Haycock, Suite 1, Deer Park Business Centre, Eckington, Pershore, Worcestershire, WR10 3DN
t +44 (0)1386 750642 **e** enquiries@haycock-associates.co.uk
www.haycock-associates.co.uk

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Lower River Otter: Long term options for drainage and flood management

Client

Clinton Devon Estates

Author

Dr. N.E. Haycock

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Haycock Associates Limited. Registered in England No. 03934665 VAT No. GB 658 1644 14
Registered office: Red Roof, Wick Road, Little Comberton, Pershore, Worcestershire WR10 3EG.

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Executive Summary

The Clinton Devon Estates commissioned Haycock Associates in late 2009 to undertake a review of the current drainage and flood management of the Lower River Otter from Otterton to the discharge point of the River Otter into the sea. The key issues to be addressed relate to the long term options for the drainage and flood management of this section of the Valley, and how the underlying hydrological, geomorphological and climatic change regimes may impact the farming and conservation operations on this land.

Data and information on the dynamics of flooding and drainage has been sourced from local residents and land users, plus reports generated by the Clinton Devon Estates over the past decade. Environment Agency reports on the River Otter and the dynamics of the shoreline and coastal flood risks have also been reviewed.

Floods in October 2008 have provided an insight into the dynamics of the site, but this flood event was extreme (>220 year return period) and this report has focussed on smaller storms that have resulted in 21 flood events in the Lower Otter Valley since 1959.

The historical development of the floodplain, from the leating of the channel prior to 1066, the need for navigation to Otterton until 1540 and then the embankment of the floodplain in 1812, plus the railway embankments created in 1903, have all complicated the natural flood and geomorphological regime of the river. Further complications arise in the form of a major storm surge in the decade of 1480 that created the pebble bar, and also recent sea level adjustments, that have accelerated the siltation of the estuary and the geomorphology of the coastal sediment supply.

Taking this information together, a series of recommendations and options have been proposed, 10 in total, which seek to address single issues, or combinations of issues. These recommendations build on detailed hydraulic flood models developed for the Lower Otter, that seek to track the movement of water through the landscape and the lessons that can be taken from this information. Furthermore, detailed hydraulic models of tidal flood inundation have been developed to explore the implications of major tidal breaches of the embankments.

In reviewing the current hydrology, hydraulics and landscape operations within the Lower Otter, it is apparent that the impact of poor drainage and flooding is becoming worse and more damaging to the economics of the Estate and users of the landscape. The poor performance of the sea outfalls, the reduced hydraulic capacity of the River Otter and the siltation of the estuary since 1812 are all conspiring to increase the flood frequency of a number of assets, most visibly at South Farm Lane and the Cricket Club.

The future performance of drainage will become increasingly challenging, with increased fluvial runoff and higher tides, plus the aggressive sedimentation of the sea outfall, both at the Lime Kiln and also within the estuary.

The Estate could simply allow this situation to become progressively worse, farming of the floodplain to become less viable, conservation management more demanding and recreational access more difficult. At some point, either due to fluvial flooding or tidal flooding the current embankments, which are nearly 200 year old, will fail and the resulting impact will be extensive loss of terrestrial land and access to South Farm and its businesses.

It is proposed that there may be a series of options to phase the retreat of agriculture from the marshes in some locations, upgrade the functioning of assets in other locations, and enhance the life of some of the embanked lands through small modifications of the current land levels and linkages of the river to its floodplain. The options, in combination, will allow the long term retreat of agriculture from the marshes, but allow the controlled formation of designated habitats without recklessly endangering the current designated areas.

The options, either in combination, or independently, have not been subject to detailed flood modeling in the same detail as the current environment, simply because the options raise numerous challenges in terms of the long term management of the Lower Otter, its commercial use and as an Area of Outstanding Natural Beauty. The next stage of this process is to review the options with key stakeholders and develop these with the Clinton Devon Estates to determine the way forward, along with the financing of any major structural adjustments to the site. The aspiration of the Estate is to create an exemplary project, that builds on the unique history of ownership and use of this valley, and ensures it has a viable future for the Estate and the larger community.

Aims of the Report

The Clinton Devon Estates commissioned Haycock Associates in late 2009 to undertake a review of the current drainage and flood management of the Lower River Otter from Otterton to the discharge point of the River Otter into the sea. The key issues to be addressed relate to the long term options of the drainage and flood management of this section of the Valley and how the underlying hydrological, geomorphological and climatic change regimes may impact the farming and conservation operations on this land. It also examines the implications for key infrastructure, namely South Farm Lane and White Bridge as well as the Budleigh Salterton Cricket Club.

During the review of this section of the river, three main issues have arisen:

1. The drainage of the floodplain and its ability to gravity drain through its sea outfall at Salterton.
2. The flood dynamics of the River Otter and how this floodwater passes through this section of floodplain and the implications for land operations and infrastructure.
3. The tidal dynamics of the Otter Estuary and influence on fluvial flooding as well as the drainage of the site.

In undertaking this review we have had access to key documents in the Clinton Devon Estates archive plus access to information held by the Environment Agency and Natural England. Additional information has been secured from Howick and Partners (Engineers) on the operation of the piped sea outflow. Data-sets from the Met. Office, BODC, CEH-NERC have also been secured. A detailed fluvial geomorphological audit, undertaken for the Environment Agency, of the River Otter upstream of Otterton has also been assessed and was supplied by Southampton University (Geodata, Professor David Sear and Chris Hill). Budleigh Salterton Cricket Club have given the Haycock team access to their archive of documents from 1959 onwards. In addition, key documents from the Otter Valley Association have been secured. Finally, discussions with key land and building managers in the Valley have also been undertaken in order to check key observations and develop initial options.

Introduction

The current issues facing the Clinton Devon Estates within the Lower Otter Valley centre on the poor drainage of the embanked farmland (locally referred to as Big Bank and Little Bank), which has reduced the level of farming operations that can be sustained on this land. The poor drainage of normal runoff impacts the use of South Farm Road and frequently results in the inundation of the Budleigh Salterton Cricket Club. The operation of drainage of the embanked land is linked to the runoff regimes of the main River Otter, western tributaries and the performance of the sea outfall at Budleigh Salterton, locally to the Lime Kilns. Drainage and the objectives of drainage within the embanked land is a key issue for the Estate. Drainage also needs to be managed to sustain wetland habitats under Countryside Steward Schemes, and there appears to be a challenge in meeting this objective in parallel with the need to effectively drain other blocks of land within the embanked area of the Lower Otter.

Drainage issues are compounded by the impact of flooding on the Lower River Otter. A number of recent flood events have resulted in substantial damage to a number of buildings, loss of access to South Farm and the prolonged storage of water within the embanked lands, which have damaged farming operations. The flooding in the last decade is believed to have become worse, both in terms of frequency and consequential damage. The inability of the flood waters to drain from the embanked compartments is linked to underlying concerns about the the normal drainage capacity of the site.

Fluvial flooding appears to be a main concern, but current concerns also centre on the tidal inundation regime, how this regime is impacting the estuarine and river SAC / SSSI. Equally, a breach of the embankments in 1982 resulted in salt water ingress into the embanked compartment, which was mitigated by freshwater dilution from the River Otter. If salt water does ingress into the embanked area, then implications to farming and terrestrial conservation interests is unclear.

In relation to predicted changes in sea level and predicted changes in the runoff regime of the Otter catchment, the Estate have also raised the question of how the Lower Otter will respond, or be transformed, and the implications for current assets like South Farm Lane, the Cricket Club, Otterton Mill and a number of private houses in Budleigh Salterton. The embankment of the River Otter below Otterton, the capacity of this channel to cope with future changes in runoff and associated floods is of concern, and also how sedimentation of the embanked channel and relic floodplain will respond to changes in catchment sediment supply. The future regime of the River Otter, in the embanked section, is of concern since there is a perception that current conservation management guidance on this section of the river is resulting in a loss of channel capacity and therefore an increased flood risk to the embanked lands to the west of the channel.

It is against this back ground of current concerns, both from the Estate, tenants and property owners that Clinton Devon Estates commissioned a strategic review of the Lower Otter in order to define more technically the nature of the issues and from this define possible options for the long term management of the Lower River Otter, which has been in the Estate's ownership since 1785.

Figure 1: View South over the Lower Otter Valley towards Budleigh Salterton. (Environment Agency)

Background

Catchment Topography and Geology

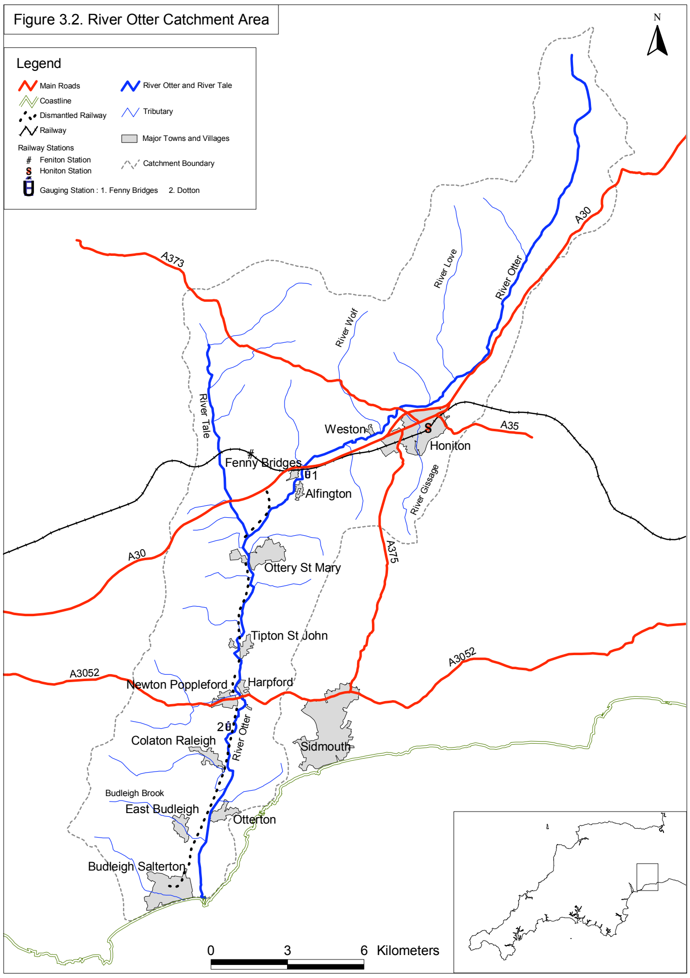


Figure 2: Catchment of the River Otter taken from the “River Otter Fluvial Audit, February 2004, Environment Agency and Geodata”

The Otter catchment is 230 km^2 upstream of Otterton and is summarised in “River Otter Fluvial Audit, February 2004, Environment Agency and Geodata” as:

“The River Otter rises in the Blackdown Hills in the north east of the catchment and drains in a south-westerly direction to its estuary at Budleigh Salterton on the south coast of Devon, England. The upstream limit of the 30km section of channel investigated coincides with where the river becomes designated as ‘Main River’, at the confluence with the River Love (near Langford Bridge). At this point the floodplain has widened to approximately 200 to 300m, although the valley remains steep-sided.

The River Otter then follows the line of the A30 as it skirts the suburbs of Honiton. The A373 crosses the Otter immediately upstream of the confluence with The Gissage, a heavily culverted stream which is the main drainage channel for Honiton. Between the A373 bridge and Weston (Trafalgar Bridge) the course of the Otter is very sinuous, although further meander development is constrained by the A30 and a natural embankment at Cottarson. From Weston to Fenny Bridges the planform is predominantly straight and the main channel is heavily reinforced as it passes under the A30 and South-Western Railway viaduct.

Downstream of Fenny Bridges the underlying geology switches from Mercia Mudstone to Otter Sandstone (Figure 3.1), the floodplain widens further and the valley sides decrease in gradient. Just upstream of Gosford Bridge a disused railway embankment, which runs from Honiton to Budleigh Salterton, constrains the planform migration of the Otter to the west, while natural Otter Sandstone Cliffs which outcrop repeatedly impinge upon the rivers development to the east.

After its confluence with the River Tale, the River Otter passes through the western side of Ottery St Mary. For approximately 1km downstream of Ottery St Mary the channel is extremely active and bank erosion is particularly intense. Thereafter the channel is confined again between the disused railway to the west and bedrock bluffs to the east, and follows a straight course to Tipton St John.

Figure 3.1. Location and Geology of the River Otter Catchment Within East Devon

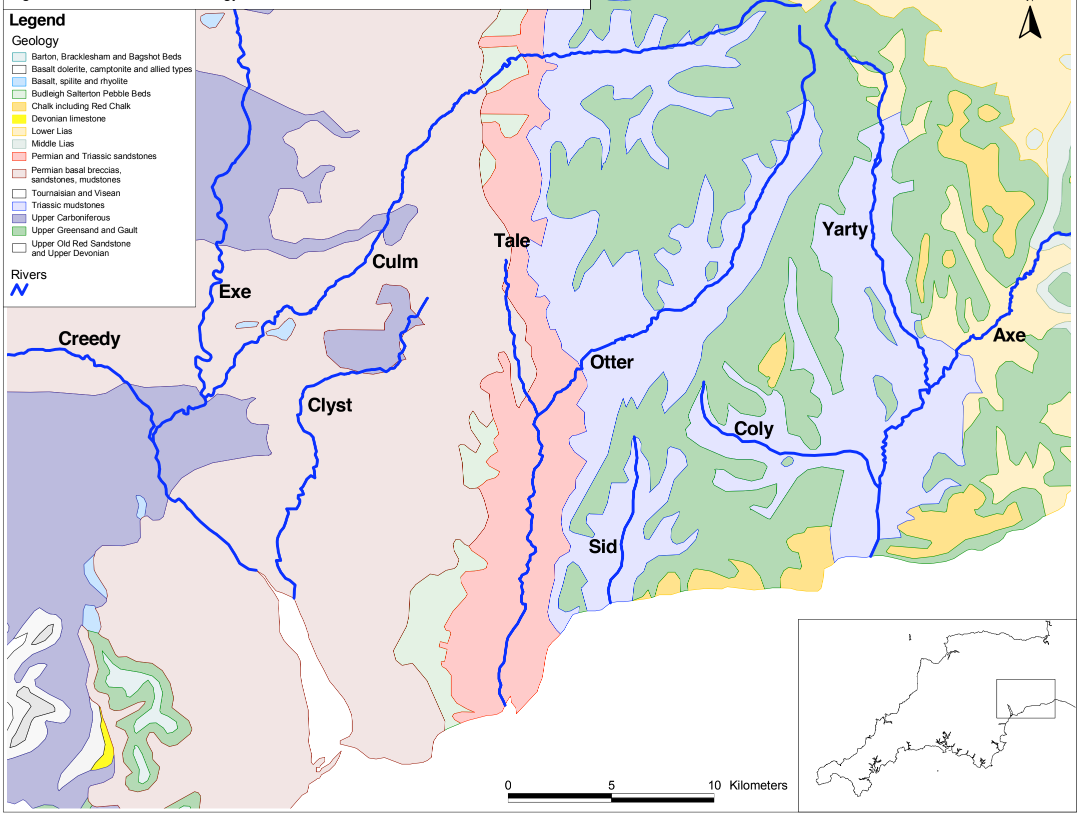


Figure 3: River Otter Geology, taken from the "River Otter Fluvial Audit, February 2004, Environment Agency and Geodata"

At Tipton St John the Otter crosses the disused railway embankment and meanders across a wide, flat floodplain, constrained only by the bridge which fixes the location of the apex of the central meander bend. Downstream the channel crosses back under the disused railway and follows a straight course along the embankment of the main road between Tipton St John and Harpford.

At Harpford the channel actively meanders to Newton Poppleford Bridge, thereafter a large, stable meander bend takes the river west, under the disused railway, until it impinges against a series of sandstone cliffs. Here, the river passes through the Dotton EA gauging station and is narrowly constrained between the cliff line and railway embankment until the river passes east under the railway just north of Colaton Raleigh. Between Colaton Raleigh and Otterton the Otter follows a fairly straight course along the base of a series of sandstone cliffs to the east of the river. The disused railway embankment is some 350m to the west, however this narrows to approximately 100km at Otterton Bridge.

Downstream of Otterton the valley sides steepen and clearly define the floodplain. The Otter flows between the sandstone cliffs on its eastern bank and a wide, flat floodplain to the west, until its outfall to the sea. A flood protection embankment *lines the west bank of the Otter from the normal tide limit at the confluence with Budleigh Brook (downstream limit of the Otter in this study) to its outfall at Budleigh Salterton.*

It is clear that the course of the River Otter has been, and remains today, significantly affected by anthropogenic interventions. Some 17 road and railway bridges (many disused) cross the Otter, while 7 major weirs and numerous smaller weirs are used to control river flow, check bed erosion and supply the mill leats which run through Ottery St Mary, Tipton St John, Otterton and Tracey Mill Farm north of Honiton." (p4-10)

Lower Otter Topography and Geology

The area of investigation starts upstream of Otterton and its Mill, and extends downstream to the pebble bar at Budleigh Salterton. The floodplain has a natural land elevation of 6.0m AOD upstream of Otterton, with the estuary land levels to the south at 1.8-2.2m AOD. The floodplain ranges from 400-500m wide and the total length of the area of interest is approximately 3.5 km long. In figure 4, key features are marked within the floodplain.

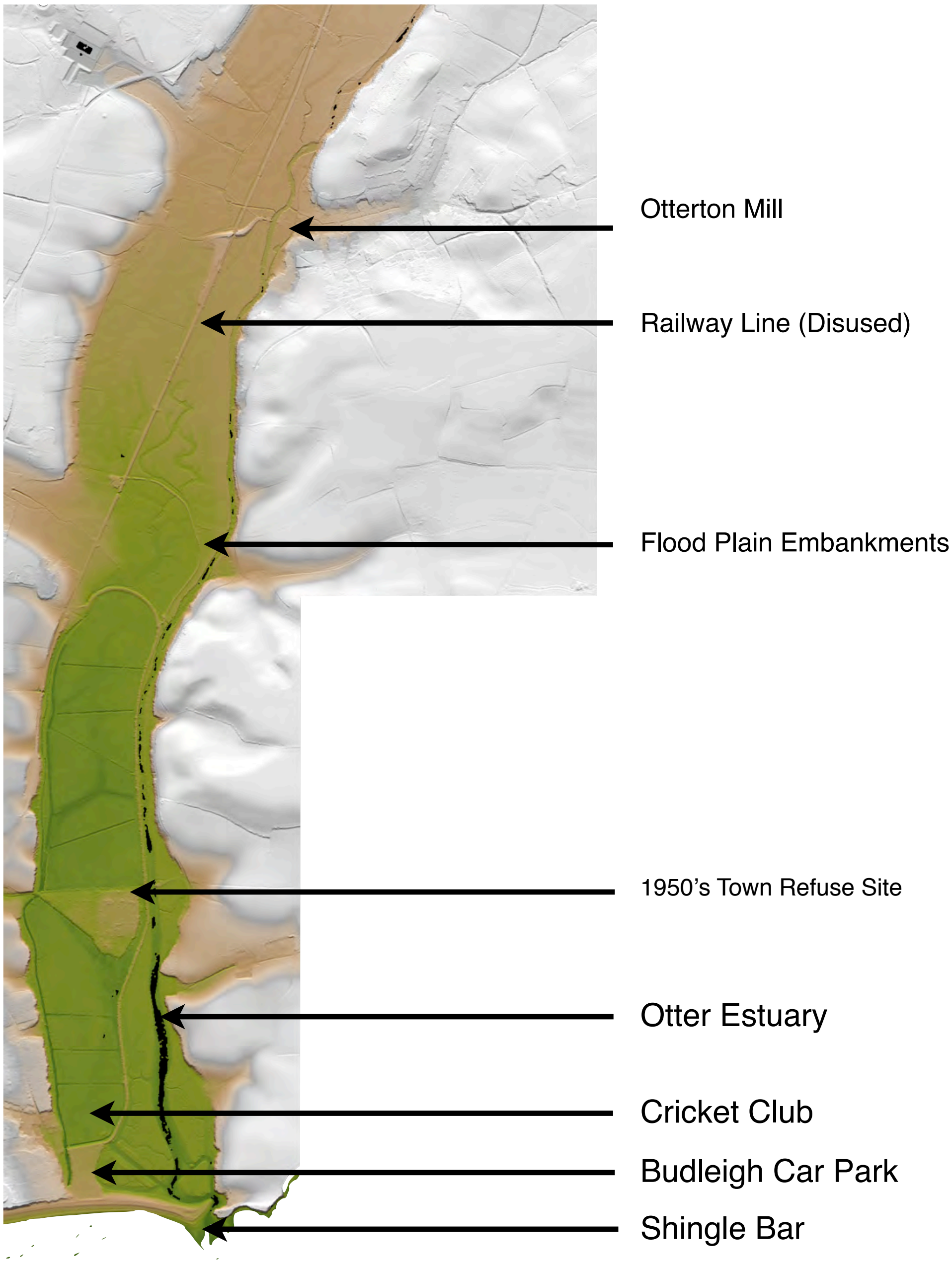


Figure 4: Illustrative surface elevation map of the Lower Otter Valley (Image based on Environment Agency LiDAR data)

In terms of topography, the main features of interest, affecting drainage and flood dynamics, are the cross valley roads and associated bridges at Otterton and South Farm. The railway line cuts diagonally through the floodplain, with land levels of the track ranging from 0.5-1.5m above the natural floodplain. The embankment is clearly visible within the topographic map, as are the fossilized tidal channels and creeks from below Otterton through the embanked section of the floodplain. In the lower half of the floodplain, the triangular elevated land level is the town's refuse dump, closed in the 1950's. South of the refuse site, the floodplain is split in half with the current estuary to the east and the embanked floodplain to the west. Within this section of the floodplain, the Budleigh car park is clearly elevated relative to the estuary and floodplain, with an average elevation of 3.6m AOD. The highest section of the pebble bar is 6.8-7.2m AOD.

The only section of the floodplain that is naturally narrower, is at East Budleigh, where the former natural channel has formed a debris fan into the former estuary and floodplain.

The floodplain's underlying geology is sandstone with most of the floodplain soils at the surface consisting of fine sand and silt soils associated with historical alluvial sediments settling within the floodplain. There are small sections of gravel based soils, but these are limited in area. Upstream of Otterton the floodplain soils are formed of more coarse sediments with more visible sand and gravels at the surface. Peat, either at the surface or buried, is not known to be present in the floodplain.

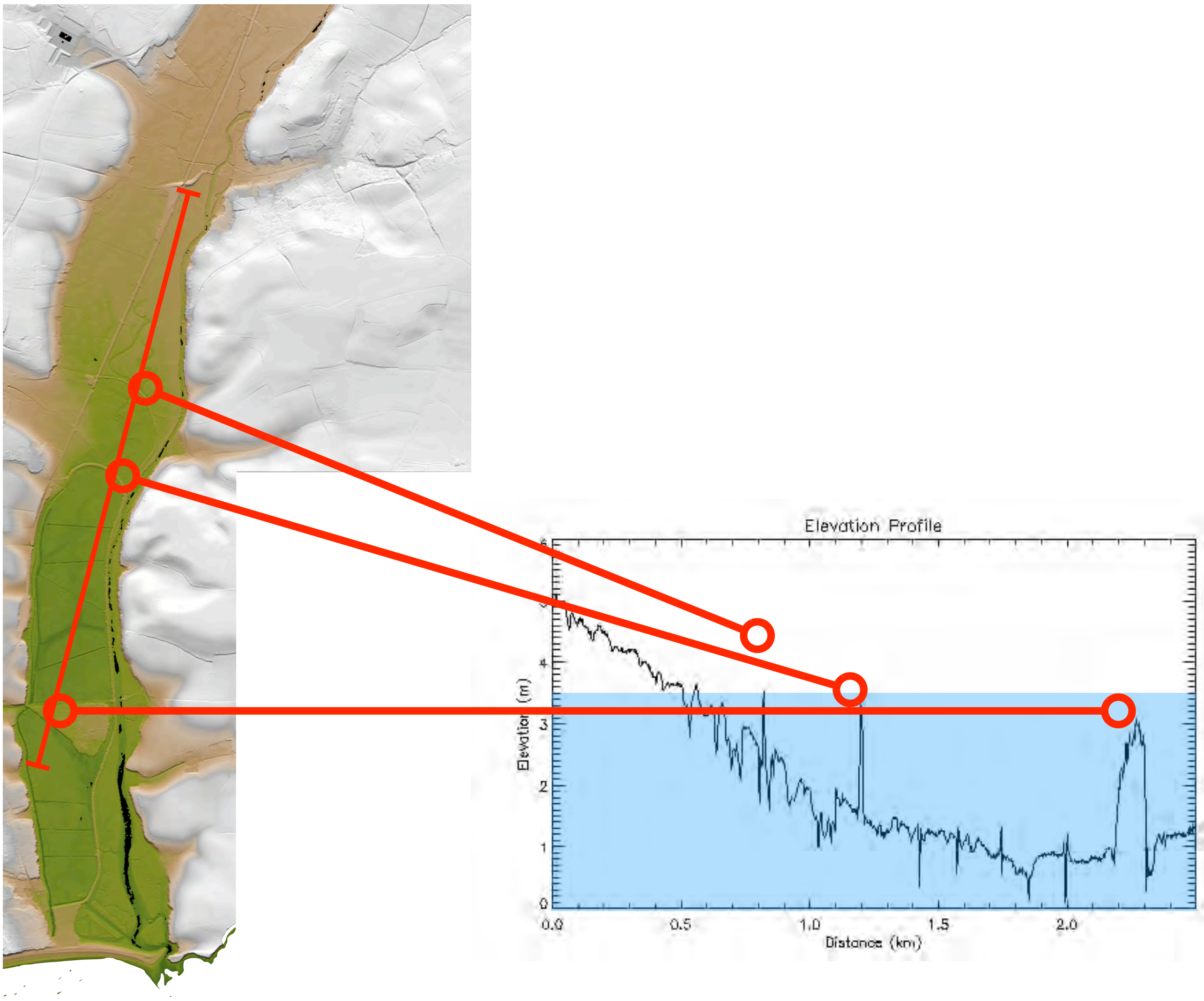


Figure 5: Section through the Lower Otter floodplain to illustrate the elevation of three key features, the embankments and refuse site. Information based on Environment Agency LiDAR at 1m resolution (2009 post processing).

Catchment Hydrology

Since extensive flooding in the Otter Valley in 1968, government agencies over this period have maintained flow gauging stations in the catchment, notably at Dotton, upstream of Otterton. In the past decade the flows for the Otter have been extensively reviewed and analysed and since the floods of 2008, additional work on the flow statistics of the River Otter at Dotton has also been undertaken by HydroLogic, building on the Environment Agency April 2008 Catchment Hydrology Report. It is therefore not the intention of this report to review this data extensively, but just to summarise the key figures.

The overall hydrological regime of the River Otter lies between the extremes of a flash flood river and a true groundwater based catchment. The peak flow recorded for the catchent divided by the catchment area (Q2 / km^2) is approximately 0.35 cumecs / km^2. This compares to a flash flood river with an index of 0.95 cumecs / km^2 or a chalk stream with a runoff index of 0.02 cumecs / km^2. As a sandstone river, with large areas of mudstone, runoff responses can be fast, but the sandstone does not retain large volumes of groundwater to sustain flows in the summer. The net effect is that rainfall tends to pass through the catchment in less than 24 hours, with base flow often being very low and unable to sustain flow in the upper catchment.

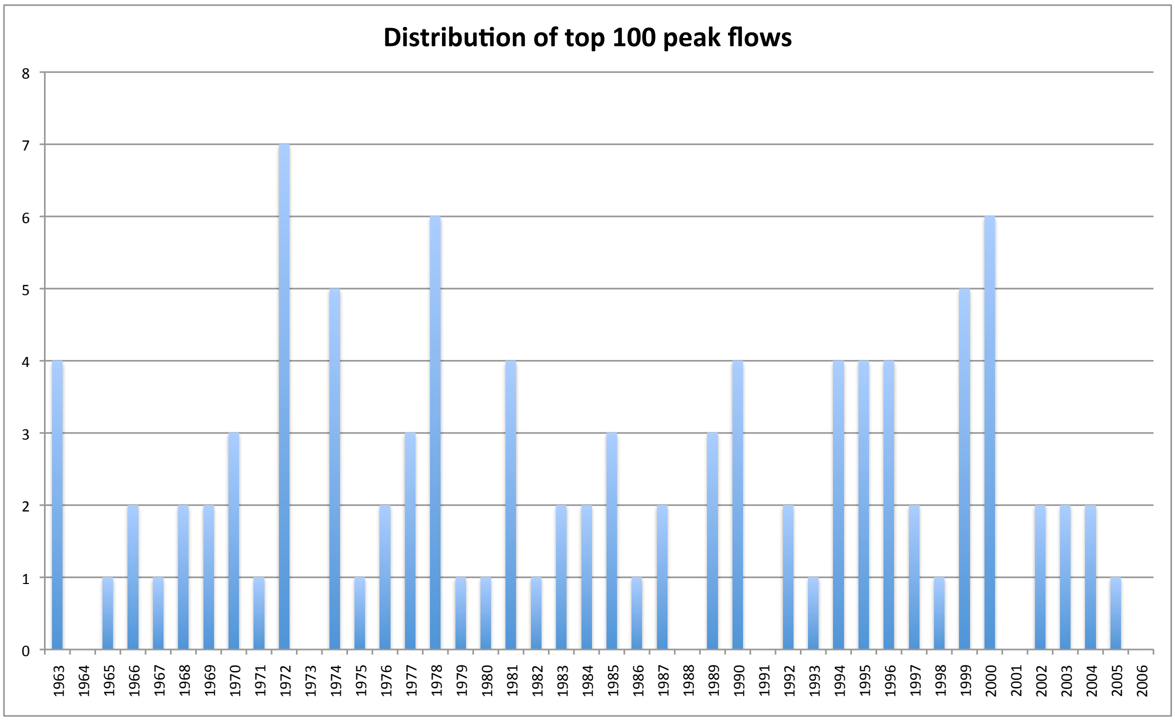


Figure 6: Number of peak flows over 25 cumecs per annum. Dotton Gauge (45005: 1963-2006: >25 mean daily flow: cumecs)

Using the Dotton flow gauge, and the peak daily mean flow statistics (figure 6 and 7), the highest recorded daily flow in the 1960's was 52 cumecs, in the 1970's was 61 cumecs, in the 1980's 56 cumecs and in the 1990's 41 cumecs. In the 2000's, up to 2006, peak flow was 67 cumecs. There is no underlying trend, but the peak daily flows post 2000 are higher than before this period.

The lack of major floods in the 1990's is confirmed by Budleigh Salterton Cricket Club records for the period 1960 onwards, which records a lack of major flooding in the period 1987 until 1997.

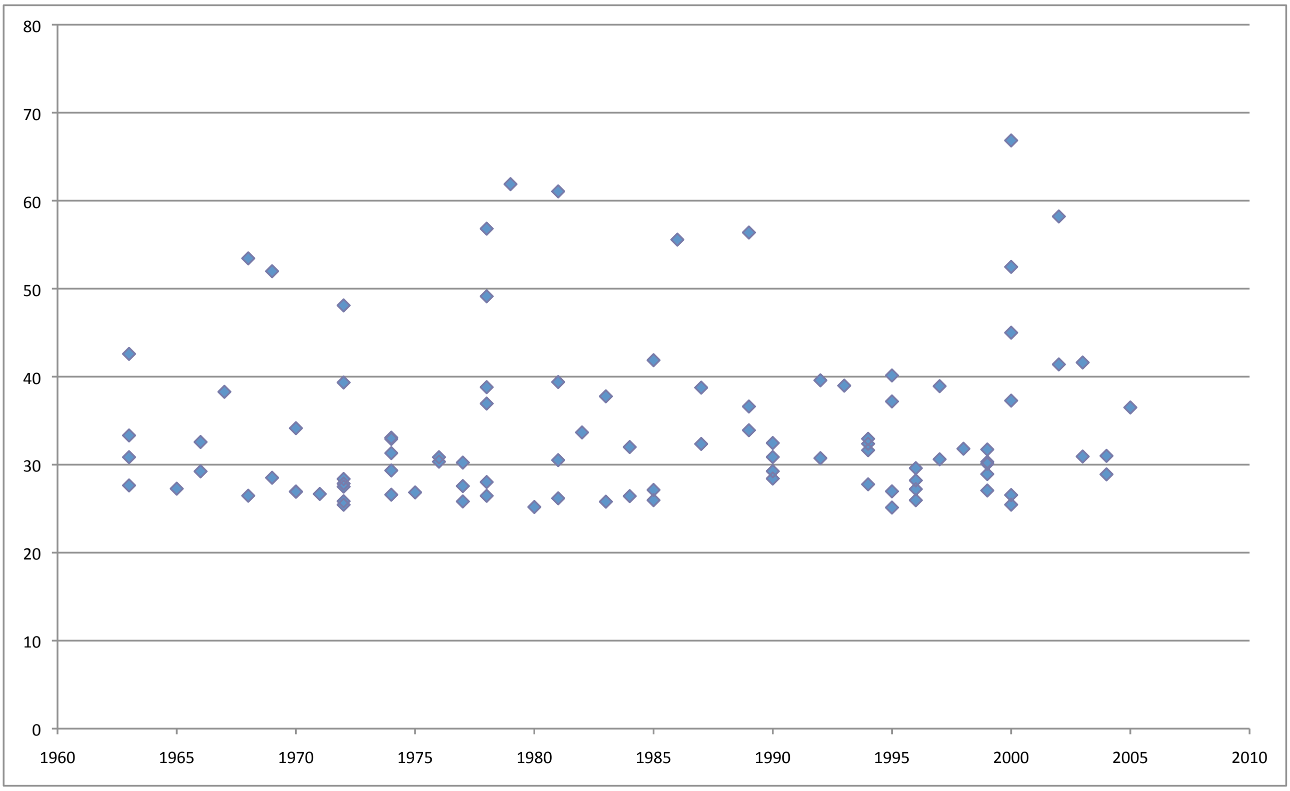


Figure 7: Time plot of the recorded peak daily mean flows greater than 25 cumecs for the Dotton gauge for the period 1963 until 2006.

Recent flood events of the catchment are presented in figure 7. The number of flood events over 25 cumecs, in the last decade has been low compared to the period 1963 until 2000. However, post 2008, there have been a number of serious floods, notably on the 29th - 30th October 2008, which generated an estimated 212 cumecs of flow based on a localised rainfall event of 187mm in 27 hours. This event was 3.0 times larger than the mean annual flood (Q2 = 70.45 cumecs) and based on the April 2008 rating curves for the catchment at Dotton, would equate to a 170-220 year return period. The peak flow was principle generated by the core of the rainfall, namely 135mm, landing in 2 hours. The rainfall return period was estimated to be greater than 1:200 years (table 1).

Table 1: Met Office Statistics for the Rainfall at Ottery St. Mary, 29th - 30th October 2008

Rainfall total (mm)	Duration (hrs)
187	27
160	3
135	2

Figure 8: Aerial Photograph of Otter St Mary post the 30th October 2008 rain fall event with hail still present in the fields west of the town, but also showing runoff lines through the hail. Image from Environment Agency archive (2008-10-30 110.jpg)

Current Drainage Layout

The arrangement of the current drainage of the Lower Otter valley is illustrated in figure 9. The River Otter flows north to south on the eastern side of the valley. The Otter passes into the estuary and then discharges into the sea. On the western side of the valley the normal drainage is collected into a north-south flowing drain that receives water from Bicton, Budleigh and Kersbrook catchments. Budleigh Brook's normal flow is channelled into East Budleigh Aqueduct (constructed during the second world war) and is discharged directly into the Otter. In spate flow, the aqueduct does not have the capacity to cope with the Brook's flow, and it discharges into Little Marsh and then gravity drains into the main north-south drain to the sea outfall (figure 9).

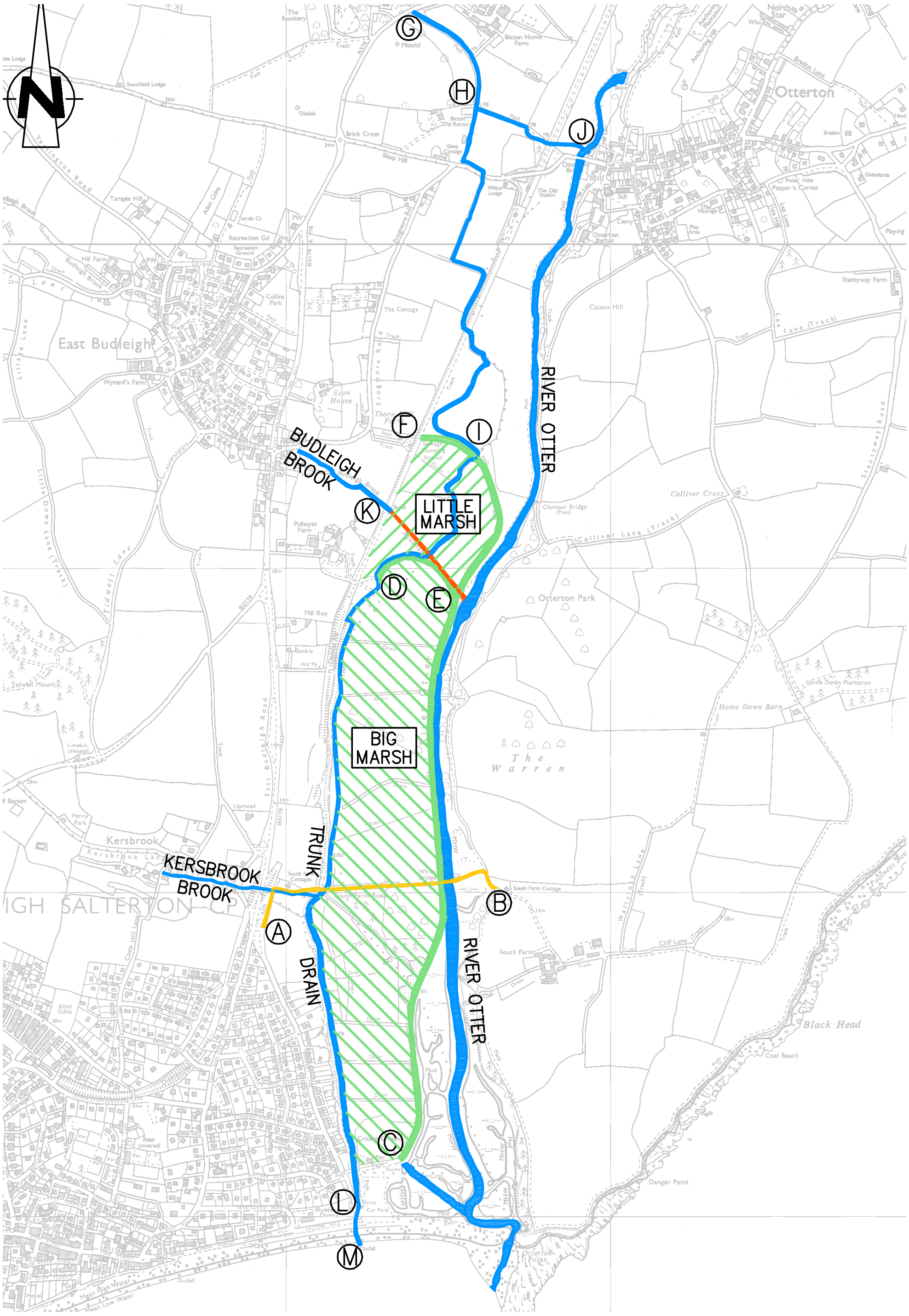
The condition of the aqueduct is of concern to the Estate and options for the larger valley need to consider the long term future of this asset. Likewise the condition of the embankments (Little and Big Embankment, figure 9) is of concern and frequent overtopping of the embankments, especially Big Embankment locally to the East Budleigh Aqueduct is cause for concern.

Additional concerns are the poor drainage of the land to the north of South Farm Road and its dependency on the performance of the sea outfall locally to the Lime Kiln (point L, figure 9). Up until the early 1990's sections of Big Marsh and Little Marsh have sustained arable cultivation. The current land is improved grassland, in small sections, and reverted wet grassland communities in the southern portion of Big Marsh.

The River Otter, south of Otterton, is a channelised section of river and has various degrees of bank erosion, typical of a channelised river. The river is tree lined on its right bank (west bank) and on the left bank tree and scrub cover is present both on the bank and the relic floodplain that exists between the current channel and the sandstone valley cliff. The River Otter channel geomorphology is depositional 150m upstream of where Little Marsh embankment encroaches into the floodplain. The constriction of flood flow on the floodplain by Little Bank has markedly changed the channel geomorphology in this section, with erosion of the channel banks and bed marked at the confluence of Budleigh Brook.

The River Otter also shows excessive sediment deposition upstream of South Farm Road and its associated bridge. The combination of a restrictive channel and scrub floodplain plus daily intertidal influences has resulted in visible sediment accumulation within this section of the floodplain. This accumulation may have resulted in recent floods, but the accumulation of sediment in this section is impacting the hydraulics of this section of the Otter and pushing erosion onto the right bank (western) bank.

Figure 9: Current Drainage arrangements for The Lower Otter Valley (taken from Howick and Partners report to Clinton Devon Estates)



Annotation: **A-B** is South Farm Road, which crosses the embanked compartment. **C** is the EA sea discharge behind the Cricket Club. **D** is the main embankment drain. **D-E** is Big Bank. **K-E** (orange line) is the East Budleigh Aqueduct. **E** is the discharge point of Budleigh Brook. **F-E** is Little Bank. **G** is Bicton Brook. **J** is Otterton and Otterton Mill. **L-M** is the culvert discharge to the sea. **M** is the sea outfall of the embankment drain. **F-C** (green line) is the length of the embanked compartment consisting of Little Marsh and Big Marsh.

Recorded Flood Events

Since 1959, Budleigh Salterton Cricket Club (BSCC), whose grounds lie on the embanked floodplain of the River Otter, have kept an archive of the impact of floods on the grounds and associated buildings. In reviewing this archive, with the assistance of the Cricket Club, we have sought to classify the dominant source of flooding. Namely drainage and associated pluvial flooding, fluvial flooding from the River Otter and estuarine flooding (saline). The one recorded saline flood event was in 1959, although Estates records indicate that in 1982 a section of the embankment, upstream of the Cricket Club failed and was repaired, and may have resulted in saline inundation, but this was not recorded by the Cricket Club.

Figure 10: Flooding of the 1959 Cricket Club (Image from BSCC archive)

Fluvial flooding of the embanked compartment appears to have occurred 9 times since 1959 until February 2009 (table 2). The dominant source of flood water is the River Otter, with floodwater entering the embanked compartment some 2km upstream and once within the embankment, gravitating towards the Cricket Club and the sea outfalls behind the current buildings.

Flooding resulting from drainage or impeded drainage seems to have occurred at least 11 times since 1959, although not all incidents were recorded. The events cited below resulted in ingress into the main buildings.

In total, 21 fluvial and drainage flood incidents have been cited in the embanked section of the River Otter, affecting the Cricket Club and South Farm Road.

It should be noted that a number of properties, possibly 3, have flooded on Granary Lane, locally to the entrance to the Cricket Club Grounds. Interviews with residents suggest that when the Big Marsh floods with more than 2m of water, then these properties are impacted. The flooding of these properties in October 2008 was compounded by urban runoff not being able to drain to the Big Marsh drain and the Lime Kiln culvert because of a local depression in the road surface. This appears to have resulting in the first surge of water through these properties, and then the more sustained flood arising from the inundation of Big Marsh and the submergence of the Cricket Club Grounds. Options to reduce the risk to Granary Lane from fluvial flooding are discussed in option A.

The duration of flooding can be days if not weeks, with the trapped flood water held within the embanked floodplain by a possible combination of blocked sea outfalls, on the seaward side. In extreme floods, blockage of the sea outfall on the landward side has also been recorded, but is rare.

Based on this information, the frequency of flooding of the embanked compartment appears to be once every two years or 1:2 years. The depth of flooding in the compartment can exceed 2.8m, since when the outfalls are blocked, the only effective discharge is over the current embankments and into the tidal section of the River Otter.

Table 2: Analysis of local press and BSCC archive on the flood history of the Lower Otter Valley

Date	Incident Number	Theme	Source	Classification
December 19th 1959	1	Floods the week prior to publication along with outfall pipe proposed. States in 1812 embankment on western side of river built up and therefore restricted the free movement of water in and out of the estuary.		Tidal
March 1960	2	Floodwaters continued to be a problem.		Fluvial
1986		Suggestion of flood in 1997 correspondents		Fluvial
August 1997	3	Thursday 7th August rainstorm caused flooding along Otter Valley. Friday 8th August cricket grounds inundated, flood water reaching steps of clubhouse. Tidal valve examined and found to be purposefully blocked with plugging clay. Penstock valve also remained closed. Both valves freed on Saturday 9th and floodwaters able to dissipate.	Chronicle of events relating to flooding of cricket ground 8:Aug:97 from cricket club	Fluvial
October 22nd 1997	4	Flooding during August 1997, prior to event no flooding since 1989 due to flood defence work carried out by National Rivers Authority further upstream. During this time there were equally heavy rainstorms with no flood events. Tidal flap blocked by Environment Agency at the request of Heritage Preservation Agency who wanted to preserve wetlands.	Letter from Cricket Club to Crawford & Company	
April 28th 1998	5	Record of flooding during August 1997, thought to be due to faulty tidal flap. Grounds unfit for use for period of 8 months from August.	Situation report from Cricket club	Drainage
April 26th 2000	6	Cricket grounds flooded for 2 weeks prior to letter. All land drains blocked and surface water not able to drain away.	Letter from cricket club to Ctawford & Company,	Fluvial
November 9th 2000	7	5ft of water at cricket club pavillion. 2nd flooding in 7 days. Outfall cleared on the Friday. Grounds re-flooded on following Wednesday.	The Budleigh Salterton Journal	Fluvial
January 11th 2001	8	Clubhouse flooded for 2 months prior to article being written.	The Budleigh Salterton Journal	Drainage
January 18th 2001	9	Unprecedented flooding over 3 month period. When outfall needs to be working at full efficiency, it is often impaired. Losses of equipment and building damage in excess of £50,000.	Letter from Cricket Club to EDDC	Drainage
November 21st 2002	10	3 Houses in Granary Lane flooded and clubhouse submerged under 15ft of water. 3rd time of serious floods in 3 years and only weeks since the last flood. 8hrs of rain between Weds and Thur.	The Budleigh Salterton Journal	Fluvial
November 28th 2002	11	EA give go ahead for flood channel and penstock (£50,000). However South Farm and businesses continue to be cut off and closed.	The Budleigh Salterton Journal	Drainage
December 5th 2002	12	November floods caused serious erosion of river walkways and banks.		
December 16th 2002	13	Cricket ground flooded for a number of weeks due to continual rainfall and outfall pipe only able to discharge flood waters for 2 hours max, before shingle begins to block pipe once again.	Letter from Cricket Club to EDDC	Drainage
Winter 2002	14	Floods over 13-14th November due to 47mm of rain falling at Dunkeswell in the headwater catchment area. Closure of South Farm Road and Granary Lane properties flooded along with cricket club.	Newsletter for Clinton Devon Estates People	Fluvial
January 9th 2003	15	Cricket grounds re-flooded		Drainage
January 20th 2003	16	After flooding of November 2002 outfall pipe was found to be operational only 30% of the time during December.	Letter from Granary Lane resident to EDDC	Drainage

Date	Incident Number	Theme	Source	Classification
September 23rd 2005	17	Tidal valve repaired to full working order and expected to work satisfactorily for 'a good few years to come'.	Letter from EDDC to Cricket Club	
January 2nd 2008	18	Problems of flooding during December 2007 , outfall pipe blocked and flooding grounds and pavillion.	Letter from Cricket Club o EDDC	Drainage
February 20th 2008	19	Early Jan 08 storms blocked outfall pipe and lead to farmers fields being 'permanently sodden', and further flooding of cricket grounds.	E-mail from Cricket Club to EDDC	Drainage
October 31st 2008	20	1ft of hail within 2hrs. Floodwaters hit homes.	The Budleigh Salterton Journal	Fluvial
February 5th 2009	21	Flood waters submerged clubhouse completely twice during the winter.	Exmouth Journal	Fluvial
February 11th 2009	22	Significant flooding during October and December 2008. Outfall pipe blocked, can take a full week before EDDC arrive to unblock.	Express and Echo	Drainage
February 2009	23	Granary Lane flooded from 30th October 2008 beyond 11th February 2009.	E-mail from resident of Granary Lane to EDDC	Drainage
Total incidents	**21**			

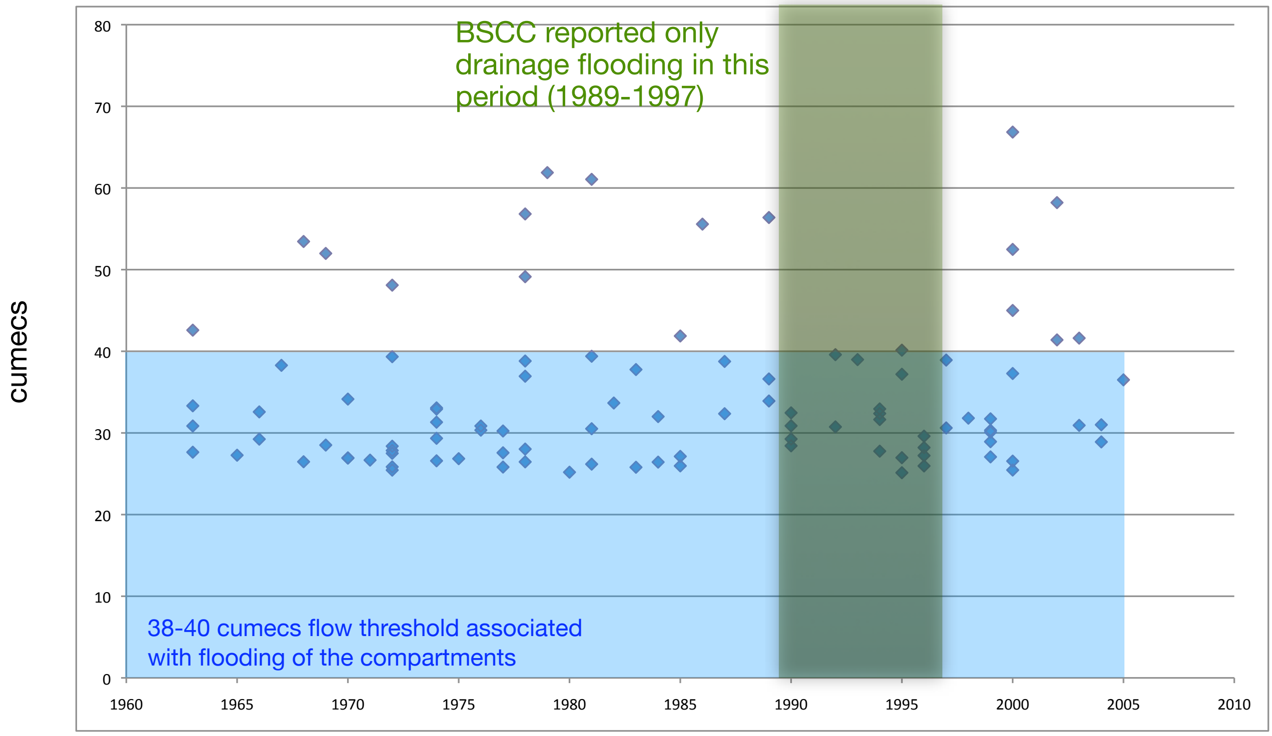
Table 3: Summary of Table 2; Analysis of Local Press and BSCC Archive on the flood history of the Lower Otter Valley

Type of flooding to critical infrastructure (1959-2009)	Number of recorded incidents (BSCC + Media + EA records)
Tidal (bund overtopping: 1959, tidal in-wash to Cricket compartment)	1
Fluvial (bund overtopping)	9
Drainage (impounded or tidal blocked outflow)	11

Taking the observed and recorded flood incidents and reviewing these periods with the Dotton gauge, there appears to be a close relationship in respect of the BSCC record aligning with the Dotton gauge. A number of drainage floods seem to have been merged with fluvial floods but out of the 20 incidents, the Dotton gauge flow effectively links up with 17 of the BSCC records.

A key period when flooding was not recorded in the embanked compartment was between 1989-1997. This is a period when mean daily peak flows were recorded at or below 40 cumecs at Dotton. The significance of this value, its return period and the implications on the management of the embanked compartments will be explored in the options section of this report.

Figure 11: Linking observed flooding of the embanked compartment with the Dotton flow gauge peak daily flow record.



Tidal Levels and Data and its Current Influence

The level of the tide exerts two main influences on the hydrology of the Lower Otter Valley. Firstly the drainage of the embanked compartments is dependent on the gravity drainage to the sea through a set of weirs and through a culvert to a sea outfall located on the pebble beach locally to the Lime Kiln, Budleigh Salterton (figure 12). The second effect is the tidal surge of water through the pebble bar and into the estuary and the impact of this volume of water on the dynamics of the estuary and interactions with the normal flow of the River Otter.

Figure 12: Photographs of the embanked compartment outfall on the pebble beach locally to the Lime Kiln, Budleigh Salterton. The left image shows the outflow blocked by gravel and pebbles. The right image shows the Council clearing the outflow which can occur weekly based on BSCC information.

The 975mm outfall at the Lime Kiln has an invert level of -1.6m AOD (Howick and Partners, 2001) and is below Mean Low Water Spring Tide (-1.3m AOD). The Mean tidal is 0.7 mAOD. For the majority of the tidal cycle the outfall is submerged and discharge from the pipe requires a hydrostatic head to build up on the inflow, greater than the tidal level. Once the tide exceeds -1.05m AOD a flap valve starts to become submerged and the discharge efficiency of the embankment drains becomes impaired or ceases. Land levels locally to the Cricket Club are 0.8-1.0m AOD with mean high neap tide approximately 1.50 mAOD. The low elevation of the outflow results in frequent periods when the normal drainage of the embanked compartment is compromised. When the drainage is impaired, excess runoff accumulates within the embanked compartment drains and the low lying fields. If a normal rainfall event (>10mm/day) coincides with impaired drainage over a number of tidal cycles, then key assets will flood. Major incidents of drainage related flooding have been recorded 11 times. But flooding of fields and amenity areas is calculated to be far more frequent based on the elevations of the embanked floodplain land.

The second impact of the outflow being so low relative to the tide, is the impact of shingle accumulation at the outflow chamber. Howick Engineers reported in 2001 that:

“On 9th February 2001 the beach level was surveyed and was found 1.5m to 2.0m higher than when the end of the outfall was reconstructed in the mid-1980s.” (BUDLEIGH SALTERTON TRUNK DRAIN SURVEY for Clinton Devon Estates, 2001, Howick and Partners, p4)

This measurement and observation suggests that the pebble beach is undergoing some form of geomorphological adjustment. As with pebble bars in other locations, its has been observed that these features are becoming steeper on the seaward aspect, with the crest of the shingle bar also becoming higher. This has also been recorded at Loe Bar and Slapton Ley. The impact of sediment accumulation at the outfall chamber is to reduce normal flow, even when the tide allows normal drainage. The net result appears to be significantly impaired drainage for periods of days and weeks until the outflow is excavated clear by the local council. This work can only occur at low tides.

Potential changes in the sediment supply and sediment circulation of the pebble bar is outlined in the Environment Agency Shoreline Management Plan (version 2, section 1.8, p29-31). In this report they discuss how the essential direction of long shore drift aids the accumulation and growth of the pebble bar eastward. However, changes in the direction of long shore drift in this section of coast have been recorded as Atlantic swells often compete with North Sea swells. In addition, the sediment supply to the mouth of the Otter and the power of flow out of the Otter mouth can result in significant volumes of sediment being laid back along the pebble beach, east of the Otter mouth.

In figure 13, BODC data for Weymouth since 1992, suggest that maximum monthly tides (cm ACD) have increased since 1992 until 2001. Since 2001, mean maximum tides have been consistently higher, but peak tides lower than 2001. This change in tidal behaviour may support the assertion that at the pebble bar, long shore drift is indeed dynamic, and dependent on the Altantic / North Sea dominance, and the sediment supply and flows from the River Otter. The observation by Howick, that the beach locally to the embankment drain sea outfall has increased by 2m in 15 years does suggest a more dynamic beech regime than previously considered.

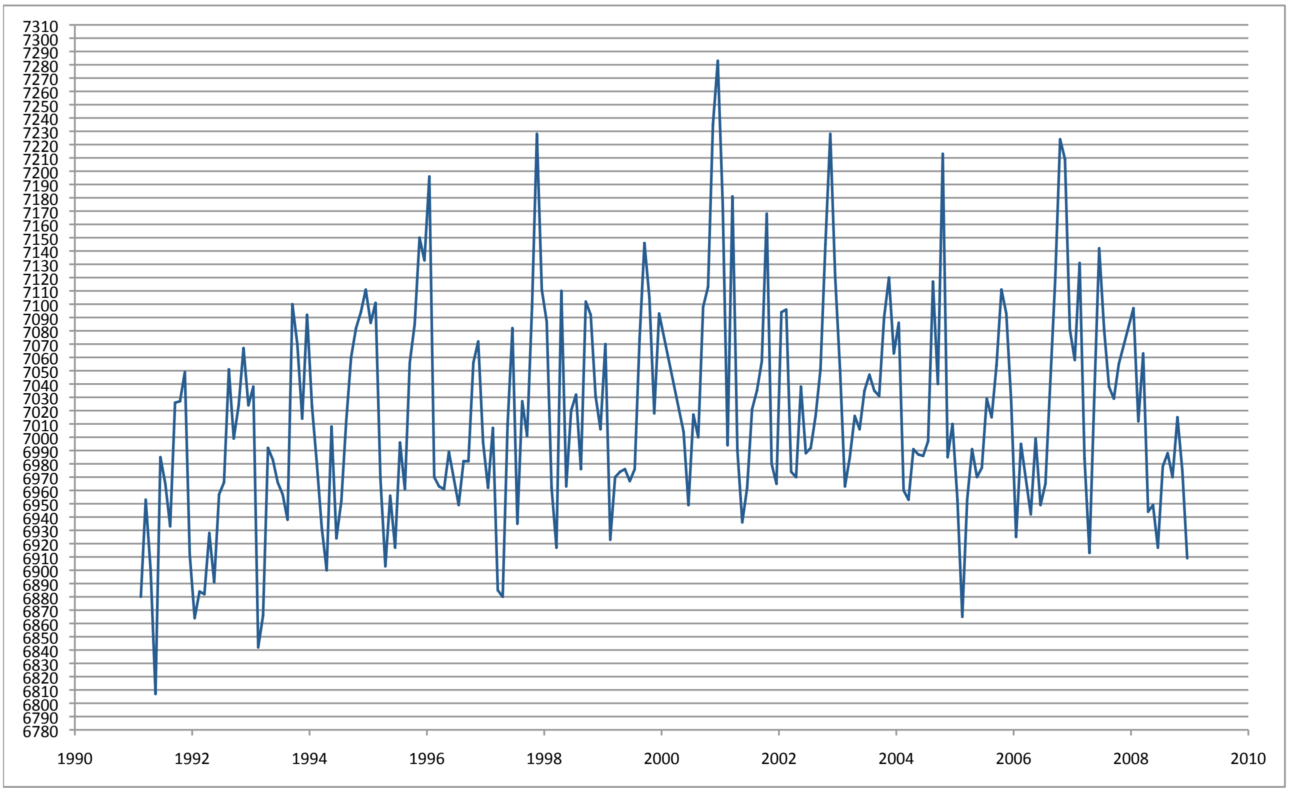


Figure 13: Extreme monthly tides for Weymouth based on BODC sea level gauge. Levels are cm ACD.

Historical Periods and Accounts of the Lower Otter Valley

The economic history of the Lower Otter Valley is very rich. We have focussed on the period from 1060 until the present and sought to illustrate the changing landscape of the river and its relationship with the sea. The key observations, taken from "Historical Guide to the Lower Otter Valley, 1993" illustrate some key changes in landform of the valley:

- In the 10th century, 3 mills recorded at Otterton, owned by Countess Gytha, mother to King Harold (7th January 1066). With Harold's death, King William passes Otterton to Abbey of Mont St. Michael, Normandy.
- Abbey of Mont St. Michael record Otterton as a sea port, with ship building one of the recorded activities. Abbots were very keen on the eels (p62).
- The Abbey records describe the silting up of Otter Mouth and formation of marshland at the end of the Mediaeval period. Extreme storms in the South West were responsible for many coastal changes in this period (e.g., Loe Pool, Slapton).
- Large vessel navigation lost on the Otter by 16th century (J. Leland, cites the period 1440, one hundred year prior to his visit). Leland writes of Otterton as a fishing port, a mile upstream of Ottermouth. Leland was Royal Librarian for Henry VIII and his 10 year tour of the Cathedrals and Churches of England resulted in the publication of "Britannia" by William Camden after Leland's death in 1552. Camden became the first Chair of History at Oxford University.
- The land passes from Syon Abbey to Richard Duke c. 1539 with its 100 acres of marsh. Richard Duke (the father) was protege to Cardinal Wolsey in Henry VIII's court. His son, also Richard Duke became Mayor of Exeter and continued the family line and its association with Otterton.
- The Duke family attempted to refloat the harbour in the period 1553 with public subscription. Efforts ended in the loss of "Bodelie Haven".
- The Rolle family purchase Otterton (1785) and record 189 acres of salt marsh, suitable for reclaiming.
- 1812 Rolle decided to tame the river, and using French prisoners, build the western embankment.
- Some evidence of a hurricane in 1824 that extended the Pebble Bar into its current form. Source Unknown.
- Rear Admiral F. Bullock (Vice-Admiral of surveying service, Woolwich, 1864) and Mr. Andrews in 1858 state navigation of 60 ton vessels possible until 1810, but embankment has accelerated siltation and allowed pebble bar to build up without estuarine wash.
- 19th century until WW1, stable farming period.
- 1897-1903 the railway was developed to Salterton, funded by the Rolle Estate.
- Large floods in 1968 result in flood works in Otterton and surrounding area.

The picture that emerges from the historical records is a valley defined by stable periods, where economic activities could be developed. The 10th until the 14th century appears to be period when the valley is predominantly estuarine with the sea port and fishing community at Otterton. Trading in minerals and fibre at the Village seems key, with the Mills providing processing of wool, lime and cereals. Extreme storms in the 1400's resulted in an apparent shift in the geomorphological regime of the pebble beech with the bar forming and the tidal regime throttled, with large ship navigation to Otterton reduced. The development of the bar may relate to a period in 1485, when the bar at Loe Pool (Lizard Point) and Slapton Ley (Devon) underwent massive changes as a result of a storm surge. This event was recorded by Chroniclers for Loe Pool, with the erosion and washout of Loe Pool harbour recorded by ships sailing locally to Lands End (National Trust, Penrose Estate Archive).

The formation of the pebble bar marked a change in the tidal and river regime of the Lower Otter. Leland, Henry VIII's chronicler records the loss of navigation of "Bodelie Haven". Efforts to clear the bar and refloat the harbour by Richard Duke in 1553 fail. The Rolle family in 1812 seek to build on the terrestrialisation of the valley and the growth of marshlands from 100 acres in 1553 to 189 acres in 1785, through a series of embankments, built with the labour of French prisoners of war. Stone from the Otter Valley walls was harvested in the construction of these embankments, with the river effectively trained from Otterton to the sea. This resulted in the marshlands being limed and restored to arable and grazing lands from the period 1812.

Concerns about the impact of these embankments and the loss of navigation up the estuary appeared to have been raised by Rear Admiral Bullock in 1858. The combination of the embankment, the pebble bar and changing sediment supply into the reduced estuary, from tidal and fluvial sources, are all legacies that the current land managers seek to deal with.

Hydraulic Model of the Lower Otter Valley

In order to generate a fuller understanding of the flood dynamics of the Lower Otter Valley, this project has constructed a 2-D flood model of the River Otter and its associated floodplain. The underlying land levels in the computer flood model have been derived from Environment Agency remote senses LiDAR data. This mapping system uses an airborne laser to scan the ground surface at 1m intervals (X-Y axis) and records the elevation of land to within 0.05-0.15m vertically. A representation of the land level data generated from this system is illustrated in figure 4 at the start of this report.

The Environment Agency LiDAR data was then checked with surveys of key assets and embankment heights secured from previous Estate surveys.

The data used in the model was scaled to represent the average land surface elevation every 5m in open areas, and the maximum land surface along the lines of key assets, for example the embankments and other structural features.

The digital terrain model was then processed in LisfloodM-MPI; a 2D hydraulic model designed by Bristol University and optimized for UNIX platforms by Haycock Associates. The flood model allows discharges to be placed in the digital terrain model and then their flow direction, rate and depth of water mapped as the flow moves through the model under gravity and momentum based forces. The flood model responds to the elevation of the land and the underlying hydraulic roughness of the land areas, as defined by land cover. The model can cope with multiple inflows (unlimited) and also enables the simulation of tidal regime. Thus the model is ideally suited to the analysis of the Lower Otter.

The model generates considerable data, both of flood water height and also of water depth and velocity. Additional functions within the model enable land elevation to be adjusted in response to geomorphological stresses, but this option was not explored in the simplified models generated for the Lower Otter Valley.

In the following section we outline the main observations of simulated floods on the Lower Otter Valley. The first analysis was of the current flood dynamics, without tidal influences. The second set of models was to explore the implications of removing the current embankments, in key sections, and the resultant flood dynamics. The final set of models sought to explore the tidal regime of the estuary and its impact on the fluvial regime. In the tidal flood simulations we also explored the implications of the breaching of the flood embankments (Big Bank) and the resultant inundation areas.

Flood Dynamics - Fluvial

The fluvial flood simulations enter a flow of 69 cumecs into the model upstream of Otterton at a single point associated with a constrained point in the channel. Flows from other tributaries were not simulated at this stage in order to concentrate on the flood route and dynamics of the River Otter. 69 cumecs represents the peak flow of a 1:2 year flood or the average sustained flow of a 1:100 year for the core 12 hours of the storm. Initial modelling work with a unit hydrograph of a 1:100 year storm simply swamped the model and did not enable any diagnostics and inspection of the processes of flooding to be examined, thus a lower volume of water was entered into the model to enable the process of flood propagation to be tracked. Based on the analysis of flows at Dotton in the previous section, we have estimated that flows greater than 40 cumecs result in flooding of the main embankment compartments.

In figure 14 a-d, key time slices of the model are presented. Key observations of the flood model, which support tenant and Environment Agency flood records for the area, are:

1. The railway embankment upstream of Otterton restricts flow to the western floodplain. If this simulation had started further upstream, then a portion of the flood water would have passed down this section of the floodplain. At Dotton, it is estimated that 30% of the flood passes down the western portion of the floodplain (verbal, HydroLogic).

2. The Bridge at Otterton does not have the capacity for 69 cumecs, with the side arches effectively restricted by high land upstream and downstream of the culvert. Flooding over the road on the western floodplain occurs.

3. Below Otterton floodwater overtops the right bank and flows diagonally towards the railway embankment and then down to Little Bank, where it ponds upstream of the embankment. Water depths on the floodplain locally to Otterton are shallow, less than 500mm (figure 14a).

4. Once the land upstream of Little Bank is surcharged, then flood water attempts to re-enter the Otter channel, but flow is restricted in this section to less than 40 cumecs. Surplus water therefore overtops Little Bank and enters Little Marsh (figure 14a).

5. Once Little Marsh is surcharged, excess water passes over Big Bank along a broad crest and into Big Marsh. The model suggests that no flow directly from the Otter enters Big Marsh, other than from flood flow entering Little Marsh. Figure 14b shows the northern section of Big Marsh flooded, but no flood water ponded by the 1950 refuse site, which has an elevation 1.8-2.5m above the embanked floodplain.

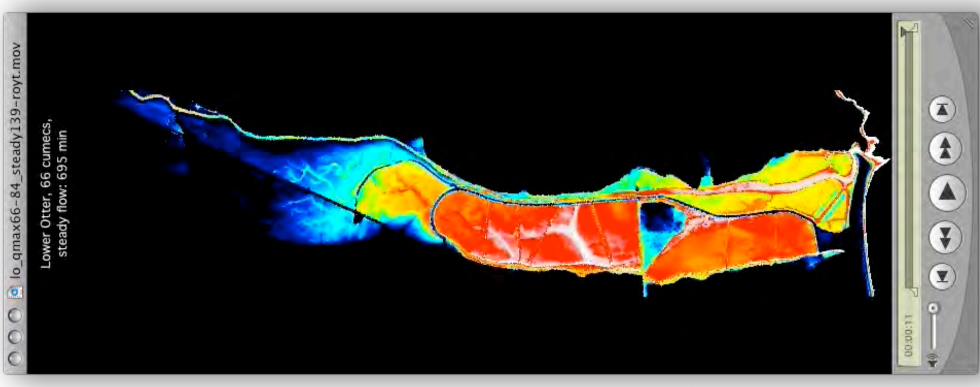
6. Water enters the southern section of Big Marsh via a depression to the western end of South Farm Road and also via overtopping water in the main Otter channel near White Bridge. The main flood water enters via the western portion of South Farm Road and results in 1.4-2.0m of standing water on the low lying road (figure 14c). It should be noted that the majority of the flood water is entering the embanked compartments, and only slowly filling the estuarine portion of the Otter, which has a land level of 1.8-2.2m AOD.

7. The final phase is the complete surcharging of the embanked compartments (figure 14d, at 695 minutes), the flooding of the estuary via the main channel flow and also flow from the Big Marsh re-entering the main channel just downstream of the refuse site. The depths of water in the embanked section exceeds 2.8m of standing water. The geometry of the channel through the pebble bar restricts flow at 69 cumecs, but extensive flooding has occurred upstream because the channel capacity is restricted and degraded.

8. We have not modelled the dewatering of the site, but we have estimated that flood water volumes in the final phase exceed 1.4 million cubic metres. Assuming no tidal influence to limit discharge to the sea, it would take a minimum of 5 days to dewater. Given that the outfalls are compromised by tidal influence, the experience of standing water for many weeks is to be expected.

Figure 14 a-d: Key time slices of the modelled water depth for a 69 cumec fluvial flood passing through the Lower Otter Valley based on LisfloodM-MPI output (model run on a 5m DTM with computation timesteps of 0.005 seconds, with model output saved at 60 second interval [text] and 300 seconds for spatial data files).

D



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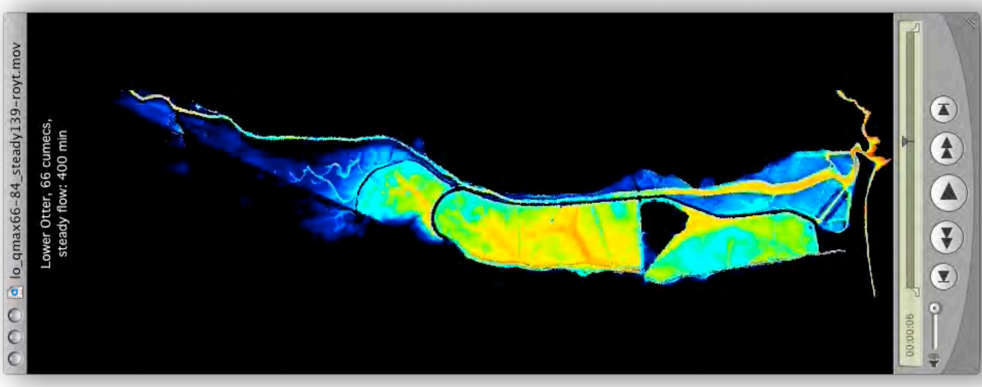

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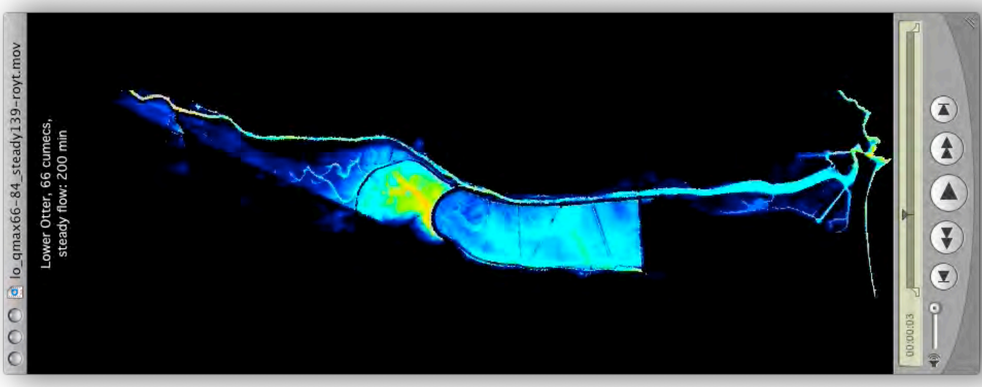

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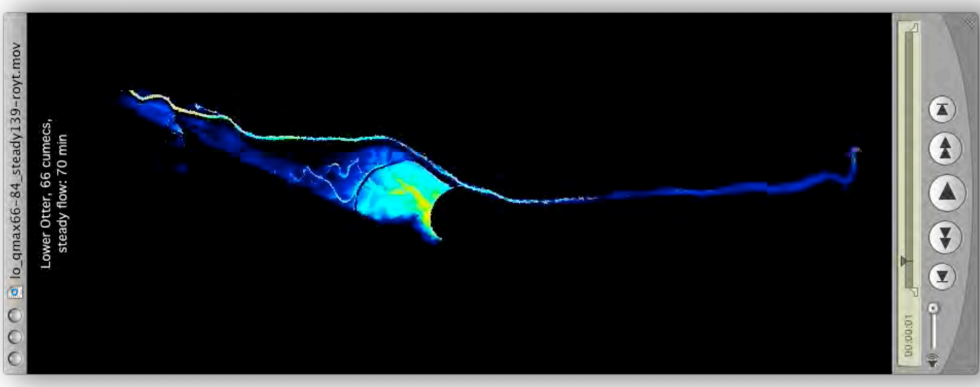
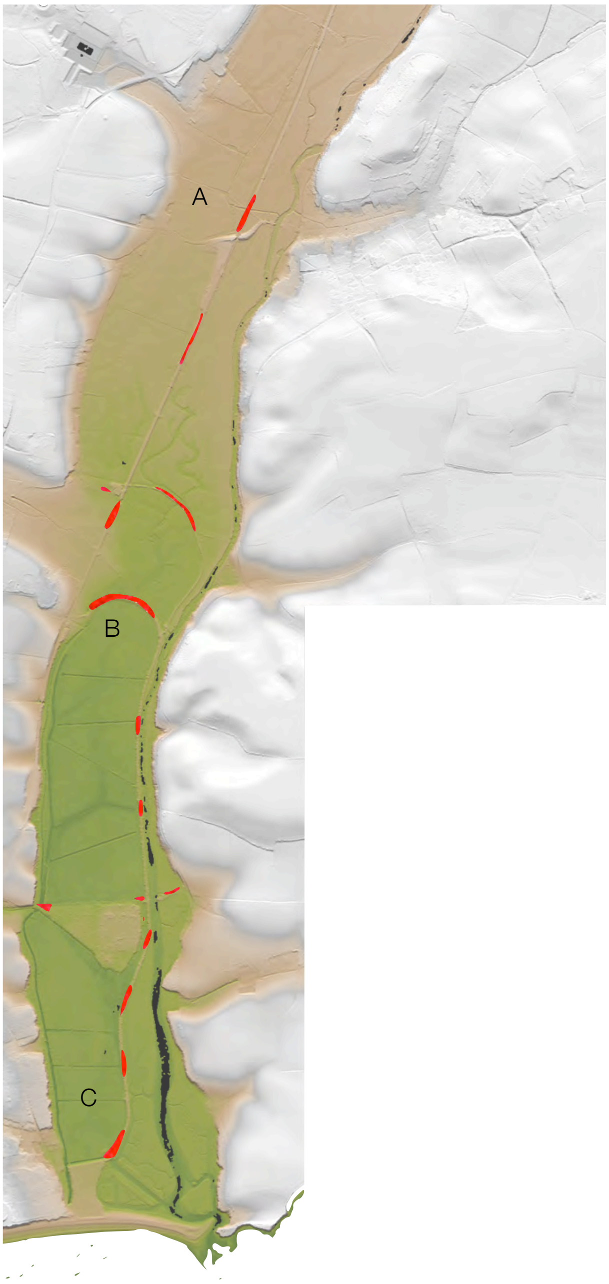


In order to simulate the impact of renaturalising the floodplain for fluvial flooding (namely Policy Unit 1, Environment Agency CFMP, 2008) we have modelled the strategic removal of flood impounding features at critical locations. Figure 15 shows the locations in red where the digital terrain model has been modified to remove features and return land levels to local elevations. Key features lowered or removed would be sections of the railway embankment, sections of Little and Big Bank, sections of the Otter embankment locally to Big Marsh (northern and southern compartment) and finally sections of the embankment locally to the estuary. The aim of this simulation is to explore if any significant benefit can be generated from upstream areas, namely Otterton and land locally to Little Marsh.

Figure 15: Option X, the removal of key land features to enable the free flow of fluvial floodwater through the Lower Otter Valley.



The result of removing key land features is summarised below (figure 16 a-d). The main observation is that the removal of the railway embankment in the upper sections does result in the movement of more water to the western side of the floodplain with the result that there is an increase in flood conveyance in this upper section. At point A in figure 15 (left) the effect is the lowering of water surfaces by 9cm locally to Otterton.

But the effect of removing Little and Big Bank is to draw water faster into these sections and result in greater depths of water in this section because the River Otter channel is not being used effectively with the flow concentrated on the western side of the floodplain. As a result at point B (figure 15, left) the water depth increases by 20cm.

In the lower section of Big Marsh at the Cricket Ground, breaches in the flood embankment, assuming no tide, would assist with lowering the flood depths in this area (point C, figure 15) by 52cm, but water depths would still exceed 2.31m at peak flows. The main problem is that with the marsh land level at 2.2m and the relic floodplain at 0.8-1.0m, once Big Marsh is flooded it would not dewater, without excavation of a large creek through the current estuary. In this simulation, tidal influences have not been assessed, but obviously the holes in the embankments would result in tidal ingress into Big Marsh on most tidal cycles.

Figure 16 a-d: Key time slices of the modelled water depth for a 69 cumec fluvial flood passing through the modified Lower Otter Valley based on LisfloodM-MPI output. Key embankments have been lowered in the simulation to represent renaturalisation of the floodplain for fluvial flooding.

Figure 16d

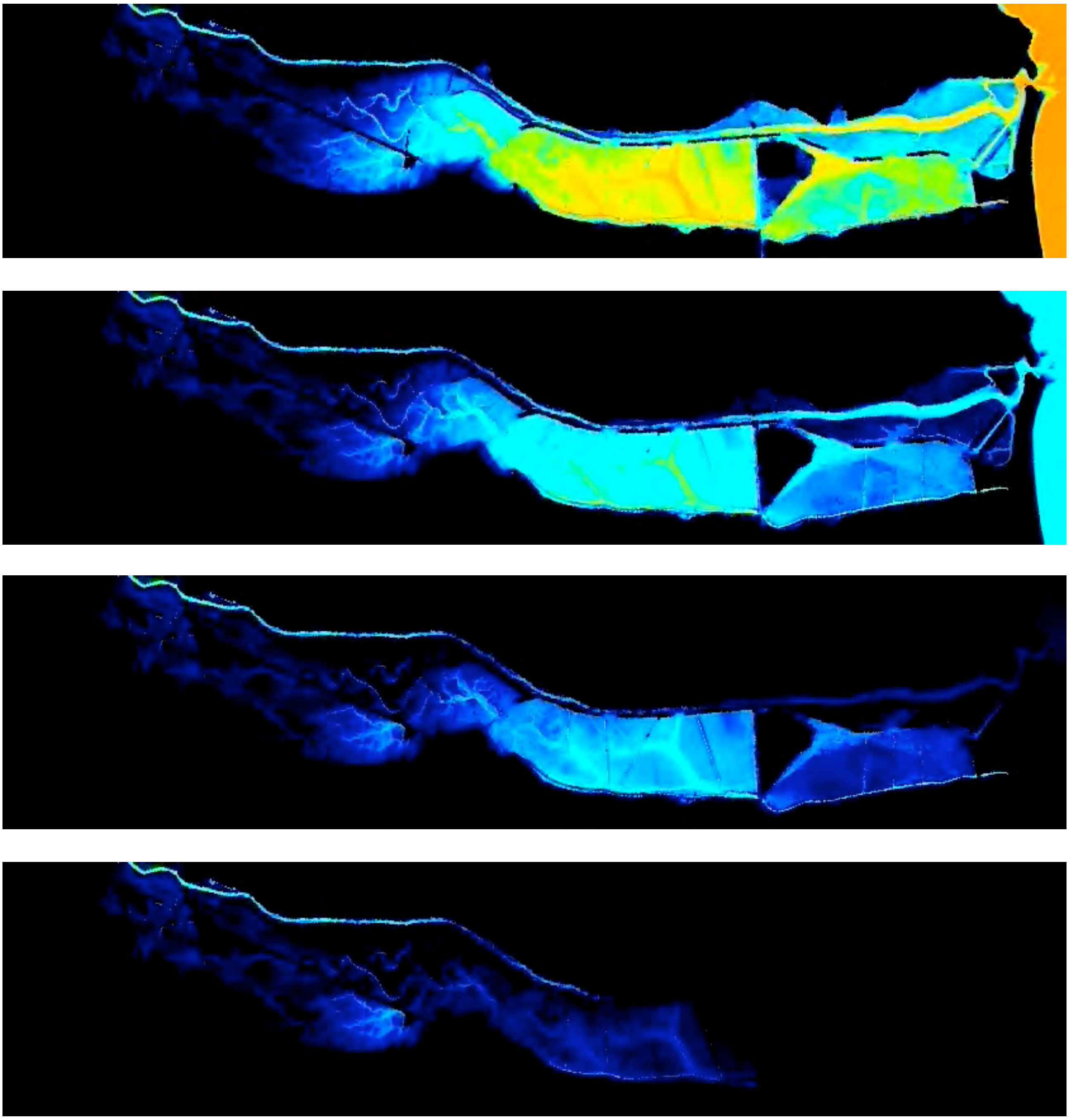


Figure 16a

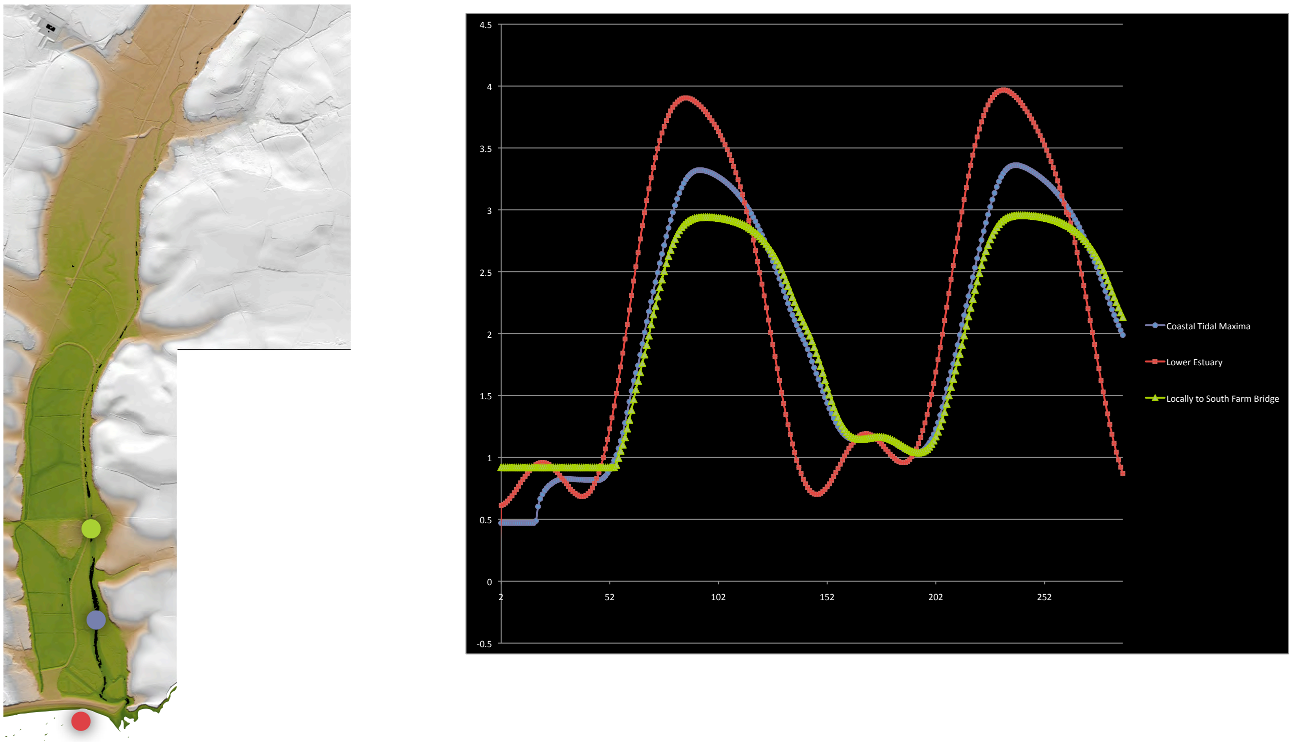
Flood Dynamics - Tidal

Two basic simulations have been undertaken to examine the tidal inundation dynamics of the Lower Otter Estuary. Firstly a normal tidal cycle, neap tide, has been modelled and these dynamic water levels applied offshore to the pebble bar to simulate the tidal flux into the estuary. The second simulation explores the impact of the highest recorded tidal levels and the extent of flooding resulting from these levels, based on the data generated by BODC Weymouth.

In figure 18, the extent of the mean low neap tide is presented, which extends up the estuary towards White Bridge and the South Farm Road. At peak height, water floods the lower salt marsh and mud flats in the estuary, but not the upper salt marsh (figure 19). The model therefore agrees with the flood frequency at which the salt marsh habitats naturally occur.

In figure 17 (below) the effect of the pebble bar's restriction on even the maximum tide is apparent, with water levels offshore some 1m higher than the levels propagated upstream to White Bridge. Rear-Admiral Bullock's comments of 1853 seem correct, namely that the bar has restricted tidal inflow and scour. This combined with a reduced estuary area, as a result of the embankment, possibly accounts for the accumulation of sediment in the estuary since embankment in 1812.

Figure 17: Plot of tidal water levels for a maximum tide at three locations: offshore (red), within the estuary (blue), and locally to White Bridge (green).



In the second analysis, maximum recorded tidal levels for both peak tide and maximum low tides is simulated and the extent of flooding shown in figure 20 and 21. In figure 20, the peak tide reaches a level higher than the current embankment, especially at a point on the Big Bank, just downstream of the refuse site. Once tidal water inundates the Big Marsh it rapidly fills the embanked compartment, as is shown in figure 20. Once the tide subsides, and assuming that the embankments are still remaining, then a large volume of salt water is retained within the embanked compartment and will only dewater through the culverts locally to the Cricket Club figure 21. As discussed in the fluvial flood section of the report, some 1.4 million cubic metres of water will be retained on the site and will take between 5 and 21 days to dewater, depending on the performance of the culverted sea discharges.

Figure 18: Extent of tidal inundation in mean low neap tide

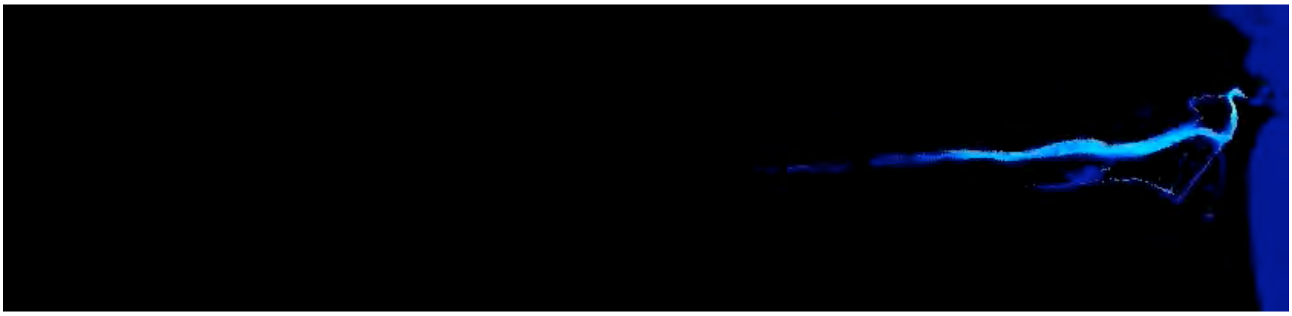


Figure 19: Extent of tidal inundation in mean high neap tide

Figure 20: Extent of maximum tidal inundation based on highest recorded level at BODC Weymouth sea level gauge

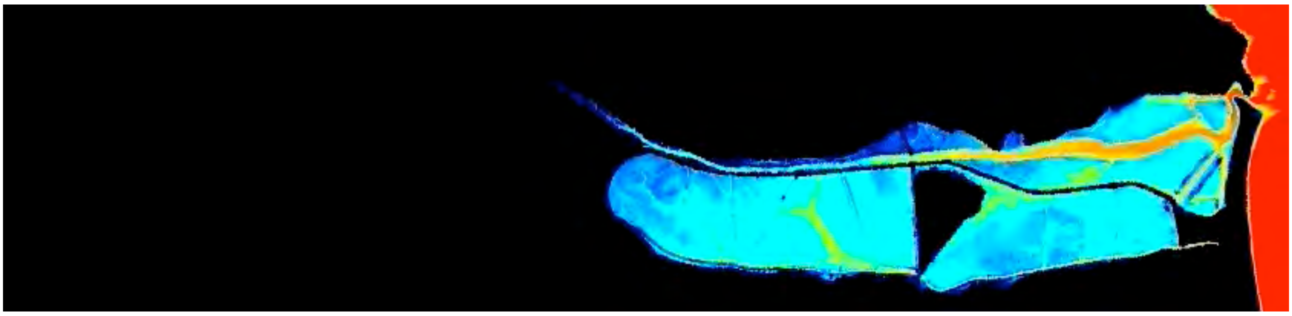
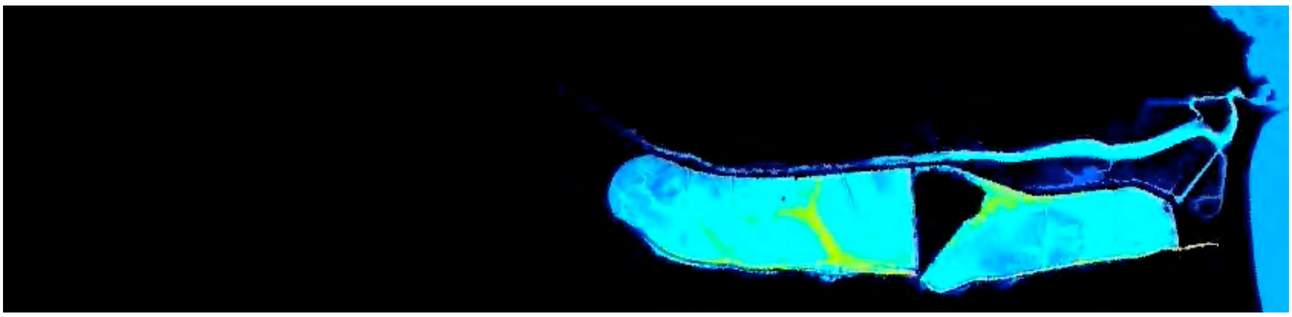


Figure 21: Extent of tidal inundation following maximum tide and after the estuary has dewatered to maximum low tide, based on BODC data.



As with the fluvial simulation, we have exposed the model to maximum tides with the strategic removal of embankments that impair the fluvial flooding of the site. In figure 22, the extent of saline flooding into the embanked compartment is extensive and extends beyond Little Embankment.

Figure 22: Extent of tidal inundation following a maximum tidal flood (BODC data) assuming that embankments have been strategically removed (Option X) as per the fluvial simulations discussed earlier in the report.

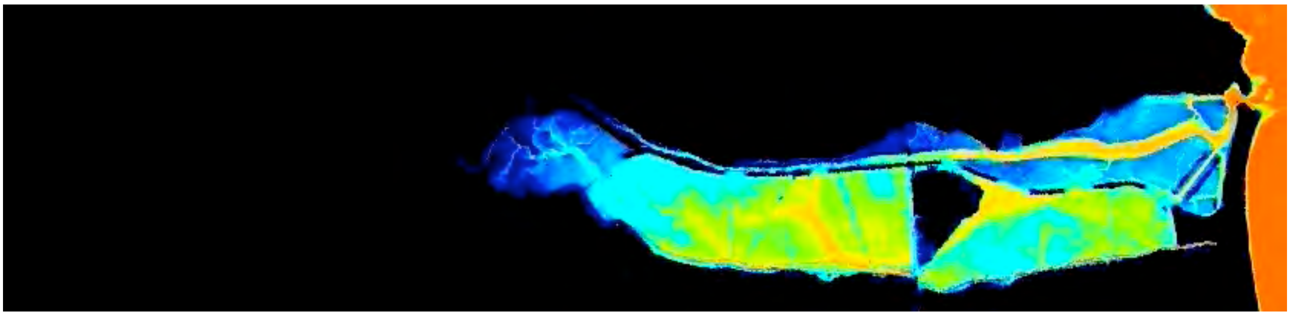
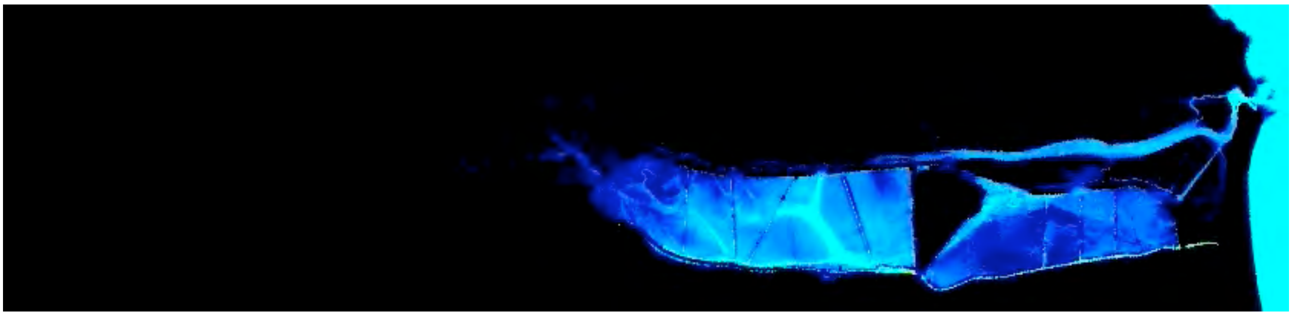


Figure 23: Extent of tidal flood water with the retreat of the tide and extent of trapped water on the Otter floodplain.



Once the maximum tide retreats, even with the key embankments removed, the embanked compartment still retains extensive areas of saline water (figure 23), since the ability of the low lying land to drain freely to the estuary is impaired by the height of the current estuary.

Figure 24 shows a cross section through Big Marsh, locally to the Cricket club. The impact of the accumulated sediments in the estuary will result in the impoundment of 1.0m of salt water on the embanked compartment, resulting in a shallow lagoon or mudflats. It is interesting to note that the sediments in the estuary have accumulated since 1812, therefore equate to 4mm per year of net vertical accumulation.

If over time the tidal ingress resulted in creeks forming through the current estuary marsh, then the majority of the embanked compartment, if not lagoon, would essentially be mudflats, and most of Big and Little Marsh would revert to saline habitat. This would result in a landscape familiar to Leland who visited the area in 1539-1540 and reported Otterton being 1 mile from the sea, with 100 acres of grazing marshland. Figure 25 shows the extent of upper mudflats based on the elevation this habitat forms in the current estuary.

It should be noted, although not illustrated, that the velocity of flow through the peddle bar with the larger volume of tidal inflow and outflow, does result in significantly higher velocities and one would therefore expect erosion of the bar and of the current estuary. This would follow the pattern experienced at recent tidal retreat projects, where the existing estuary is eroded and sediment re-deposited within the previously embanked area. The erosion of the current estuary would result in more extensive creek systems and a higher ratio of mudflat to saltmarsh.

Figure 24: Cross section of land levels from the Cricket Club (0 km on x-axis) through the embankment and into the Otter estuary.

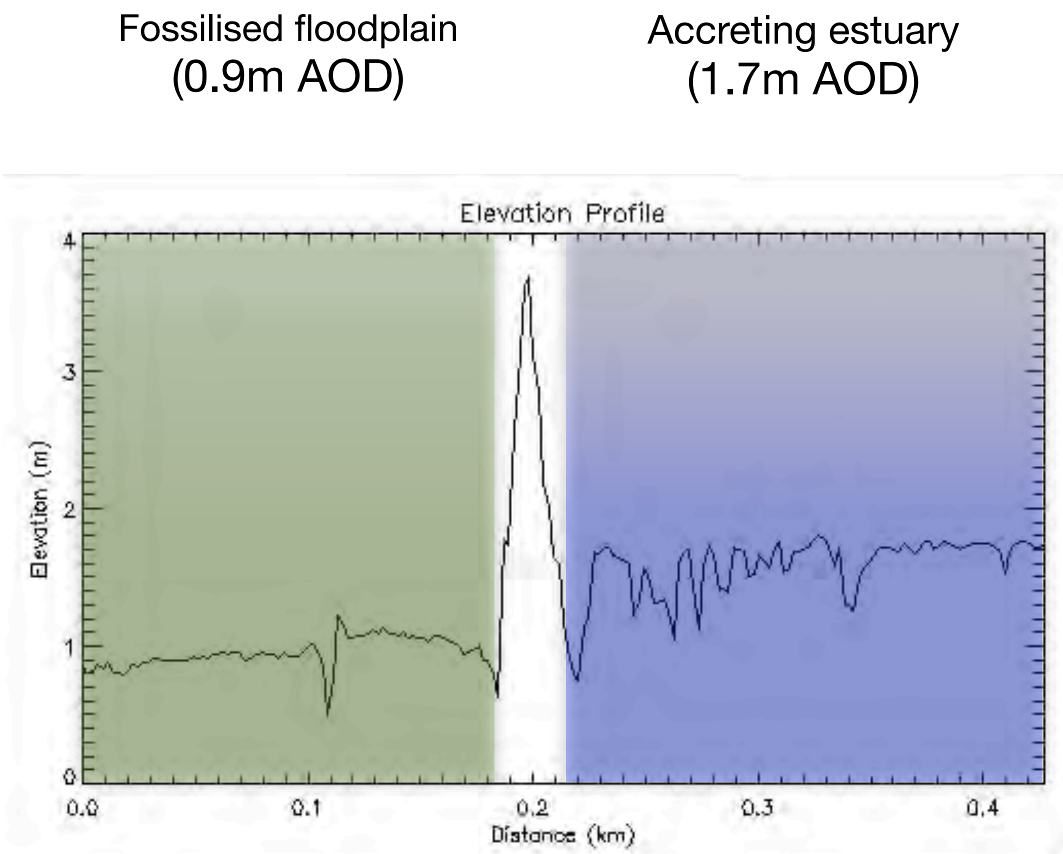


Figure 25: Cross section of land levels from the Cricket Club (0 km on x-axis) through the embankment and into the Otter estuary.

Flood Dynamics - Drainage

In this report we have not modelled the flood dynamics from the failure of the sea outfalls, but note that Howick and Partners report their estimations on the capacity of the culverted sea outfalls.

The current invert of the drains is -1.6m AOD and they are consistently submerged. This, combined with the frequent blockage of the sea outfall due to sand and pebbles, results in frequent requests, especially in the summer months, for clearance of the outfall.

Howick have prepared a scheme to extend the sea outfall to beyond the current shingle beech in order to reduce the sediment blockage of the pipe. But the elevation relative to current tidal range still results in significant hydrostatic blockage of the pipe's flow.

In relation to the Environment Agency culverted discharge to the estuary behind the Cricket Club, the elevation of this structure is below the estuary land level and without frequent dredging of the estuary to the sea, this culvert does not afford any normal drainage to the embanked compartments. Once the compartments are flooded, this pipe affords additional discharge to the sea, but only dewatering once floods have reach 300-400mm depth in the compartment.

The current poor performance of these structures, due to sediment accumulation in the estuary and within the pebble beech is working against normal drainage.

Predicted Sea Level and Flood Regime

The predicted sea level rise for the South West's, southern coastline, has recently been reviewed by the Environment Agency, in order to plan the investment in coastal defenses. The "Devon Tidal Flood Zone, ABD and Flood Risk Area Improvements, April 2008" report lays out sea level rise estimates and are summarised in table 4 (below).

Table 4: Recommended Contingency Allowances for Net Sea Level Rise (Devon Tidal Flood Zone, ABD and Flood Risk Area Improvements, April 2008, table 13.2).

Period	Assumptions	Net sea level rise (mm)
2002-2025	23 years at 3.5 mm / year	80.5
2025-2055	30 years at 8.0 mm / year	240.0
	net sea level rise to 2055	**321.0**
2055-2085	30 years at 11.5 mm / year	345
2085-2115	30 years at 14.5 mm / year	435
	net sea level rise to 2115	**1101.0**

A potential rise in mean sea levels of 1.1m by 2115 (just over 100 years) will result in substantial changes in the tidal flood risk to the Lower Otter. This would equate to the maximum recorded tidal levels occurring annually, as opposed to every 75 years. The volume of salt water entering the estuary would increase, associated scour of the pebble bar would increase, and overtopping of the current embankment frequent. In addition to the above figures, it is not clear if they also account for changes in surge tide elevations, which is typically expected to result in an increase in the amplitude of the tide of about 10%.

In relation to changes in the fluvial flood regime, current estimates suggest that we can expect a 20-30% increase in peak flow. This would result in the mean annual flood (Q2) increasing from 70.45 cumecs to 91.6 cumecs. Additional changes in land use may accelerate runoff and have in some part of England led to estimates that if land use changes over the last 40 years continue for the next 100 years that we could expect a 90% increase in mean annual flows when combined with climatic change and the associated more intense storms. That would equate to the mean annual flow going from 70.45 cumecs to 133.9 cumecs, close to the figures we currently quote as the 1:100 year flood on the River Otter. Given that it has been estimated that the current embanked compartment floods with flows greater than 40 cumecs, any change in the frequency of large flood runoff volumes, will result in more frequent and persistent flooding.

Conclusions Arising from the Simulation Flood Models.
Based on the review of the drainage, fluvial flood and tidal flood dynamics of the Lower Otter Valley, there seem to be systemic issues arising from the embankment of the Lower Otter in 1812. Since this period, the geomorphology of the estuary has been fundamentally changed with sediment accumulating in this area, resulting in a fossilization of land levels behind the embankments. The normal drainage of the embanked compartment possibly worked very well when installed, but rising sea levels, sedimentation of the beach and changes in the circulation of the sediment on the bar have degraded the drainage of the current marsh. Furthermore, since 1812, the Otter flood waters have been pressurised down the embanked channel. This combined with the construction of the railway line, has forced flows into discrete sections of the floodplain, resulting in major erosion and sediment features forming along the Otter. The designation of the Otter and Estuary for conservation reasons and the resulting lack of traditional channel maintenance, that is required on an embanked channel, is resulting in even mean annual floods not being able to pass effectively down the channel.

The contemporary flooding of the embanked compartments, due to hydraulic degradation of the Otter channel, changes to catchment runoff regime and siltation of the estuary, appear to be more frequent, and BSCC data suggest a total of 21 flood incidents in 50 years.

The future flood regime is likely to be more frequent, both from continued poor drainage of the site, higher runoff to the River Otter and with higher mean sea levels. The current agricultural regime within the embanked land, which has shifted from arable to grassland and to grazing marsh appears to be becoming wetter, and will continue to drain poorly and flood more frequently. Key assets at South Farm Road, and access to this farm and associated businesses is likely to become worse, with prolonged periods of no access, apart from tractor access over farmland to the north. The frequency of flooding to the Cricket Ground is currently frequent and likely to increase. The lack of dewatering capacity adds to the duration of standing floodwater, but changes to sea level are likely to make this situation worse.

Long Term Options for Drainage and Flood Management

In developing the options below, we have sought to either review individual options for specific locations and issues or combine these with larger visions for the embanked compartments. The challenge is to provide technically viable options that work with the frequency of flooding from the terrestrial catchments and the potential tidal inundation. Key to the Clinton Devon Estates is the future of key assets, namely access to South Farm, Otterton Mill and the future of farming operations in Big and Little Marsh and the impact on the wider farming landscape if radical changes occur in the embanked areas. The future of the Cricket Ground, on land leased from Clinton Devon Estates, is a key issue. These issues are merged with a range of conservation designations, and conservation agreements, World Heritage Site designations and geology designations (GNRs and RIGGs).

In reviewing options, we have sought to comment on the technical viability, but not look extensively at the conservation implications. We have sought to look at the sustainability of the hydrology and hydraulics and whether the option will weather the predicted changes in sea levels and climate.

The options are the basis for discussion with the Clinton Devon Estates and the wider community, and at this stage no option is preferred or pre-selected. The options will be discussed by the Clinton Devon Estates with a variety of stakeholders to further define the issues and implications of the options. From this process the wider implications, to valley economics and conservation interests will be explored, with the help of statutory agencies, in order to determine the viability of pursuing elements of these options.

Option A - Cricket Ground Bund

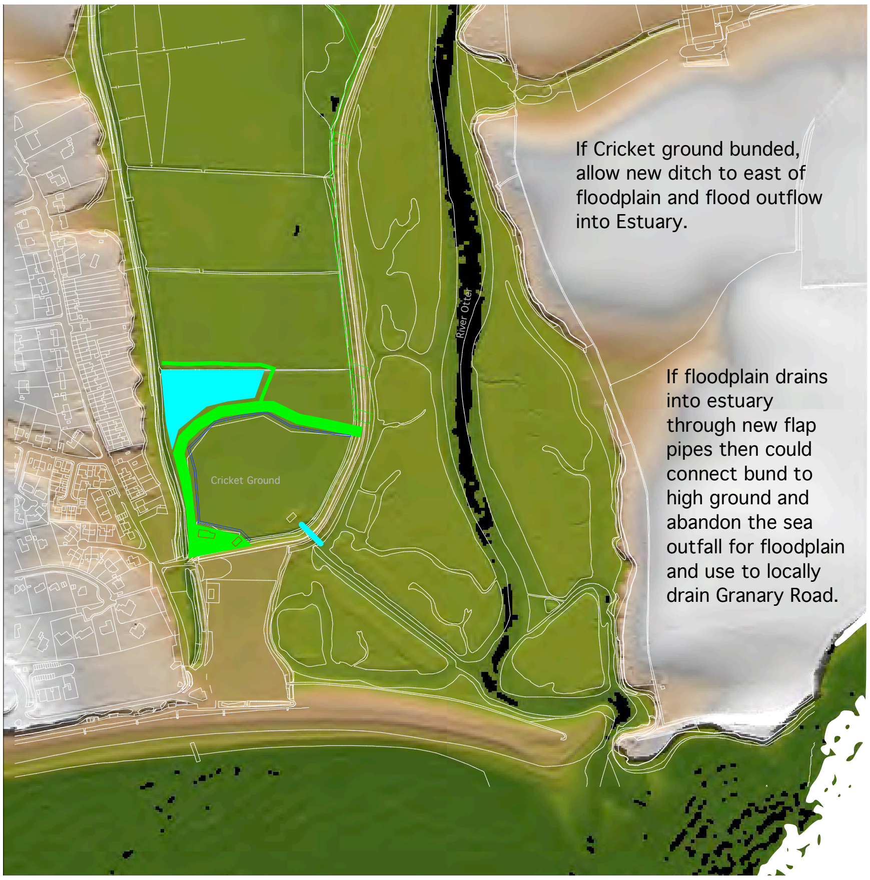
Option A - Bund Cricket Ground

Bund at 3.5-4.0m, borrow pit created, which also act as buffer storage for drainage in times of high tide.

Inner ditch to drain compartment.

Pumped discharge to estuary by adoption EA pipe and flap value.

Club house and buildings based on new bund, base level at 3.1m and critical infrastructure at +4.0m due to saline flood risk.



The location of the cricket ground, behind Big Bank, and lying at 0.8-1.0m AOD makes it one of the lowest lying cricket grounds in England. Frequent flooding is making this unique position difficult to sustain. The option for this site, if it is to remain in its historic location, is to bund the ground independently of the main compartment and ensure it is not dependent on the sea outfall at the Lime Kiln, south of the grounds. The drainage of the site would be enhanced, with an inner ring drain, which would be pumped to the Environment Agency sea outfall (marked in light blue in option figure). The current sea outfall would be modified to house a pump and also enable any fluvial flood water and or tidal water that entered the smaller compartment to be gravity drained. With the loss of the EA sea outfall to assist with drainage of Big Marsh, additional outfalls would be required to the north of the ground, to enable the gravity dewatering of Big Marsh into the estuary.

The bund could be created from floodplain material, as was done in 1812, and a borrow pit created north of the grounds. The existing Big Marsh would drain through the Lime Kiln culvert, and the borrow pit would act as a balancing pond to assist with drainage of Big Marsh. The pond would dewater at low tides, assuming that the sea outfall is not blocked.

In time, current buildings for the ground would be placed on a widened bund. The banking of the bund could be landscaped to favour spectators. The width of the bund would be wide enough to ensure vehicles could park on the feature or traffic to the north west corner and park within the compartment or to the field to the north, when county matches occur.

If it was required, the Lime Kiln culvert could only drain Granary Lane, Budleigh Salterton, and upgrade the flood protection of residents locally to Cricket Ground. Big Marsh could be drained into the estuary, but only with the construction and maintenance of a new creek system into the current low channel. The option would negate the need to upgrade the Lime Kiln sea outfall, although instead of extending it, it maybe preferable to convert the outfall into a soak-away by installing large boulders at the outfall to enable water to dissipate into the pebble bar.

This option would reduce drainage flood risk to the ground, isolate it from the fluvial flooding of Big Marsh, as long at the bund is higher than the current embankment, and remove the site from tidal flood risk, albeit for a period of less than 50 years based on the Environment Agency data. This option would require invasive works within the estuary to ensure the free drainage of the pumped drainage and also to ensure the free drainage of modified Big Marsh drains, which could be directed to the estuary if required. This could have conservation implications for the current SAC / SSSI.

Option B - Relocation of Cricket Ground

Option B - Move Cricket Ground

Move cricket ground to former land fill area, raise ground level from 2.8-3.1 to 3.5-3.8m. Spoil created by dredging the Otter floodplain locally to Bridge.
Maintain tree perimeter.

In reviewing the operation of the current cricket ground, an option is to change the location of the club, but keep it in the Otter Valley, which is a symbol of the club. In the flood model work, the former refuse site, which closed in 1950, did not flood under a mean annual flood, and in terms of elevation is estimated with be at >1:200 year flood level in relation to tidal limits. The current footprint of the ground fits into the current poplar plantation on the site with room for buildings and car parks to the north and west of the current location. The site would need to be raised to 3.5-3.8m elevation, if not higher, with buildings being placed at 4.4-4.8m invert level. The ground would have an elevated view of the estuary and the southern portion of Big Marsh. The material to fill the site is related in part to option C and D.

The removal of the ground from the floodplain would enable options for Big Marsh to be more strategic and less impaired by the need to accommodate the drainage and protection of the ground. The conservation value of the refuse site is unknown, but has been planted with poplar and pine since its abandonment in the 1950's.

This option is dependent on flood proofing South Farm Road and ensuring suitable means of evacuation of the ground in the event of a major fluvial or tidal flood.

Figure 26: Image of the poplar plantation on the eastern portion of the refuse site, as viewed in October 2009.

Option C - South Farm Road

Independently of option A and B, the issue of ensuring safe passage to South Farm and associated business and buildings, is of key concern to the Estate. An option, is to move the current road south and take advantage of the higher land levels within the refuse grounds.

In the event of fluvial flooding, the conveyance of flood water from the northern section of Big Marsh to the southern section of Big Marsh could be achieved by installing culverts under the road, to the western end of South Farm Road. The material to raise the road could be won from moving the embankment, east of the current refuse site, and aligning westwards. This would increase the hydraulic capacity downstream of the bridge and this section of the estuary.

Supporting this option would be desire to install additional flood culverts west of White Bridge to assist with the dewatering of the northern section of Big Marsh. The aim being to increase the overall dewatering capacity of the embanked compartments, and introduce fluvial flow into the upper estuary to ensure better fluvial flushing of this portion of the estuary.

To the east of White Bridge, it is recommended that the road is elevated to 3.1m on a causeway to allow floodwater to pass through this section of the relic floodplain. This option is independent to options mentioned above.

Figure 27: Annotated sketch of road route through refuse site and key drainage culverts for drainage of the northern section of big marsh. Option C

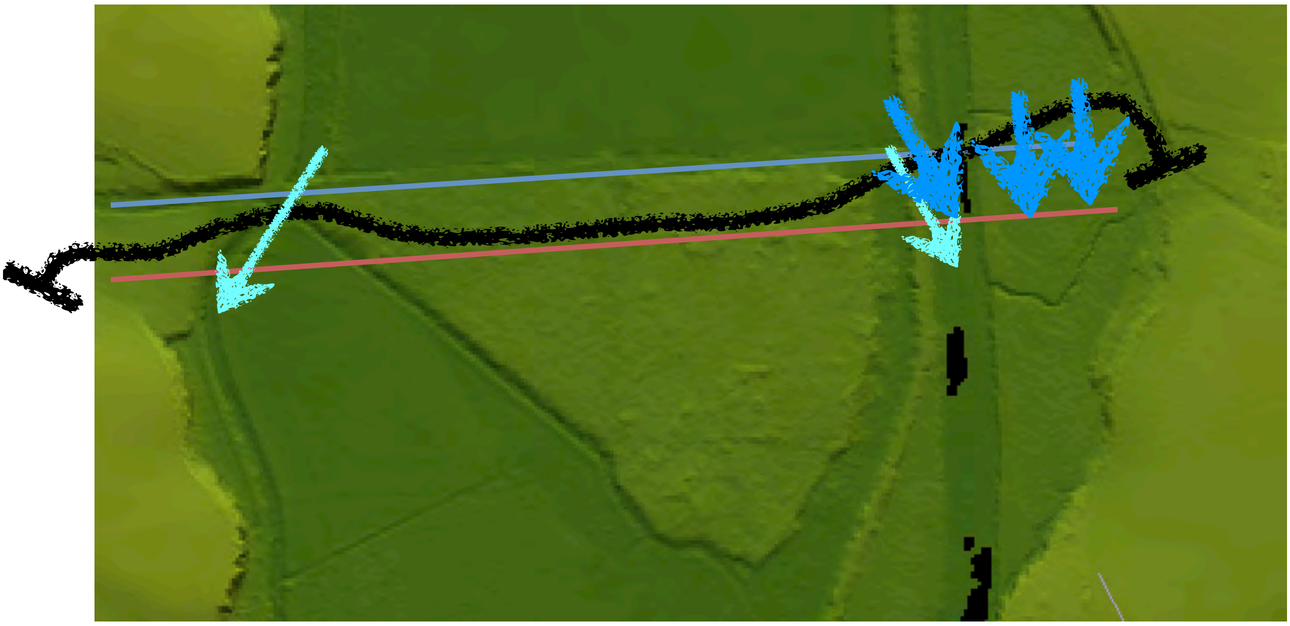
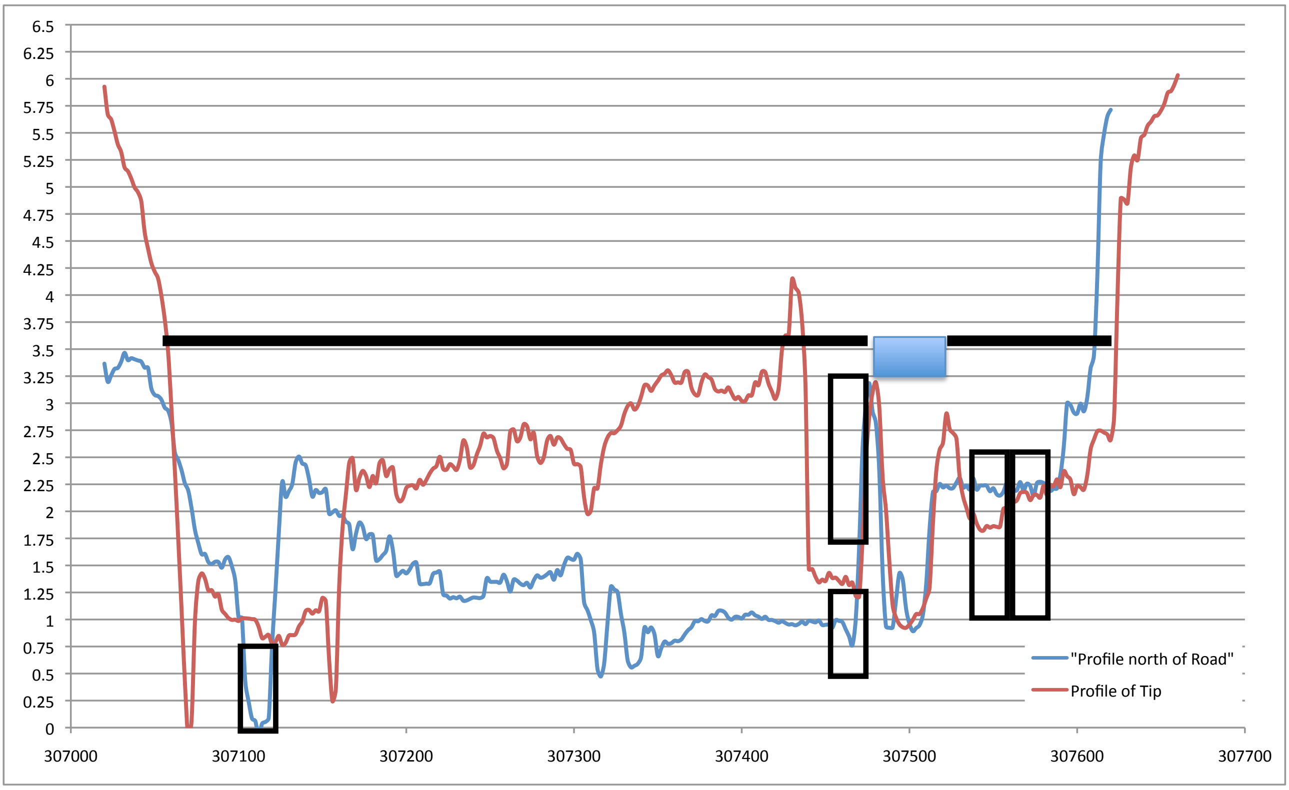


Figure 28: Cross section through refuse area using LiDAR data at 1m resolution. Option C



Option D - River Otter floodplain at White Bridge.

Option D - Otter floodplain

Lower floodplain to restore conveyance locally to bridge and floodplain flood return flow. No dredging of river and its bed - salmonoid and WFD restrictions. Spoil used to raise tip site for recreation use / car park and road causeway. High quality soil and organic material taken to thin soil locations and incorporated into field soils.

The build up of floodplain land levels locally to South Farm Road bridge is restricting the flow for the upstream section of the channelised River Otter. This section of floodplain should be functional channel to enable the enhanced flow through the Otter upstream. The suggestion is to lower land levels in this section (green boundary), possibly linked to option B and C. The excess material could be moved to the refuse site to raise land levels for the cricket ground (option B) or road levels (option C). Any surplus material could be used to furnish the thinned arable soils on South Farm.

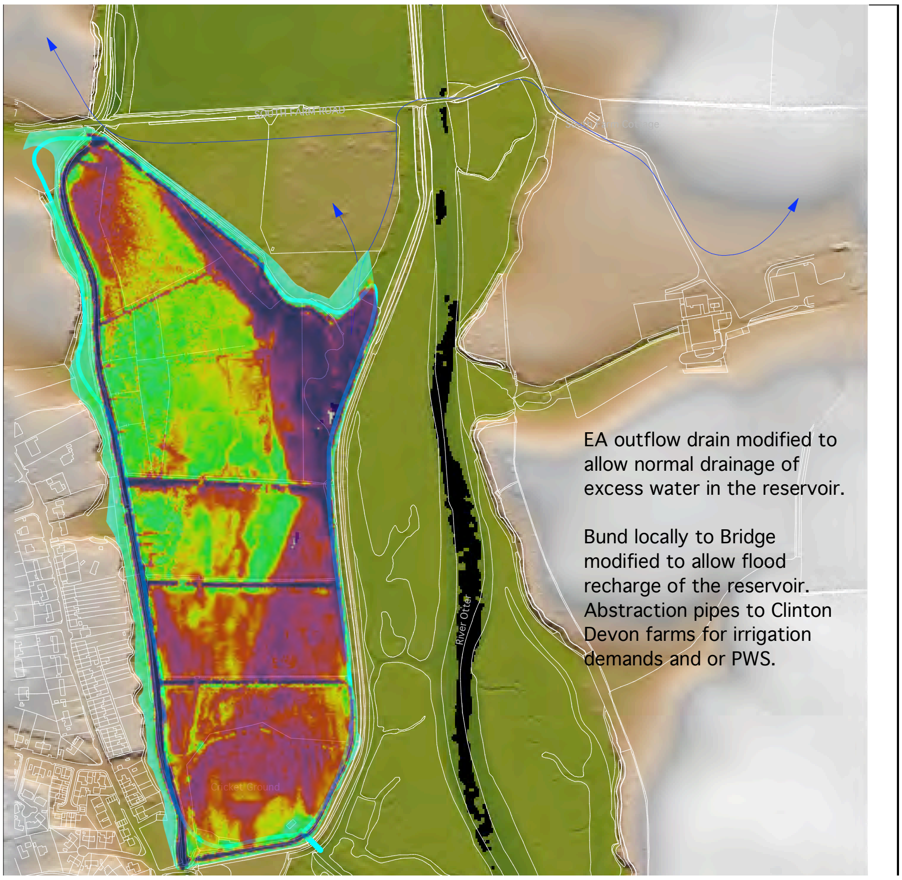
The benefit of this option is linked to enhancements of the overall channel conveyance of the Otter upstream of this location and increasing the volume of flood water through this section, reducing the frequency of flood water entering the floodplain upstream and into Little Marsh.

The conservation implications of this option would have to be addressed. The aim is not to clear the main channel or undertake works in the the main channel but to regenerate the floodplain flood capacity of this critical section of the Otter as its flow transitions into the Estuary.

Option E - Southern Big Marsh (linked to option B, C and D).

Option E - Freshwater Reservoir (linked to B and C)

If the Valley road is designed to separate the floodplain compartments and limit salt water ingress to the middle/upper compartments, then options for lower floodplain are open. Volume could be used to store winter flood water and use for irrigation / agricultural / leisure purposes if water stored at 2.5m. Alternatively revert to lower saltmarsh and mud flats. Dominant landscape is bank breached would be saline lagoon.



If the cricket ground is moved to the former refuse site, South Farm Road is elevated and the drainage of the houses in Budleigh Salterton are independently drained through the Lime Kiln culvert, then options for the southern portion of Big Marsh are opened.

Associated with this assumption is that without an upgrade to the Lime Kiln culvert and preventing this from blocking with pebbles, then the continued drainage of this site is not possible and it will be increasingly flooded with changes to sea level.

Allowing the site to become wetter with freshwater, will require the continued functioning of the Lime Kiln culvert, and in the short term this maybe possible, but the site will increasingly fail to meet conservation objectives, even for reedbed.

Allowing tidal ingress into the site is an option, if it is effectively sealed from the northern section of Big Marsh, which the upgrade to South Farm Road could effectively achieve. But the resulting site will be lagoon or mudflats.

An additional option is the capture and storage of freshwater within the embanked area and the formation of a freshwater lake. The long term geomorphological aim of this option is to allow the site to function as a freshwater lake in the short term, but sedimentation of silt and organic material will accumulate to a level contiguous with the estuarine land levels and in a number of decades enable the site to revert to lower and upper salt marsh.

In the short term, the lake could act as a freshwater reservoir for the Estate and farms, supporting the agricultural economy by providing a reservoir of 484000 m-cu of water for water dependent crops.

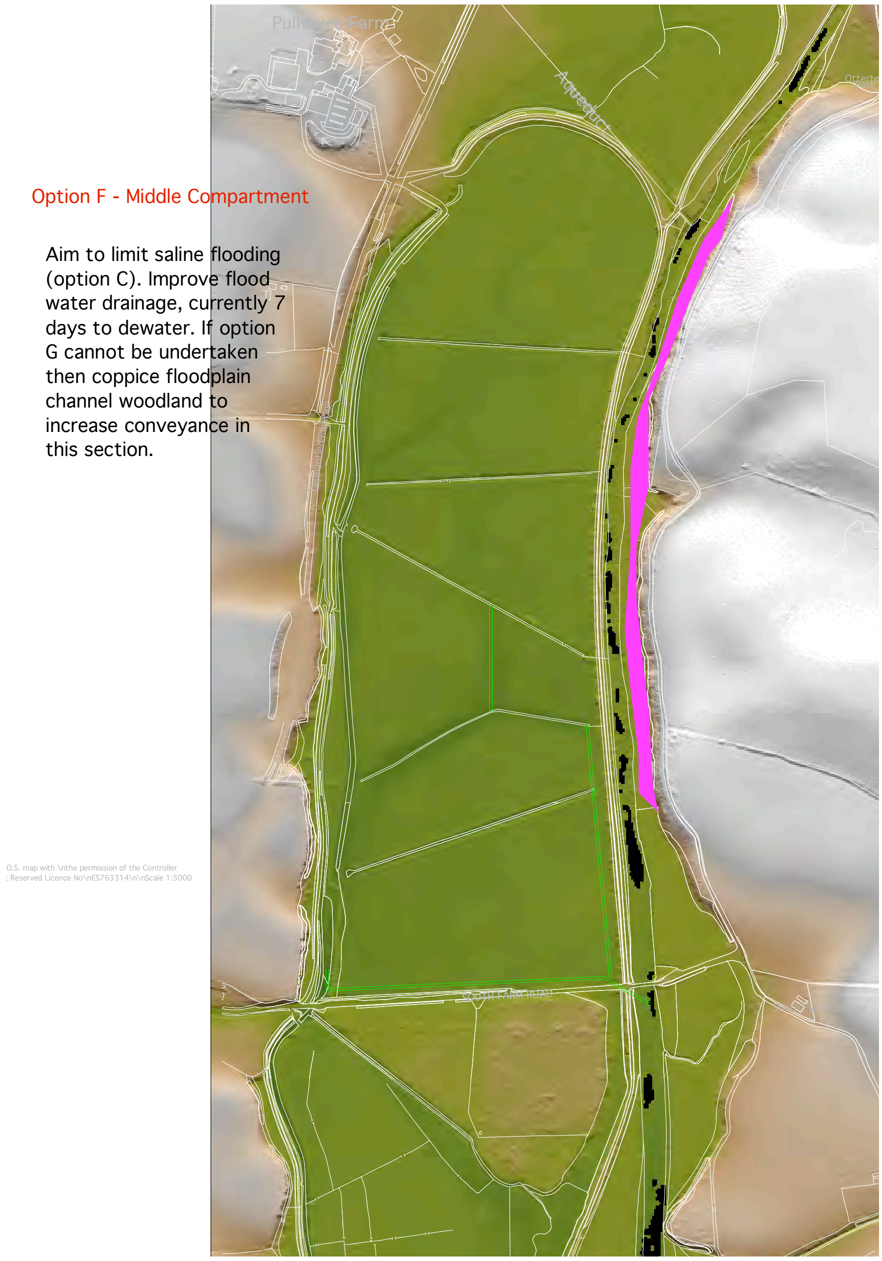
Equally the lake could support sailing with a mean water depth of 2.2m (max. 3.4m). The sailing could combine facilities with the relocated Cricket Ground.

Haycock

Once the lake has silted up to the desired level then land could be reverted to salt marsh, without exposing the current SAC to excessive erosion which would occur if the current bunds were breached and large tidal volumes sought to fill the resultant void.

This pattern could be repeated for the northern section of Big Marsh and Little Marsh over many decades, with the freshwater reservoir migrating up valley and former reservoirs reverting to marshland.

Option F - Northern Big Marsh



Option F is linked to option E, namely to provide independent drainage of the northern section of Big Marsh if the southern section is to be hydraulically isolated. In option F, the inner drainage of the compartment is to be redirected to outfall into the estuary locally to South Farm Road bridge. This option is also linked to option C, namely raising the lane to avoid disruption as a result of flooding.

The drainage to the south eastern corner would also be associated with an enhance culvert to assist with the dewatering of the site in when inundated with the River Otter flood water. The purple shaded area is linked to option G. The observations of the behaviour of the river in this section are that the accumulated scrub vegetation on the relic floodplain to the east of the river is hydraulically restricting flow and pushing the thalweg of the river to the embankment. This fast flowing water is undercutting sections of the embankment, which has visibly thinned in key sections. The management of this vegetation needs to be reviewed, in combination with option D. If option D and option K (below) are not viable, then thinning and management of the relic floodplain in this section will need to be considered in order to simply maintain the capacity to transfer the mean annual flow (Q2, 70.45 cumecs).

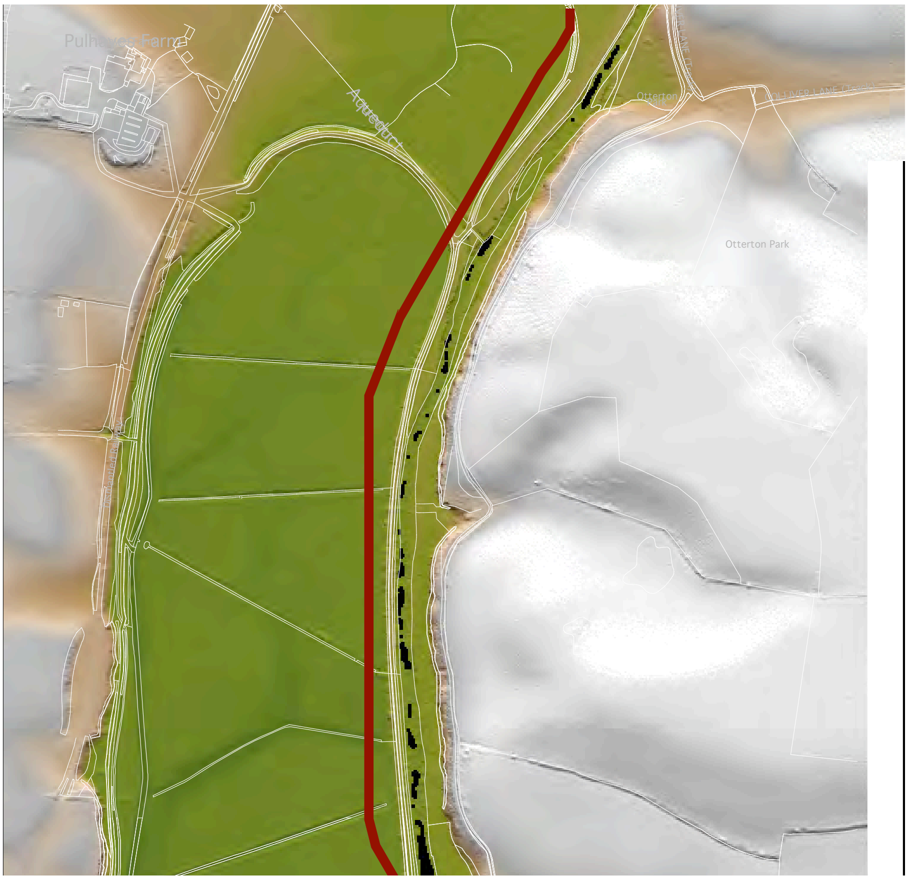
Haycock

The conservation implications of managing this section of the river are very acute, with access to the river challenging and the overall impact on the current fisheries ecology very sensitive as this section represents the normal limit of freshwater within the River Otter. High tides will influence the flow in this section, but normally this limit ends locally to White Bridge.

Option K - River Otter Big Bank Reach

Option K - Part floodplain restoration

If existing channel cannot be maintained and coppiced, then hydraulics compromised and frequent flooplain inundation will occur. If channel hydraulics to be dominated by woodland, then estimated 85m corridor required to route flood water through this section.



If option F, namely the restoration of normal flood conveyance in this section of the river, cannot be pursued, and the conservation aspiration is to maintain a woodland corridor, then an option is to set-back the current embankment to create an 85m wide corridor. The 85m wide corridor has been calculated so that even when wooded, with high hydraulic resistance, that a 1:10 year flood will pass through the corridor. This will reduce the flood frequency into LIttle Marsh and the northern section of Big Marsh. The option would allow for some limited geomorphological adjustment of the River Otter in this section, abeit within a narrower floodplain corridor, but wider that the current embanked regime.

Option G - Little Bank and Swale

Option G - Upper Compartment

Aim to direct flood flow back to River Otter and avoid frequent overtopping of bunds. Relic channel connected to river via ditch. Key section of Otter river bank lowered to enable flood flow to transition into leated section.

Option G is linked to option D, namely the functional restoration of channel hydraulics locally to South Farm Road. In this option, the aim is to improve the conveyance of small floods back to the River Otter and avoid the excessive accumulation of flood water ponding locally to Little Bank. The aim is to create a swale upstream of Little Bank, and connect this to the Otter locally to where Budleigh Brook enters the Otter. The land levels where Little Bank runs parallel to the Otter would be lowered to enable water to sweep into the Otter (figure 29). In constructing the swale, with a base width of approximately 10m, the excavated material would be laid back onto Little Bank to strengthen the feature, but not raise the crest levels.

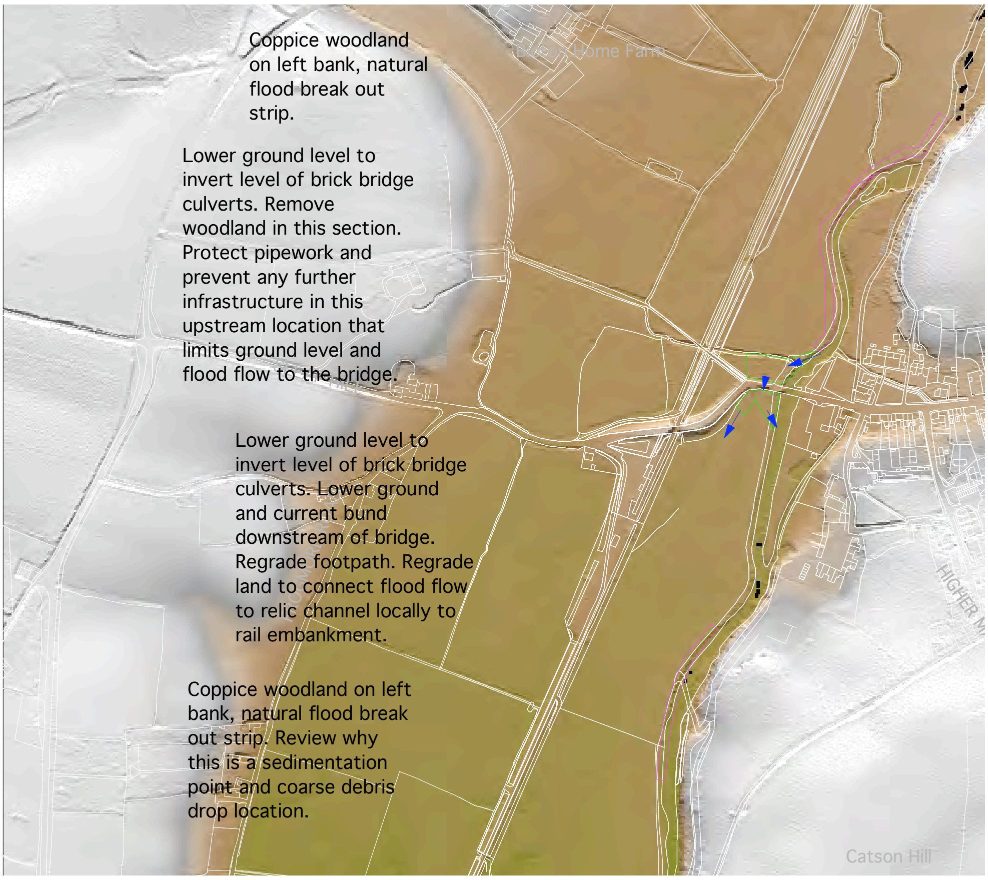
This option will allow the free passage of flood water away from Otterton, and the Mill plus associated highway. The option assumes an increase in the conveyance of the Otter downstream of these proposed works, namely option D and or option F and K.

Figure 29: Image of Little Bank where it runs parallel to River Otter. This land level is proposed to be lowered in option G.

Option H - Otterton Mill and Otterton Bridge

Option H - Otterton Mill Section

Aim to increase conveyance locally to bridge and push flood water onto the floodplain.



Option H represents an independent option, and is not critically reliant on any of the downstream options, although the implementation of option G would be preferable.

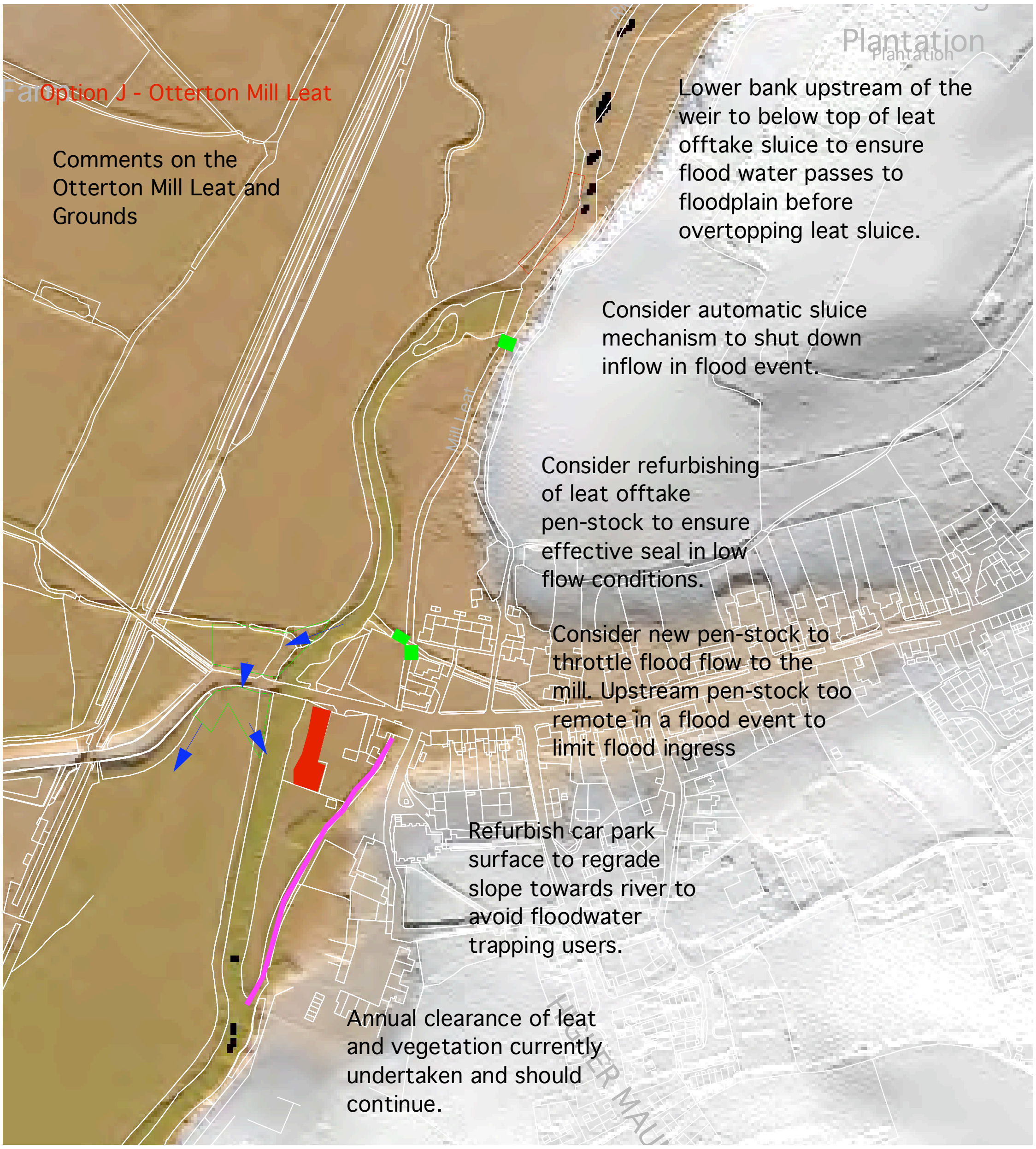
Using the flood simulation data, it is apparent that floodwater is seeking to break westwards and away from the leat mill channels both upstream and downstream of the Mill. The first element of this option is therefore to work with this reality and ensure that bank levels are lowered in key sections, and trees thinned and natural breaks in hedges widened. This is especially critical downstream of the Mill, where new fence and hedges on the right bank are interfering with overtopping flood routes (purple marked areas). Upstream of the Mill, similar treatment of the bank is required to enable flood water to move west and then be directed to the culverts under the main road.

The culverts under the main road need extensive groundwork upstream and downstream in order to lower ground levels to optimise the conveyance of these structures and reduce the build up of water. Critically the land levels downstream of the culvert need to be lowered by over 1.2m to allow return flow to the Otter and also to feed water more effectively into the Otter floodplain (figure 30).

It is not proposed at this stage to reduce the land levels of the railway line, either upstream of Otterton or downstream, since the flood dynamics upstream of Otterton is unclear and how much water is passing down the western side of the floodplain. We have been informed that approximately 30% of major flood event waters will pass via this route.

Figure 30: Image of the Otterton road culvert to the west of the current bridge and sediment accumlation in the culvert and land levels 1.2m higher on downstream face.

Option J - Otterton Mill Leat, Weir and Sluices.



Option J builds on option H and represents detailed adjustments to the options of the leats to reduce flood surges into the housing locally to the Milll and the the Mill complex itself. The key issue to reduce River Otter flood water building up, is the implementation of option G and H, and if undertaken then additional management of the leat could be undertaken to further protect this section of Otterton.

Assuming that the land levels locally to the culverts west of the Bridge are regraded, then upstream of the leat weir and its fish pass, it is suggested that land levels are lowered to enable flood water to pass westwards and start discharging onto the floodplain before the leat sluice gates are submerged.

The leat sluice gates are difficult to access in a flood period, and it is suggested that this simple penstock, which consists of a single large plate, is replaced with an automatic mechanism that can be closed by the mill when flood water levels build up. This option is aimed at reducing debris and sediment ingress into the leat and mill structure.

A second modification would be to upgrade the penstocks that allow the leat channel to be dewatered and maintained, which is located 100m upstream of the the mill. This complicated structure has an overshoot aqueduct taking runoff from the Village which discharges into the Otter, plus a penstock to dewater the leat and throttle flow into the Mill. The proposal is to upgrade this to enable it to also be remotely controlled to dewater to the Otter and assist in redirecting flood water away from the Mill and associated buildings.

It should be noted that currently the normal base flow is predominantly directed into the leat since the main weir was dry when viewed. The remaining flow passes down the fish pass, but also a major portion of flow passes under the weir and is visibly boiling up below the foundations of the structure. We would point out that is not in the best interests of this structure, composed of hydraulic lime concrete, to be dry and allowed to dry for prolonged periods. The weir leakage needs to be addressed, and also the flow through the leat and fish pass better adjusted to ensure that the weir is wet (figure 31).

Figure 31: Image of Otterton Mill main weir, located upstream of the Mill. As viewed in October 2009.

Summary of Options - Table 5

Options title	Description	Aim of option
Option A	Isolation bund for Cricket Ground with independent drainage.	This option seeks to remove the cricket ground from the effective floodplain and free up options for Big Marsh to operate its drainage independently of the Cricket Ground. Some improvement in the operation of the sea outfall at Lime Kiln maybe possible by providing a balancing pond.
Option B	Moving the Cricket Ground to high ground, but within the Otter Valley.	This option seeks to remove the cricket ground from the effective floodplain and free up options for Big Marsh to operate its drainage independently of the Cricket Ground. Relocation does not compromise other options and frees up Big Marsh.
Option C	Elevation of South Farm Road and upgrade of culverts.	This options seeks to ensure access to South Farm and associated businesses by moving the current road south onto high land. Option would work with option B and also is linked to other options below. Changes to the road level do not compromise future options of Big Marsh.
Option D	Restoration of hydraulic function of River Otter locally to White Bridge.	The embanked River Otter currently restricts flood flow, even for minor floods. This option aims to remove a strategic throttle, and minimise works on other sections of the river. This option supports option B and C, which require additional material to deliver raised land levels. Option supports reduced flood risk to Big and Little Marsh.
Option E	Long term retreat of the southern Big Marsh.	The aim is to create a large freshwater reservoir, allow this to function as a water resource for the farming and recreation. Over time the feature will silt, and when silt levels match estuarine land levels, allow site to retreated to marsh without excessive erosion risk to the existing SAC.
Option F	Northern Big Marsh - Drainage Improvements	If option E developed, and or option C, then regrade drainage of the northern section of Big Marsh eastwards and increase flood dewatering capacity. Review hydraulics of River Otter channel to reduce overtopping flood risk in this section, and erosion of Big Bank.
Option K	Migrate Big Bank westwards.	If vegetation management not possible within the currently embanked corridor, then migrate big bank west to create a 85 m wide river corridor to allow floods to pass through this section, even if corridor is fully wooded. High frequency of flooding of Big and Little Marsh linked to high roughness of this key section of the embanked channel.
Option G	Little Bank Swale	Aim of this option is to redirect floodplain flow back to the River Otter embanked section more effectively and reduce overtopping of Little Bank. Option linked to either option D, F and K.
Option H	Local improvements to River Otter at Otterton.	This option seeks to allow floodwater to pass to the west and into the floodplain. The aggressive groundworks local to the current culvert are sought to effectively use this asset. Tree removal at key sections, plus land level lowering is required.
Option J	Otter Mill Leat	Proposed upgrade of mill leat and associated sluices to enable floodwater to be throttled and redirected into floodplain. Linked to option H and G.

Overview and recommendations

In reviewing the current hydrology, hydraulics and landscape operations within the Lower Otter, it is apparent that the impact of poor drainage and flooding is becoming worse and more damaging to the economics of the Estate and users of the landscape. The poor performance of the sea outfalls, the reduced hydraulic capacity of the River Otter, and the siltation of the estuary since 1812 are all conspiring to increase the flood frequency of a number of assets, most visibly at South Farm Road and the Cricket Club.

The future performance of drainage will become increasingly challenging, with increased fluvial runoff and higher tides, plus the aggressive sedimentation of the sea outfall, both at the Lime Kiln and also within the estuary.

The Estate could simply allow this situation to become progressively worse, farming of the floodplain to become less viable, conservation management more demanding and recreational access more difficult. At some point, either due to fluvial flooding or tidal flooding the current embankments, which are nearly 200 year old, will fail and the resulting impact will be extensive loss of terrestrial land and access to South Farm and its businesses.

In reviewing the hydrology, hydraulic and geomorphological processes, it is proposed that there may be a series of options to phase the retreat of agriculture from the marshes in some locations, upgrade the functioning of assets in other locations, and enhance the life of some of the embanked lands through small modifications of the current land levels and linkages of river to its floodplain. The options in combination will allow the long term retreat of agriculture from the marshes, but allow the controlled formation of designated habitats without recklessly endangering the current designed areas.

The options, either in combination or independently have not been subject to detailed flood modelling in the same detail as the current environment, simply because the options raise numerous challenges in terms of the long term management of the Lower Otter, its commercial use and as an Area of Outstanding Natural Beauty. The next stage of this process is to review the options with key stakeholders and develop ideas and options with the Clinton Devon Estates to determine the way forward, and the financing of any major structural adjustments to the site. The aspiration of the Estate is to create an exemplary project, that builds on the unique history of ownership and use of this valley, and ensures it has a viable future for the Estate and the wider community.

Key Documentation

(documents not listed in order of importance).

1. Historical Guide to The Lower Otter Valley, OVA, 1993
2. River Otter Fluvial Audit, February 2004, Environment Agency and GeoData, Southampton University.
3. Photo archive of Otterton Mill, copyright Mr and Mrs Spiller, Otterton Mill, 2009.
4. NERC / BODC tidal data for Weymouth, copyright BODC and Proudman Laboratories.
5. Geomorphological Assessment of the River Otter, Devon, December 2003, Environment Agency
6. Devon Flood Hydrology Strategy Study Volume 1: Main Report, January 2007, Environment Agency
7. Devon Tidal Flood Zone and Flood Risk Area Improvements: Flood Zone Review, Environment Agency, June 2007
8. BUDLEIGH SALTERTON TRUNK DRAIN SURVEY, Howick and Partners, Clinton Devon Estates, 2001
9. East Devon Catchment Flood Management Plan, August 2008, Environment Agency.
10. East Devon Flood Hydrology Strategy Study, *unknown data*, Environment Agency (key figures and tables from report).
11. Dotton Flow Gauge Data, 1962-2009, Environment Agency.
12. Aerial Photographs of October 2008 Ottery St Mary Floods and Lower Otter Floods, Environment Agency.
13. Devon Tidal Flood Zone, ABD and Flood Risk Area Improvements : Project Report, April 2008 (Appendix A-H), Environment Agency
14. Flood Reconnaissance Reports for October and November 2002, October 2008, Environment Agency.
15. Historic Flood Outlines for 10th July 1968, Environment Agency.
16. Historic Flood Outlines for 12th November 2002, Environment Agency.
17. Historic Flood Outlines for 30th October 2008, Environment Agency.
18. Lyme Bay and South Devon Coastline Group, Shoreline Management Plan, June 1998.
19. Shoreline Management Plan SMP2, Durlston Head to Rame Head, Draft Baseline Processes Understanding, October 2008. South Devon and Dorset Coastal Authorities Group (SDADCCAG).
20. Environment Agency Asset and Structure Maps for Lower Otter, Generated December 2009.
21. River Otter Corridor Survey, October 1990, produced by Eclogue for the National Rivers Authority.
22. Water Authority, South West, Annotated Maps of the July 1968 Floods and Images of Damage to the Lower Otter, from Environment Agency Archive, secured December 2009.

Appendix A: Long section through the Lime Kiln Culvert (Howick and Partners, 2001).