or imported spoil which must be engineered to raise an existing bank by some desired extent per unit length (the exact change in cross-sectional area is $(A_n-A_{(n-1)})$, where A_n is the area after being raised and $A_{(n-1)}$ the area of the prior structure). Hence the square law imposes increasingly severe demands on money and labour, whether the earth-moving is done by hand or machine. As water levels rise, the flooding of enclosed land after seabanks are breached during storms becomes increasingly severe and long-lasting. Shortening is desirable, because it reduces the number of breaches that a given exceptional event is likely to create and, consequently, the overall cost in time and money of the repairs and the damage to settlements and farmland. The pace of shortening is constrained, however, by technical advances in engineering materials and methods, since it is desired to move the outfalls closer to the sea where the tidal channels are wider and deeper. The development of earth-moving machinery, at first steam-driven and then by internal combustion, and advances in concrete technology, have allowed sluices to be built across increasingly large channels.

Much has been lost from the lower Banwell. The first identifiable seabanks and their several outfalls have not as such survived further enclosure, agricultural improvements and the increasing scale of sea-defence work. Consequently, these decisive field monuments are not available to be recorded and conserved, and we shall remain in ignorance of their age by direct dating and their modes of construction and maintenance. It is, therefore, even more important to attend to the identification and interpretation of what remains, and to recognise its significance as a contributor to the historic landscape.

Acknowledgements

The help given me over the years by the staffs of the Somerset Record Office and the Bristol Record Office is much appreciated. I am especially grateful to Mr Barry Paine of the Environment Agency (Bridgwater) for his interest and for allowing me to see the Agency's plans, manuals and records relating to the seabanks and outfalls on the lower Banwell. Simon Haslett (Bath Spa University College) very kindly allowed me to make use of his paper on the Holocene of the Axe valley prior to publication.

REFERENCES

Allen, J. R. L., 1990a. 'Salt-marsh growth and stratification: a numerical model with special reference to the Severn Estuary, southwest Britain', *Marine Geology*, 95, 77–96.

Allen, J. R. L., 1990b. 'The Severn Estuary in southwest Britain: its retreat under marine transgression, and fine-sediment regime', *Sedimentary Geology*, 66, 13–28.

Allen, J. R. L., 1991. 'Salt-marsh accretion and sea-level movement in the inner Severn Estuary: the archaeological and historical contribution', *Journal of the Geological Society, London*, 148, 485–494.

Allen, J. R. L., 1993. 'Muddy alluvial coasts of Britain: field criteria for shoreline position and movement', *Proceedings of the Geologists' Association*, 104, 241–262.

Allen, J. R. L., 1995. 'Salt-marsh growth and fluctuating sea level: implications of a simulation model for Flandrian coastal stratigraphy and peat-based sea-level curves', *Sedimentary Geology*, 100, 21–45.

Allen, J. R. L., 1998. 'The geoarchaeology of land-claim in coastal wetlands: a sketch from Britain and the Northwest European Atlantic-North sea coasts', *Archaeological Journal*, 154, 1–54.

Allen, J.R.L. 1999. 'Geological impacts on coastal wetland, landscapes: some general effects of sediment autocompaction in the Holocene of northwest Europe. *The Holocene*, 9, 1–12.

Allen, J.R.L. 2000. Late Flandrian (Holocene) tidal palaeochannels, Gwent Levels (Severn Estuary), SW Britain: character, evolution and relation to shore. *Marine Geology*, 162, 353–380.

Allen, J. R. L. and Fulford, M. G., 1990. 'Romano-British wetland reclamations at Longney, Gloucestershire, and the evidence for early settlement of the inner Severn Estuary', *Antiquaries Journal*, 70, 288–326.

Allen, J. R. L. and Pye, K., 1992. *Saltmarshes, Morphodynamics, Conservation and Engineering Significance*. Cambridge.

Allen, J. R. L. and Rippon, S. J., 1995. 'The historical simplification of coastal flood defences: four case histories from the Severn Estuary Levels', *Transactions of the Bristol and Gloucestershire Archaeological Society*, 113, 73–88.

Anderson, J. G. C., 1968. 'The concealed rock surface and overlying deposits of the Severn Valley from Upton to Neath', *Proceedings of the South Wales Institute of Engineers*, 83, 27–47.

Anderson, J. G. C., 1974. 'The buried channels, rock floors and rock basins, and overlying deposits of the South Wales valleys from Wye to Neath', *Proceedings of the South Wales Institute of Engineers*, 88, 11–25.

Bakker, W. T. and Vrijling, J. K., 1980. 'Probabilistic design of sea defences', *Proceedings of the Seventeenth Coastal Engineering Conference, March 1980*, Sydney, 2040–2059.

Bell, M., 1995. 'Field survey and excavation at Goldcliff, Gwent 1994. *Archaeology in the Severn Estuary*, 5, 115–144, 157–165.

Bloemers, J.H.F., Louwe Kooijmans, L.P. and Sarfatij, H. 1981. *Verleden Land. Archaeologische Opgravingen in Nederland*. Amsterdam.

Boon, G. C., 1980. 'Caerleon and the Gwent Levels in early historic times', in F. H. Thompson (ed.), *Archaeology and Coastal Change*, Society of Antiquaries Occasional Papers (New Series) I, 24–36.

Brand, K. J. J., 1985. 'Zeeuws-Vlaanderen—een gebied met een lange en rijke bedijkingsgeschiedenis', *Waterschapsbelangen*, 70, 383–393.

Fairbanks, R. G., 1989. 'A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the younger Dryas event and deep-ocean circulation', *Nature*, 342, 637–642.

French, J. R., 1993. 'Numerical simulation of vertical marsh growth and adjustment to accelerated sea-level rise, north Norfolk, U.K.', *Earth Surface Processes and Landforms*, 18, 63–81.

Fulford, M. G., Champion, T. C. and Long, A. J., 1996. *England's Coastal Heritage*. London.

Garniel, A. and Mierwald, U., 1996. 'Changes in the morphology and vegetation along the human-altered shoreline of the Lower Elbe', in K. F. Nordstrom and C. T. Roman (eds.), *Estuarine Shores*. Chichester, 375–396.

Gornitz, V., 1995. 'Sea-level rise: a review of recent past and near-future trends', *Earth Surfaces Processes and Landforms*, 20, 7–20.

Grieve, H. E. P., 1959. *The Great Tide*. Chelmsford.

Hall, D. and Coles, J., 1994. *Fenland Survey. An Essay in Landscape and Persistence*. English Heritage Archaeological Report 1. London.

Harley, J. B. and Dunning, R. W., 1981. *Somerset Maps. Day and Masters 1782, Greenwood 1822*. Taunton.

Haslett, S. K., Davies, P., Curr, R. H. F., Davies, C. F. C., Kennington, K. and Margetts, A. J., 1998. 'Evaluating late Holocene relative sea-level change in the Somerset Levels, southwest Britain', *The Holocene*, 8, 197–207.

Hawkins, A. B., 1971. 'The late Weichselian and Flandrian transgression of southwest Britain', *Quaternaria*, 14, 115–130.

Hawkins, A. B., Larnach, W. J., Lloyd, I. M. and Nash, D. F. T., 1989. 'Selecting the location, and the initial investigation, of the SERC soft clay test site', *Quarterly Journal of Engineering Geology*, 22, 281–316.

Heyworth, A. and Kidson, C., 1982. 'Sea-level changes in southwest England and Wales', *Proceedings of the Geologists' Association*, 93, 91–111.

Kramer, J., 1969. 'Neue Deiche, Siele under Schöpfwerke zwischen Dollart und Jadebusen (ab 1945), in J. Ohling (ed.), *Ostfriesland im Schutze des Deiches*. Pewsum, 389–687.

Lambeck, K., 1993a. 'Glacial rebound of the British Isles—I. Preliminary model results', *Geophysical Journal International*, 115, 941–959.

Lambeck, K., 1993b. 'Glacial rebound of the British Isles—II. A high-resolution, high-precision model', *Geophysical Journal International*, 115, 960–990.

Lambeck, K., 1995. 'Late Devensian and Holocene shorelines of the British Isles and North Sea from models of glacio-hydro-isostatic adjustment', *Journal of the Geological Society, London*, 152, 437–448.

Lennon, G. W., 1963a. 'The identification of weather conditions associated with the generation of major storm surges along the west coast of the British Isles', *Quarternary Journal of the Royal Meteorological Society*, 89, 381–394.

Lennon, G. W., 1963b. 'A frequency investigation of abnormally high tidal levels at certain west coast ports', *Proceedings of the Institute of Civil Engineers*, 25, 451–484.

Mazure, P. C., 1984. 'The development of Dutch polder dykes', in *Polders of the World. An International Symposium: Final Report*. Wageningen, 64–81.

Meier, D., 1994. 'Geschichte der Besiedlung und Bedeichung im Nordseeküstenraum', in J. L. Lozan, E. Rachor, K. Reise, H. van Westernhagen and W. Lenz (eds.), *Warnsignale aus dem Wattenmeer*. Berlin, 11–17.

Pirazzoli, P. A. and Pluet, J., 1991. *World Atlas of Holocene Sea-level Changes*. Amsterdam.

Rippon, S., 1997. *The Severn Estuary: Landscape Evolution and Wetland Reclamation*. Leicester.

Scaife, R. and Long, A., 1995. 'Evidence for Holocene sea-level changes at Caldicot Pill', *Archaeology in the Severn Estuary*, 5, 81–85, 157–165.

Shennan, I., 1989. 'Holocene crustal movements and sea-level changes in Great Britain', *Journal of Quarternary Science*, 4, 77–89.

Summers, D. 1978. *The East Coast Floods*. Newton Abbot.

Tomalin, D. J. and Crook, C. D., 1993. *Woodspring Priory, Somerset*. Maidenhead.

van de Plassche, O., 1986. 'Introduction', in O. van de Plassche (ed.), *Sea Level Research: a Manual for the Collection and Evaluation of Data*. Norwich, 1–26.

van de Ven, G. P., 1994. *Man-made Lowlands*. 2nd. Ed. Utrecht.

Whitaker, A. and Green, G. W., 1983. *Geology of the Country around Weston-super-Mare*. Memoirs of the British Geological Survey, London.

Williams, D. J., 1968. 'The buried channel and superficial deposits of the lower Usk and their correlation with similar features in the Lower Severn', *Proceedings of the Geologists' Association*, 79, 325–348.

Williams, M., 1970. *The Draining of the Somerset Levels*. Cambridge.

Woodworth, P. L., Shaw, S. M. and Blackman, D. L., 1991. 'Secular trends in mean tidal range around the British Isles and along the adjacent European coastline', *Geophysical Journal International*, 104, 593–609.

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