NERC Environmental Risk to Infrastructure Innovation Programme (ERIIP)

Coastal Landfill and Shoreline Management: Implications for Coastal Adaptation Infrastructure

Case Study: **Wicor Cams**

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This report was produced by the University of Southampton Waste Management Research Group and Energy and Climate Change Group as part of a study for the “Coastal landfill and shoreline management: implications for coastal adaptation infrastructure” project. This was funded by the Natural Environment Research Council (NERC: NE/N012909/1) as part of the Environmental Risks to Infrastructure Innovation Programme.

Suggested citation: R.P. Beaven, R.J. Nicholls, I.D. Haigh, A.S. Kebede, J. Watts, A. Stringfellow, 2018. Coastal Landfill and Shoreline Management: Implications for Coastal Adaptation Infrastructure —Wicor Cams Case Study. Report for Natural Environment Research Council. 39pp.

Cover photograph, courtesy of Anne Stringfellow, University of Southampton. View of sea defence wall at Wicor Cams (August, 2018).

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Abbreviations

aOD	above Ordnance Datum
AONB	Area of outstanding natural beauty
ATL	Advance the line
EA	Environment Agency
HSLR	High sea level rise
HTL	Hold the (existing defence) line
H++	Extreme high (H++) sea level rise
LSLR	Low sea level rise
LS	Liquid-solid ratio
NAI	No active intervention
MHWS	Mean high water springs
MR	Managed realignment
MSL	Mean sea level
MSLR	Medium sea level rise
ODN	Ordnance Datum Newlyn (defined as the MSL at Newlyn in Cornwall between 1915 and 1921)
SMP	Shoreline Management Plan
SAC	Special Areas of Conservation
SPA	Special Protected Areas
SSSI	Site of special scientific interest

1. Introduction

This case study contributes to a project "Coastal landfill and shoreline management: implications for coastal adaptation infrastructure" funded by the Natural Environment Research Council (NERC) as part of the Environmental Risks to Infrastructure Innovation Programme.

The project aimed to improve understanding of the long-term management of coastal landfills on dynamic coasts and assess different management approaches to the problems that such sites pose. In the UK, there are approximately 2000 (mostly historic) landfills in England and Wales which are located in coastal flood plains and/or erosion zones. Flooding of landfills could lead to flushing of contaminants from the waste, and erosion may potentially release the waste into the marine environment. This is likely to increase in future due to sea level rise. In some less developed parts of the coastline, shoreline management plans (SMPs) seek to allow natural physical processes such as erosion to progress. Where landfills are present however, the shoreline is usually defended to protect the environment and people from hazards that may be released if the landfill is flooded or subject to erosion.

Coastal landfills therefore need to be protected, but this may be at odds with SMPs which may recommend "managed realignment" or "no active intervention" in less developed areas where there is a move towards allowing coasts to be more dynamic. The presence of coastal landfills in such areas may dictate a "hold the line" plan to defend the landfill against flooding and erosion due to sea level rise. However, many of these landfills are the responsibility of local authorities who do not have a budget to address these problems.

The project estimated the long-term impact of coastal processes affected by sea level rise on three selected landfills and investigated different management options to prevent pollution, including removing the waste material or protecting the sites. The outputs from the three case studies have given the project partners a better understanding of the impacts these landfills have on shoreline management plan strategic options (hold the line, managed realignment, and no active intervention) under different climate change scenarios. The three landfills selected are located on the south coast of England: (1) Lyme Regis, Dorset, (University of Southampton, 2018a), (2) Wicor Cams near Fareham, Hampshire, and (3) Pennington near Lymington, Hampshire (University of Southampton, 2018b).

2. Background

2.1 Study Area: Wicor Cams

The study site Wicor Cams (also known as Fareham Lake) is located within Fareham district in Southeast England, lying near Cams Bay at north-west Portsmouth Harbour in the East Solent. The site lies in a low-lying/estuarine environment, with the land mainly used for recreation, including the Cams Hall Golf Course behind the Fareham Creek Trail and the sports playing field at the Wicor Recreation Ground. These facilities lie on or near remnants of the old landfills of "Cams Bay Tip", "Birdwood Grove Tip" and "Land near Wicor Hard", respectively. The coastal fringe at Cams/Wicor forms a discrete area of open landscape with an eroding frontage, with parts of the low-lying area at Cams Bay containing intertidal mudflats and saltmarshes. The surrounding shoreline (including in front of the landfill sites) is of national, European and international conservation interest, and is designated as a SSSI, SPA, and listed as a Ramsar site[1] (FBC 2006). Figure 1 shows the geographic location of the study region and the historic landfill sites described in section 4, together with distributions of the designated areas of nature reserve in the region.

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[1] SSSI: Sites of Special Scientific Interest; SPA: Special Protected Areas; and Ramsar: Wetland of International Importance.

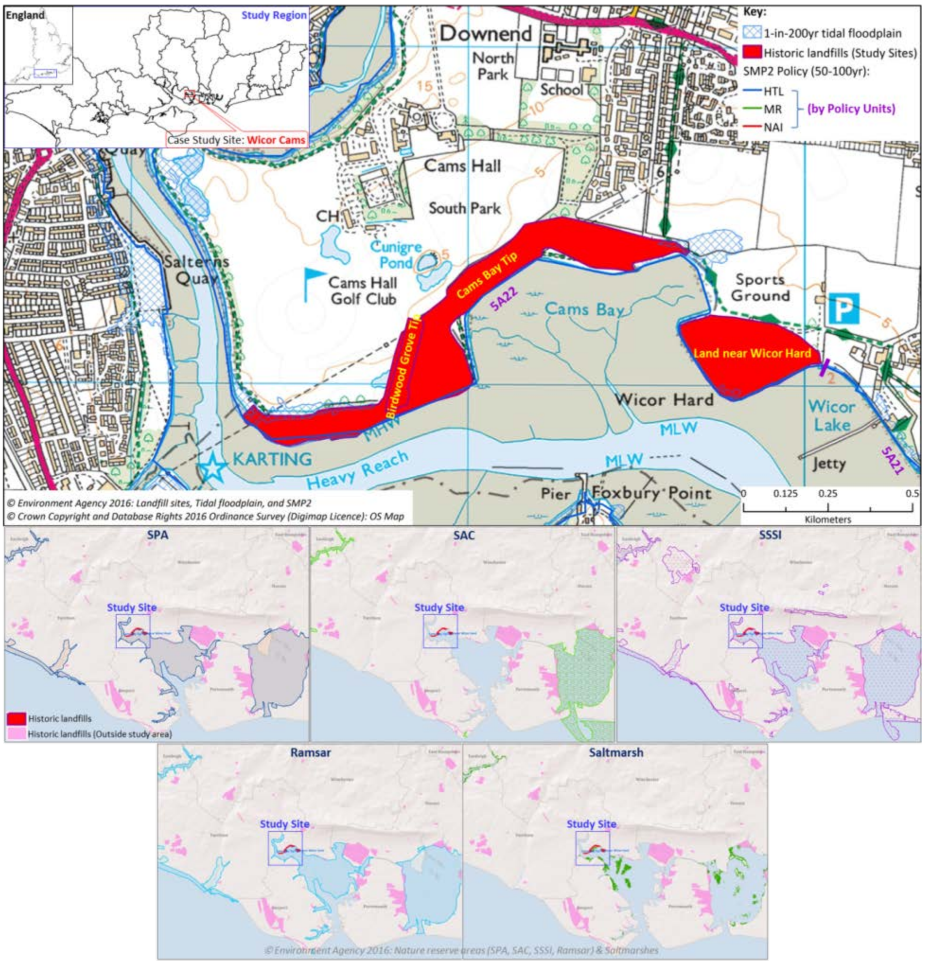

Figure 1: Geographic location of the study site near Cams Bay (1:10,000) and nature conservation areas (1:75,000).

2.2 Shoreline management plans

A SMP[2] provides descriptions of the management measures most likely to be preferred options for managing a stretch of coastline from the threats of coastal flooding and risks of erosion in the short, medium, and long-term (Nicholls et al, 2013). It is a high-level, non-statutory policy document that provides guidance aiming to balance risks of coastal flooding and erosion with natural processes and the potential implications of future climate change. It aims to determine appropriate shoreline management policies (over three time periods/epochs: short-, medium-, and long-term) that are technically, economically, and environmentally sustainable at a particular area/region. The choice of a preferred policy options for a particular area (i.e., stretch of coastline) takes into account the natural and built environments, existing sea defences, as well as associated compatibility with

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[2] SMPs divide the shoreline into a series of cells/sub-cells, policy development zones, management areas, and policy Units. In the SMP2 policy, there are a total of 22 cells and related SMPs for the shoreline of England and Wales (i.e., classified based on coastal type and natural processes such as beach and seabed sediment movements within and between them) (see Burgess et al., 2004; Nicholls et al., 2013). These larger sediment-based plans/divisions are then sub-divided into nearly 2000 policy units, which represent detailed classification of the stretch of coastline along England and Wales.

adjacent coastal areas. There are four different SMP policy options that can be implemented for a particular stretch of coastline. These are listed below as defined by the Environment Agency[3]:

(1) Hold the (existing defence) line (HTL): "An aspiration to build or remain artificial defences so that the position of the shoreline remains. Sometimes the type or method of defence may change to achieve this result",

(2) Advance the line (ATL): "New defences are built on the seaward side",

(3) Managed realignment (MR): "Allowing the shoreline to move naturally, but managing the process to direct it in certain areas. This is usually done in low-lying areas, but may occasionally apply to cliffs", and

(4) No active intervention (NAI): "There is no planned investment in defending against flooding or erosion, whether or not an artificial defence has existed previously".

Figure 1 shows the proposed short, medium, and long-term shoreline management plan (SMP) policies for the two policy units at the study region (units 5A22 and 5A21). The SMP for the policy unit representing the coastal stretch fronting the landfill sites (i.e., between Cador Drive and A27) is to hold the existing defence line (HTL) for all the three epochs (NFDC, 2010). However, the medium-term and long-term SMP policies for the 5A22 policy unit also identified additional "requirements for more detailed study (for management of site to be determined following contaminated land investigations)". The "River Hamble to Portchester Coastal Flood and Erosion Risk Management Strategy" (ESCP, 2016) developed for the shoreline management zone which includes policy unit 5A22, states that the preferred option is to sustain or protect the landfill sites and maximising the life of existing defences. From 2030, the aim would be to sustain defences with a minimum 1:100 year (1% annual chance) standard of protection. The report noted that environmental improvement of currently undefended potentially contaminated land should be planned and new funding would need to be found to implement remediation or protection of the landfill sites. However, Flood and Coastal Risk Management (FCERM) funding is not provided on the basis of protecting the environment, and there are a only a small number of properties in the vicinity of the study site. Thus there are no clear funding avenues to allow authorities to up hold the preferred HTL policy at this site.

3. Method

3.1 Literature and site visit

The Environment Agency's (EA) landfill database[4] ["What's In Your Backyard?" (WIYBY) website] was consulted to investigate the history and ownership of the landfill sites at Wicor Cams. Literature searches were carried out to find information relevant to the landfill sites and to shoreline management plans for this area. A site visit was carried out on 11 August 2017 to examine the frontage to Cams Bay and Wicor Lake from the shoreline, together with a walk over of the sports ground and the footpath adjacent to the Cams Hall golf course.

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[3] See: http://apps.environment-agency.gov.uk/wiyby/134834.aspx

[4] The Environment Agency "What's in your backyard" map service is now closed. Further information about access to data regarding historic landfill sites is available from http://apps.environment-agency.gov.uk/wiyby/37829.aspx

3.2 Coastal erosion study

The analysis of potential coastal erosion and flooding used publicly available data as well as values and observations in published literature. Geographical models have been created using ArcGIS software. Descriptions of the data used, its application in these analyses, and relevant sources/citations are provided in Table 1.

The exposure of the site to potential flooding under different still water level scenarios was assessed using a simple bath-tub flood analysis. In the bathtub method, areas which lie below the current and projected still water levels will be flooded if they are hydraulically connected to the source of flooding. The topographic data (LiDAR DEM) was re-classified in ArcGIS to indicate the areas with an elevation below the still water levels predicted for each time-slice under low, medium, high and extreme high (H++) sea level rise predictions. These were then assessed for hydraulic connectivity and edited accordingly to remove any areas which were incorrectly classified.

Landfill site cross-section profiles are extracted from the LiDAR DEM. Each profile extends into the estuary starting from 20 m landward of the landfill sites (the extent of which was determined using the combined Environment Agency and East Solent Coastal Partnership datasets on the landfill). The profiles were then compared to both MHWS and a 1-in-200 year extreme water level (current, 2050 and 2100) under low, high and H ++ sea level rise predictions.

Erosion was assessed using the EA predictions for the short, medium and long term, and compared to evidence from Ordnance Survey mapping over the last 100 years together with topographic profiles of the landfill site and fronting beach taken between 2007 and 2011. The “at risk” areas of erosion and potential timescales for erosion are discussed. To further assess the potential for the release of waste from the landfill site over time, a lower and higher rate of erosion are calculated.

Table 1: Data Description and usage for Wicor Cams study site

Data Description	Usage	Source/Citation
Environment Agency Historic Landfill data (last revised: 3/10/2015). Polygon data set that defines the location of, and provides specific attributes for, historic (closed) landfill sites.	Visualisation of the EA recognized area of landfill. Calculation of the area and volume of eroded waste (both historic and future).	Environment Agency, downloaded from data.gov.uk. Environment Agency (2015).
East Solent Coastal Partnership historic landfill data: Polygon data set defining what they recognize as the location of the landfill site.	Visualisation of the ESCP recognized area of landfill. Calculation of the area and volume of eroded waster (both historic and future)	Provided by East Solent Coastal Partnership. East Solent Coastal Partnership
Digital Elevation Model (DEM) consisting of multiple LiDAR tiles with a 2m resolution mosaicked in to a single dataset. Collected in 2014.	Flood zone maps using the 'bath tub' or still water level method. Extraction of topographic profiles to compare to still water level scenarios.	Environment Agency, 2014.
Topographic profiles at a number of locations along the length of the landfill site from 2007, 2008, 2010 and 2011.	Analysis of erosion at the site.	Channel Coastal Observatory, downloaded from channelcoast.org Channel Coastal Observatory (2007, 2008, 2010, 2011)
Recession Predictions of anticipated recession at the site for the short, medium and long term.	Visualisation of the potential area of recession possible over the three epochs. Calculation of potential eroded area and volume of waste in the future over time.	Environment Agency
Sea level Rise Scenarios extracted from UKCIP09 projections for low, medium, high and extreme high (H++) sea level rise by the year 2050 and 2100 under low, medium and high sea level rise. Extreme Sea levels	Examination of the impact of sea level rise on future erosive rates affecting the landfill site. Flood analysis	UKCIP09 relative projections (sea level rise and land subsidence). Lowe et al, 2009 Environment Agency

4. Landfill sites

As shown in Figure 1, the Wicor Cams study area consists of three historic landfill sites, known as: (i) Cams Bay Tip (with coordinates of its centre approximately located at 458919 Easting, 105201 Northing), (ii) Birdwood Grove Tip (with approximate centre coordinates of: 458819 Easting, 105072 Northing), and (iii) Land near Wicor Hard (with approximate centre coordinates of: 459820 Easting, 105106 Northing). The following subsections provide details of each of the landfill site.

4.1 Landfill site visit

There were no obvious signs of the underlying landfill visible at the sports field at Wicor Hard, apart from the change in elevation, (c. 1m), between the landfill area (known as “land near Wicor Hard”, Figure 1) and the adjacent sports ground. Similarly, no obvious signs of the Cams Bay tip or Birchwood Grove tip were seen from the footpath and golf course.

The landfill frontage and the sea wall was examined from the shore at low tide. Various forms of sea wall were observed, including concrete or granite blocks or slabs (e.g. Figure 2a) and a discontinuous wall of concrete sandbags (Figure 2b). Some lengths either had no defences or the defence wall had washed away or been overgrown (Figures 2c & 2d), while ad hoc defences/degraded walls were apparent. Waste material, e.g. glass, metal and plastic, was visible (Figure 3a to 3c), and in some parts there appeared to be a soil horizon, potentially indicating where the tipped waste had been covered with soil (Figure 3d).

Some areas of coastal erosion were identified, where material from the sea wall had been washed away and was distributed over the shore (e.g. Figure 4).

Figure 2: The sea wall and frontage to the landfill sites at the Wicor Cams study site (11 August 2017).

Figure 3: Visible waste in the sea wall/landfill frontage at the Wicor Cams study site (11 August 2017)..

Figure 4: Erosion of the sea wall at the Wicor Cams study site (11 August 2017). The arrow on the map shows the location of stone blocks from the sea wall which are now on the foreshore.

5. Landfill History and Characteristics

5.1 Filling History and Waste Types

Table 2 presents a summary of the landfilling history as well as key characteristics of the sites in terms of details related to the licence as well as the types, age, and volume of waste material deposited within each site. The surface area and the ranges of ground elevations of the landfill sites presented in Table 2 were estimated using ArcGIS based on the size of the polygons as currently recorded in the EA's database and the LiDAR[5] DTM (digital terrain model) data, respectively. The landfills contained commercial, household, industrial and inert wastes. A report by URS (2013) for the Eastern Solent Coastal Partnership (ESCP) states that (based on a report by Atkins in 2005) the eastern end of the Wicor Cams site (including Wicor Hard and Cams Bay tip areas) was landfilled progressively between 1942 and 1967, the centre of the site was landfilled between 1968 and 1973, and an area to the west between 1983/87 to 1993. A refuse tip at Wicor Hard is shown on a 1952 Ordnance Survey map (Figure 5a); the waste tip is shown in a 1968 map, but in a map from 1978 there is no evidence of the tip (Figure 5b). An article found in the Portsmouth Evening News reports that the Wicor Hard tip was present in 1951, and recycling from household and trade waste occurred at the tip in 1952-3 (British Newspaper Archive). The URS 2013 report describes waste in boreholes at the Wicor Hard site and at the eastern end of the Cams Bay Tip.

Table 2: Key summary of the history and characteristics of the landfill sites at Wicor Cams[6].

	Landfill Sites	**General Information and Landfill Characteristics**	
1	Cams Bay Tip	▪ Site operator: *Fareham Urban District Council* ▪ Licence holder: *Fareham Urban District Council* ▪ Licence issued/surrendered: *No data* ▪ Waste type: *Commercial, household*	▪ Landfilling period: *01.02.1969– c. 1973 (no end date recorded in WIYBY)* ▪ Gas control: *No data* ▪ Leachate control: *No data* ▪ Surface area: *15.4ha* ▪ Ground elevation ranges: *1.31 – 7.47m*
2	Birdwood Grove Tip	▪ Site operator: *No data* ▪ Licence holder: *Fareham Borough Council* ▪ Licence issued/ surrendered: *05.09.1984/no end date recorded* ▪ Waste type: *Inert, industrial*	▪ Landfilling period: *05.09.1984–c. 1993 (no end date recorded in WIYBY)"* ▪ Gas control: *no data* ▪ Leachate control: *no data* ▪ Surface area: *1.39ha* ▪ Ground elevation ranges: *2.73 – 7.47m*
3	Land near Wicor Hard	▪ Site operator: *No data* ▪ Licence holder: *No data* ▪ Licence issued/ surrendered: *No data* ▪ Waste type: *Household*	▪ Landfilling period: c.1942-1976 (no information recorded in WIYBY) ▪ Gas control: *no data* ▪ Leachate control: *no data* ▪ Surface area: *6.65ha* ▪ Ground elevation ranges: *1.42 – 5.49m*

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[5] Light Detection and Ranging: *an airborne mapping technique that uses a laser to measure the distance between aircraft and the ground.*
[6] The summary is mainly based on the EA's "What's in Your Backyard?" database.

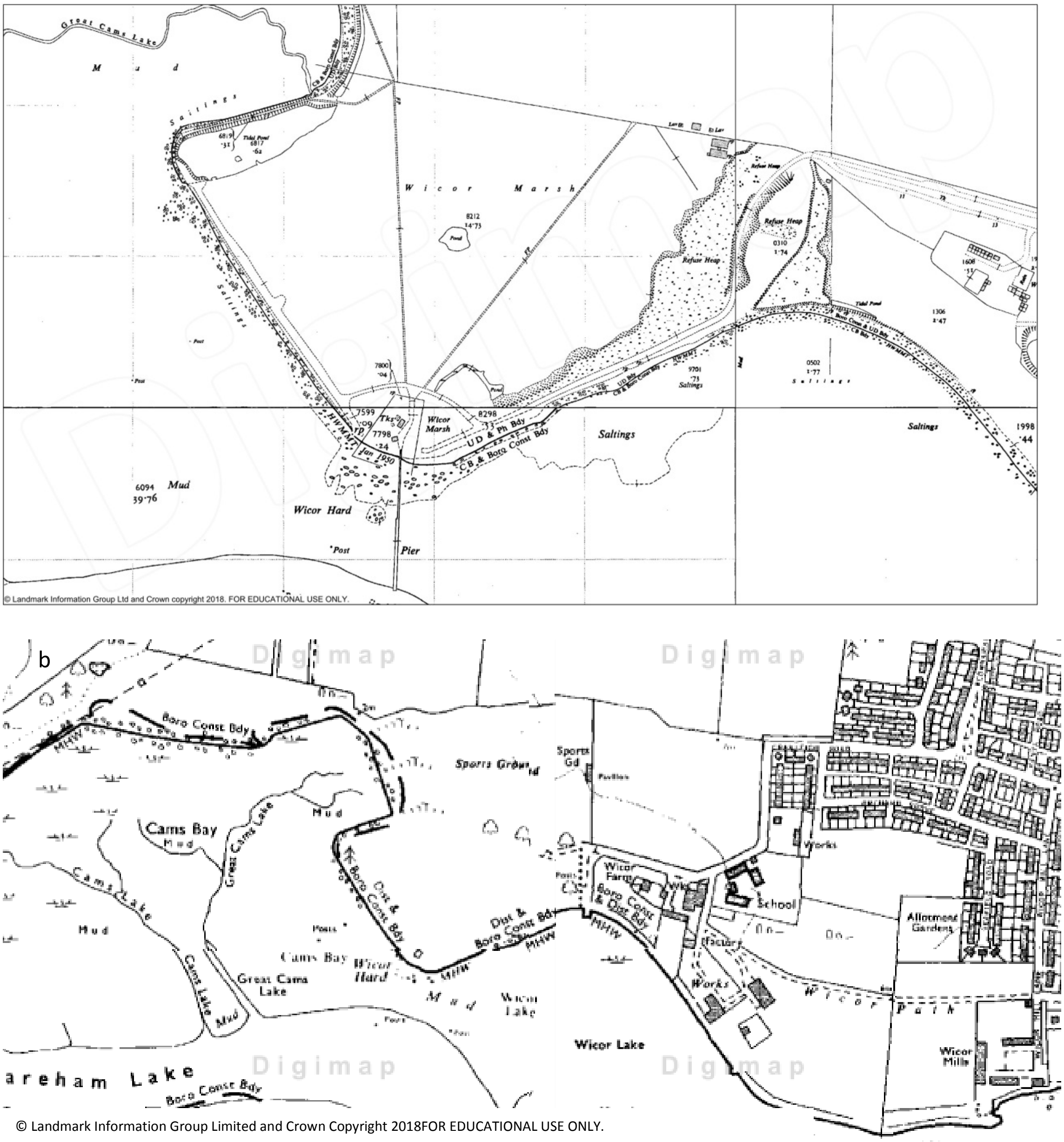

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Figure 5: Wicor Hard, showing location of refuse tip in (a) 1952 and (b) 1978.

5.2 Area, Depth, and Volume of Waste

The landfill sites consist of a narrow stretch of land following the coastline approximately 2km in length. Although EA data shows separate records (Table 1) for the landfills, the majority of Birdwood Grove Tip lies on top of the Cams Bay Tip (Figure 6a). The landfill on Wicor Hard is separated from the eastern end of Cams Bay Tip by 200m. The surface area of each landfill is estimated as 15.4 and 1.4 hectares (see Table 1) and the combined overall surface area of both sites (without double counting the overlapping area) is estimated at approximately 15.42ha. This estimate, combined with the area of the landfill on Wicor Hard (i.e., 6.65ha, Table 1), means that the total surface area of all the landfills at the site is approximately 22 hectares. However, based on the 'Land Contamination' dataset received from the ESCP (Figure 6b), the total area is estimated at approximately 20.3

hectares. Although the discrepancy in the total land area is about 10%, there are considerable differences in the shape of the landfilled areas, especially for the Birdwood Grove tip and the eastern end of the Cams Bay tip.

During the site investigation commissioned by URS seven boreholes were drilled on the central and eastern part of Wicor Cams landfills (URS, 2013a). The boreholes were drilled to a maximum depth of 5 metres, and the logs record “made ground” for their full depth; no definitive base to the site was established at depths of between -0.5 and -0.9m OD.

The drilling method utilised was a hollow stem rotary auger which is not the best method for producing clean borehole logs, so it is possible that the boreholes had drilled through the base of the site. If the base of the site had not been reached, this implies that at the time of tipping, original ground would have been excavated.

The discrepancies in both the area landfilled and the very poor data on waste depth means it is not possible to develop an accurate estimate of the potential volume of waste at the site. At best the waste volumes can be bounded between an upper estimate of approximately 1 million m^3 (based on an area of 22 ha and an average waste depth of ~ 4.6 metres) and a lower estimate of approximately 300,000 m^3. The lower estimate is derived from an average waste depths of 2 metres for the landfill at Wicor Hard, 1.5 metres for Birdwood Grove and 1 metre for Cams Bay tip. However, it must be emphasised that even these upper and lower waste volume estimates must be treated with some caution. Assuming a bulk waste density of 1.2 t/m^3 then the upper estimate of the mass of waste in the site is approximately 1.2M tonnes.

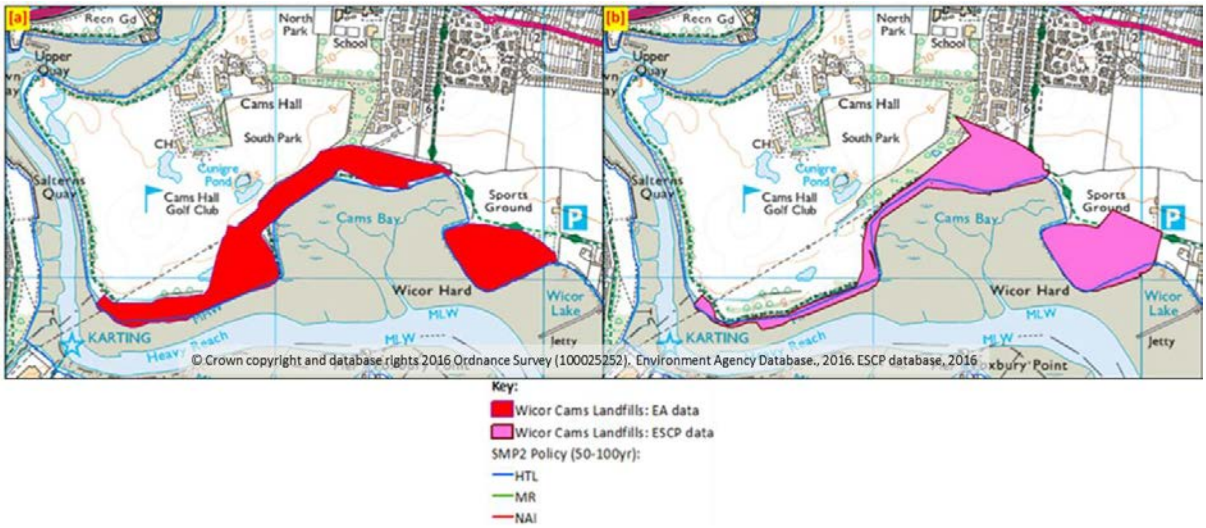

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Figure 6: Wicor Cams case study historic landfill sites based on the EA (a) and (b) ESCP databases.

5.3 Site Characteristics

The study site is public open space including a recreation ground and golf course with footpaths running adjacent to the shore. The presence of historic landfill means that there are potentially high levels of contaminated material below the surface; other historic land uses on the sites including “bone works, refuse sites, sewage works, and a quarry… also with some references to a burial site” (URS, 2013a). In the 1952 map (Figure 5), there are tanks marked adjacent to a pier which was then located at Wicor Hard. A fuel pipeline was laid across Wicor Hard in the late 1930s to this point, and from there across the creek to southeast of Foxbury Point (http://www.portsdown-tunnels.org.uk/fuel_bunkers/fuel_pipeline_p5.html).

5.3.1 Surface characteristics and underlying geology

There are no records of landfill engineering at the site which is founded directly on marsh/saltings. Investigations by URS (2013) found made ground at the site (described in 4.2.3). Reports from the borehole logs in the area of the Cams Bay and Wicor Hard landfills recorded made ground in all locations with silty brown gravelly clay and fragments of brick, chalk and concrete observed below the grass cover. Landfill material was found in both landfill sites and comprised concrete, glass, wood, red brick, cloth, metal, plastic and occasional clinker in a gravel, clay matrix. A “strong landfill” odour (organic/decomposing material odour) was noticed in the some of the borehole samples.

The superficial geology of the area is recorded as either Head (clay, silt, sand, gravel) underlying the west and central area of Wicor and River Terrace deposits underlying the east of the Wicor site comprising ~2 metres of stiff sandy gravelly clay. Bedrock Geology consists of the Reading Formation (secondary A aquifer) underlain at a depth of ~40metre by Chalk. The Head deposits are classified by the Environment Agency as a secondary undifferentiated aquifer, while the River Terrace deposits are a secondary A aquifer. The bedrock underlying the eastern border of Wicor is a Principal Aquifer associated with the Cretaceous Chalk, and most of the site is underlain by a secondary A aquifer, associated with the Reading Formation.

5.3.2 Soil/Waste Quality Analysis

During the URS (2013) site investigation, soils and sediment samples were collected for chemical analysis. Samples were analysed for total metal content, Polyaromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH) and volatile compounds.

A summary of the metals analysis in the soil samples is provided in Table 3. Borehole soil samples from Wicor Hard had high levels of lead and zinc. Maximum recorded concentrations of copper, lead and zinc exceed the CEFAS action level 2 for the disposal of dredged material to the marine environment. There are no CEFAS action level standards for PAHs, but the URS report stated that PAH concentrations in borehole samples where elevated at “probable effect levels” (PEL) set in Canadian sediment quality guidelines (Canadian Council of Ministers of the Environment). Total petroleum hydrocarbon concentrations in the samples taken from Wicor Hard landfill were greater than the average for samples from Cams Bay. PAH concentrations were also above the PEL guideline values in three sediment samples taken from the shoreline adjacent to the landfill sites; total petroleum hydrocarbons were high in the sediment samples near to Wicor Hard landfill. Metal concentrations were greater than Canadian PEL guidelines in sediment samples from the foreshores at Wicor Hard and Cams Bay tip.

Table 3: Summary of the metals analysis for the Wicor Cams landfill sites.

	As	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**[1]	**Zn**
	mg/kg	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*	*mg/kg*
Average	12.9	0.7	23.2	104.9	21.1	173.6	223.1
STD	7.3	1.2	8.8	209.8	10.4	171.7	282.1
Max	38.2	4.26	45	923	47.6	677	1020
CEFAS action level 2	100	5	400	400	200	500	800
Canadian PEL guidelines	41.6	4.2	160	108	42.8	112	271

[1] *Excluding one anomalous value of 24,300 mg/kg*

5.3.3 Landfill Gas

There are no records of landfill gas monitoring from the site. Hydrogen sulphide, methane and ammonia odours where noted in some of the borehole samples taken by URS (2013).

5.3.4 Groundwater/ leachate levels

Groundwater levels within shallow <5m deep boreholes from the URS 2013 site investigation were recorded at between 1.6m bgl (2.1 to 2.6 m aOD) at Cams tip and 1.8 to 2.1 m bgl (1.6 to 2.6 m aOD) at Wicor Hard. Groundwater levels were lowest in boreholes nearer to the foreshore indicating flow towards the estuary. Continuous logging of water levels over a six day period demonstrated there was no tidal influence on water levels in the site.

5.3.5 Groundwater/leachate quality

URS obtained one set of samples from boreholes installed in Wicor in March 2013, (URS, 2013b) . Samples from seven boreholes were obtained and analysed for a comprehensive suite of inorganic and organic compounds. Ammoniac nitrogen is a good indicator of leachate, and the degree to which contamination has been flushed out. Four boreholes had NH4-N concentrations between 27 and 40 mg/l. Ammonia in the other three boreholes was ~1mg/l with at least two of these associated with elevated chloride levels which may be an indication of previous estuarine water incursion.

URS compared metal and organic contaminant concentrations with EQS (Environmental Quality Standards) for saline waters. Significant exceedances were seen for chromium, iron, copper and zinc. In the case of chromium, for the highest detected concentration a minimum 26 fold dilution would be needed to bring concentrations to match EQS standards for saline waters. There are also significant exceedances for certain PAHs, including Benzo(g,h,i)perylene.

The “North Portsmouth Harbour Controlled Waters & WFD Assessment Report” identified key direct contaminant pathways: (1) direct exposure to contamination as a consequence of the foreshore eroding exposing the landfill and slumping into the harbour, (2) the leaching of contaminants from the unsaturated zone into the shallow groundwater table and flowing into the harbour, and (3) direct leachate from the landfill flowing into the harbour (URS, 2013b). As borehole groundwater levels suggested a flow towards the shore, leachate is likely to be diluted due to daily tidal flow, and little would potentially enter coastal waters.

6. Erosion and flooding risk analysis

The coastline is estuarine and sheltered, with low wave energy. In Fareham and Portchester there is “a complex mix of erosion and flood defences, structures built to enclose land reclamation, privately owned frontages, and expired landfill site and some natural coastline” (FBC, 2006). According to URS (2014), “the section around Cams and Wicor has no formal defences, except placed curb stones and rubble attempting to slow erosion of made ground underlain with historic landfill material”. This was confirmed during the site investigation in August, 2017. Furthermore, the shoreline at the study area, particularly at the west end of the Cams Bay Tip, is at risk of coastal flooding, while areas particularly to the west of Wicor along Fareham Lake is “subjected to slow erosion following the partial collapse of the defences” (FBC, 2006).

6.1 Flood risk analysis

Tidal levels in 2015, 2050 and 2100 under different sea level rise scenarios in the south of England are shown in Table 4. Sea level rise at Portsmouth tidal gauge is 1.73 mm/year (1962 to 2007) (Haigh et al, 2009).

Table 4: Tidal levels for Portsmouth

	Sea level rise scenario	MHWS	MHW	MHWN	MSL	MLWN	MLWS
2015		1.97	1.52	1.07	0.15	-0.83	-1.93
2050	Low SLR	2.02	1.57	1.12	0.2	-0.78	-1.88
	Medium SLR	2.12	1.67	1.22	0.3	-0.68	-1.78
	High SLR	2.22	1.77	1.32	0.4	-0.58	-1.68
	H ++	2.47	2.02	1.57	0.65	-0.33	-1.43
2100	Low SLR	2.17	1.72	1.27	0.35	-0.63	-1.73
	Medium SLR	2.37	1.92	1.47	0.55	-0.43	-1.53
	High SLR	2.72	2.27	1.82	0.9	-0.08	-1.18
	H ++	3.47	3.02	2.57	1.65	0.67	-0.43
MHWS = Mean High Water Springs; MHW = Mean High Water; MHWN = Mean High Water Neaps; MSL = Mean Sea Level; MLWN = Mean Low Water Neaps; MLWS = Mean Low Water Springs							

Table 5: Extreme water levels under different return periods and sea level rise scenarios for Portsmouth Harbour.

Return Period		1	2	5	10	20	25	50	75	100	150	200
2015 Water Level (m OD)		2.59	2.69	2.76	2.83	2.85	2.93	2.96	2.99	3.03	3.06	3.08
2050	LSLR	2.64	2.74	2.81	2.88	2.9	2.98	3.01	3.04	3.08	3.11	3.13
	MSLR	2.74	2.84	2.91	2.98	3.0	3.08	3.11	3.14	3.18	3.21	3.23
	HSLR	2.84	2.94	3.01	3.08	3.1	3.18	3.21	3.24	3.28	3.31	3.33
	H ++	3.09	3.19	3.26	3.33	3.35	3.43	3.46	3.49	3.53	3.56	3.58
2100	LSLR	2.79	2.89	2.96	3.03	3.05	3.13	3.16	3.19	3.23	3.26	3.28
	MSLR	2.99	3.09	3.16	3.23	3.25	3.33	3.36	3.39	3.43	3.46	3.48
	HSLR	3.34	3.44	3.51	3.58	3.6	3.68	3.71	3.74	3.78	3.81	3.83
	H ++	4.09	4.19	4.26	4.33	4.35	4.43	4.46	4.49	4.53	4.56	4.58
LSLR = low sea level rise; MSLR = Medium sea level rise; HSLR = high sea level rise; H++ Extreme sea level rise.												

Based on (2009) UK Climate Impact Projections (UKCP09), the 1 in 200 year extreme water levels (maOD) for the area including Portsmouth Harbour are projected to be 3.08 (2015), and 3.23 (2050), and 3.48 (2115), assuming a medium sea level rise scenario (Table 5). Details of the method used to calculate sea level projections and extreme water levels are given in Appendix 1.

Using the bath-tub analysis method, the current day flood zones under extreme water levels of different return periods were assessed for the Wicor Cams site (Figures 7 to 12). This gives an indication of how the flood plain may expand across the site over time.

6.1.1 2015 flood risk

A small channel behind the western extent of the landfill site (Figure 7) is currently at risk of flooding (based on 2015 sea level) at relatively low return period water levels (1-in-1 to 1-in-5). Flooding at a strip connecting the two main landfill site areas (to the northwest of the sports ground) only becomes significant at extreme water levels with a 1-in-200 year return period. However, it must be noted that low connectivity means that flooding to the extent shown in Figure 7 is unlikely at both of these locations.

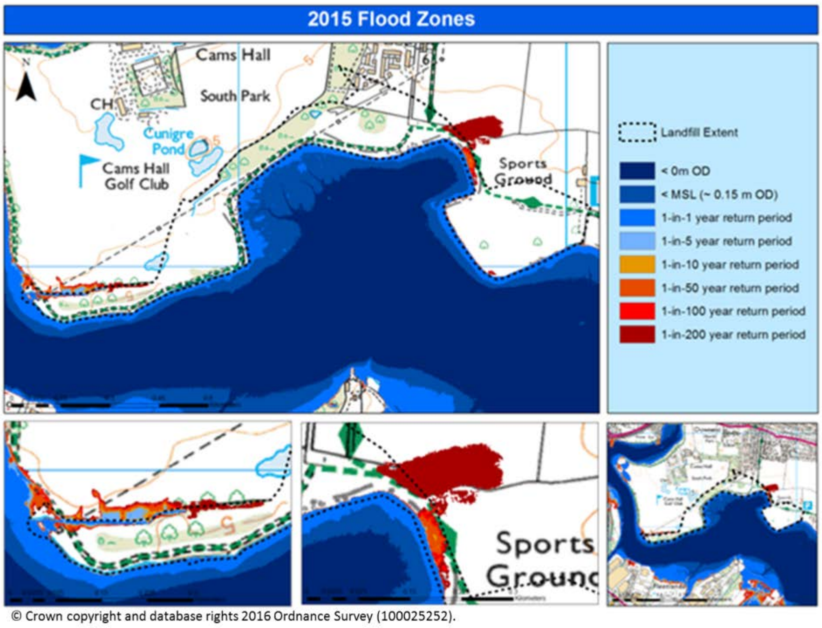

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Figure 7**: Potential flood zones with 2015 sea levels (i.e. present conditions) under a range of water level scenarios of differing return**

6.1.2 2050 flood risk

Figures 8 and 9 show the potential flood zones in 2050 under low and high sea level rise, respectively. Flooding remains limited to the same areas as seen in the current day map (Figure 7). The total potential flood area increases marginally (< 5%). The key difference between the low and high sea level rise scenarios is that the threshold for flooding decreases, occurring under a 1-in-50 as opposed to a 1-in-200 year event.

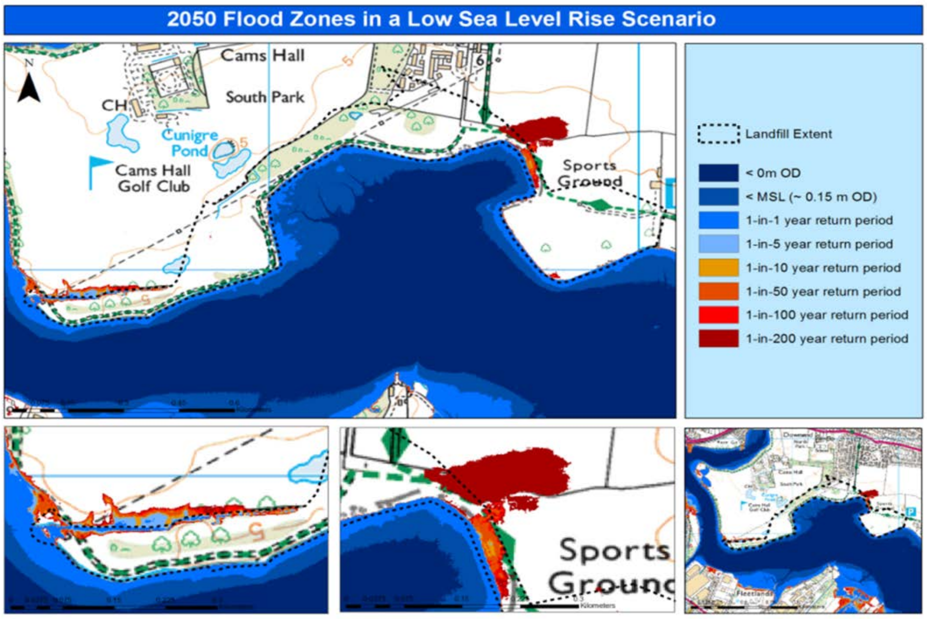

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Figure 8: Potential flood zones with low sea level rise by 2050 under a range of water level scenarios of differing return periods

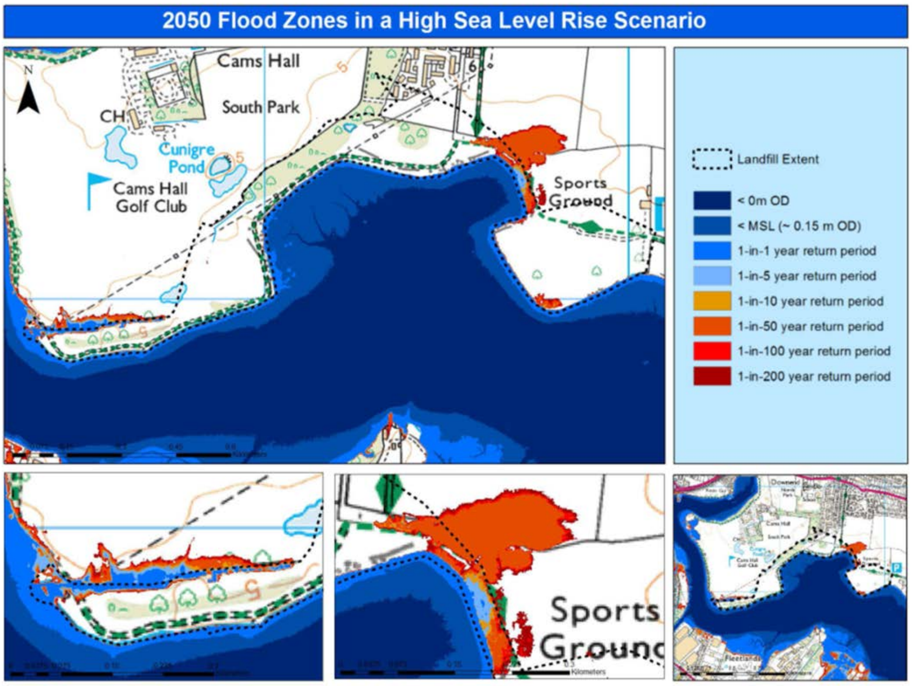

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Figure 9: Potential flood zones with high sea level rise by 2050 under a range of water level scenarios of differing return periods.

6.1.3 2100 flood risk

Figure 10 and 11 show the potential flood zones in 2100 under low and high sea level rise scenarios, respectively. For low sea level rise, the flood zone in 2100 matches that of high sea level rise in 2050, indicating that more extensive flooding may begin to occur near the sports ground under 1-in-50 extreme water level events. The largest change occurs by 2100 under high sea level rise with 1-in-1 year water levels beginning to completely overtop this section, causing widespread flooding behind the landfill site. Adjacent to this, a potential flood zone opens up, with a channel occurring under a 1-in-50 year event across the landfill site. However, considering the hydrodynamics of flooding and the low connectivity, flooding of this extent is unlikely. At the eastern area of the study site near Wicor Hard, flooding also begins to occur along the coastal border of the landfill site, starting at 1-in-1 year water levels, but becoming more extensive during a 1-in-50 year event. At the western end of the study site, flooding becomes more extensive during a 1-in-1 year event, with the connection to open water becoming significant indicating flooding of this extent is much more likely. Under the extreme high (H++) sea level rise scenarios, flooding is even more extensive (Figure 12) with large parts of Wicor Hard flooding regularly.

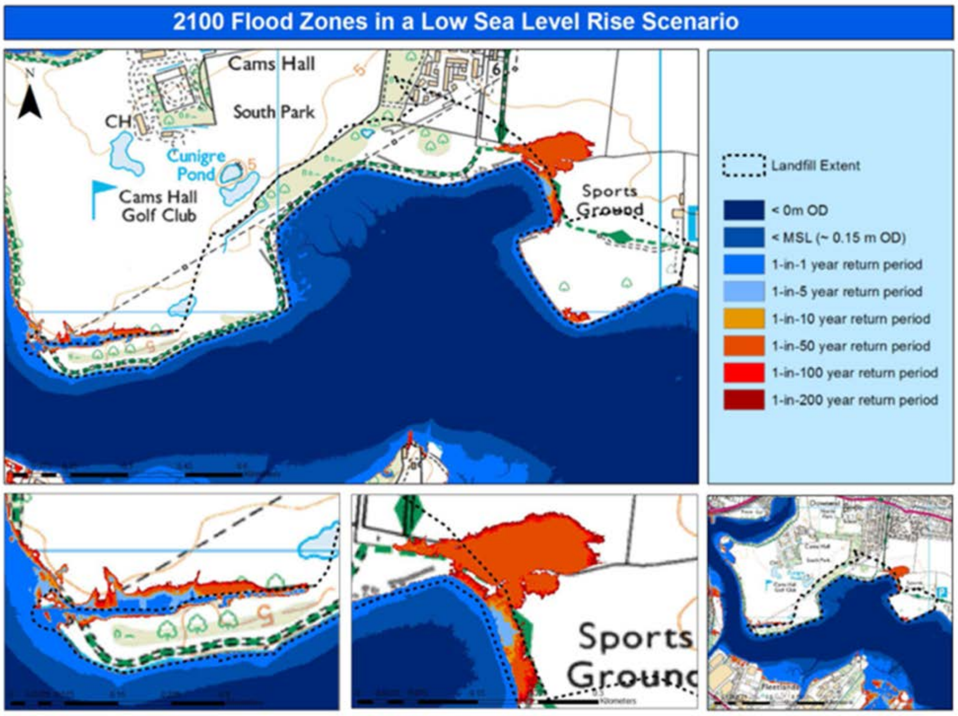

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Figure 10: Potential flood zones with low sea level rise by 2100 under a range of water level scenarios of differing return periods.

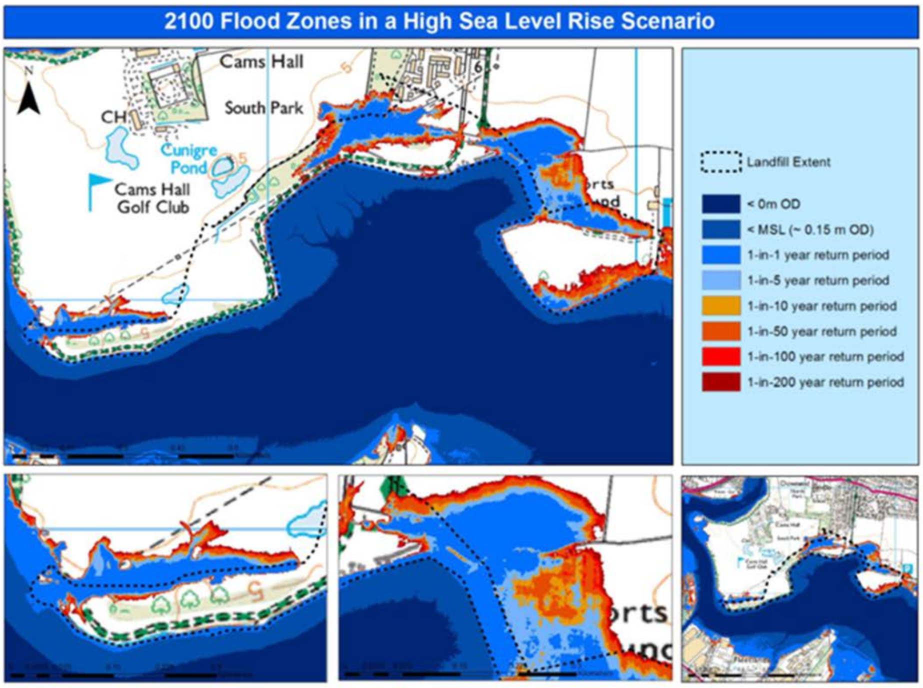

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Figure 11: Potential flood zones with high sea level rise by 2100 under a range of water level scenarios of differing return periods.

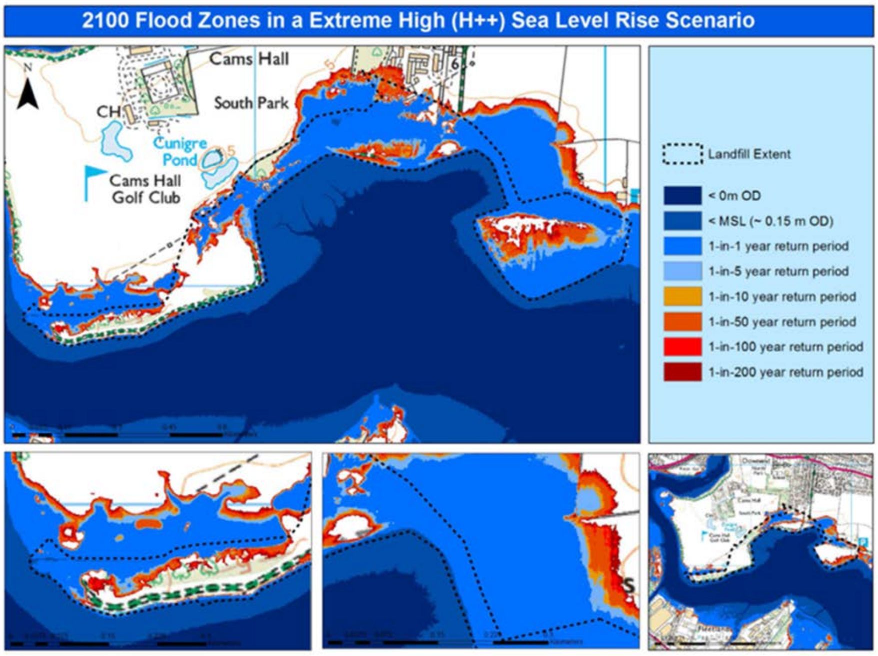

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Figure 12: Potential flood zones with extreme high sea level rise by 2100 under a range of water level scenarios of differing return periods.

6.1.4 Potential for leachate release from flooding

Data (albeit limited in scope) from Wicor Hard and Wicor Cams landfills indicate that leachate levels within the main body of the site are at ~ 2 to 2.5 m aOD, which are higher than the mean high water level 1.52 maOD) in the creek. This indicates that there is limited hydraulic connection between the landfill and the estuary, a fact supported by the lack of significant visible seeps and the absence of any reported diurnal fluctuations in leachate levels.

The analysis of flooding maps (Figures 7-9) indicates that by 2050 a 1 in 200 year storm under both low and high sea level rise predictions does not result in significant inundation of landfilled areas. Land behind and to the north of the western end of Cams Bay tip is at risk of flooding, as too is the area between Cams Bay Tip and the Land near Wicor Hard, but neither locations involve flooding of waste materials, assuming the landfill extent as indicated in the maps.

There is more of a problem by 2100, with the possible partial flooding of Wicor Hard. The areas of flooding are limited under low sea level rise predictions, where a land area of approximately 2,000 m^2 is inundated by storms of between 1 in 10 year and 1 in 200 year frequency. Under high sea level rise predictions 2,000 m^2 is predicted to be inundated every year and up to ~20,000 m^2 inundated by storms of between 1 in 10 year and 1 in 200 year frequency. There is also potentially some limited flooding of land behind and to the north of the western and eastern ends of Cams Bay Tip. The H^{++} sea level rise scenario predicts much more extensive flooding: over 50 % of the land area of Wicor Hard is flooded on an annual basis in 2100, with 1:200 year storms inundating the majority of the Wicor Hard waste; large portions of Cams Bay Tip are also flooded.

Inundation of waste will result in the saturation of waste materials and the generation of new leachate which will be released back into the estuary once flooding recedes. However, this is likely to occur over several days or weeks rather than occurring in full at the next low tide following the flood.

The volume of leachate created following a flooding event is related to the elevation of the flood and the area of waste flooded. The area of waste flooded will be potentially larger than the areas under inundation reported above, as there will be flow of leachate into areas not totally submerged.

An example of the amounts of leachate generated was calculated for 2100 caused by a 1:200 extreme water level event under a high sea level rise projection. Sea level during this event is projected to be at ~3.83 m aOD (Table 5), which is approximately 2 metres above existing leachate levels in Wicor Hard. It is assumed (as a worst case scenario) that this results in leachate levels in the whole of Wicor Hard (6.65ha) increasing by 2 metres. Assuming a drainable porosity of 15%, then this would result in ~20,000 m^3 of leachate being created.

URS 2013 (reporting the work of Townend et al from the Estuaries research programme), states that the tidal flushing volume of Portsmouth Harbour is estimated to be 4.58×10^7 m^3 per tidal cycle. Assuming that the tidal flow in the upper reaches of Portsmouth Harbour around Wicor Cams represents one twentieth of this flow, then the locally available volume of creek water that may dilute any leachate discharges is estimated very approximately at 2.3×10^6 m^3. Taking the 20,000 m^3 of leachate generated by a 1:200 storm in 2100, and assuming that this volume entered the creek over one tidal cycle then there is at least a 100 fold dilution available in the immediate vicinity of Wicor Cams.

URS (2013) compare EQS threshold values for saline water with the maximum concentration recorded in leachate samples taken from the site. Assuming zero background concentration of a contaminant in Poole Harbour, then a 100 fold dilutions is sufficient to reduce the maximum recorded concentration of all metal and most organic contaminants to less than the respective EQS. The one exception is for Benzo(g,h,i)perylene, where a 130 fold dilution is needed to reduce maximum recorded leachate concentrations to below EQS values.

6.2 DEM topographical profiles

Figure 13 shows the location of seven topographic profiles extracted from LiDAR data for the three landfill sites. Figures 14a-g and 15a-g show variations in topography across the seven cross-sections. Further cross-sections were examined, however this sub-set describes the full range of main topographic variations at the site, taken from each point at which the topography changes. Figures 14a-g shows current day and future mean high water springs under low, high and H++ sea level rise scenarios. Figures 15a-g examines a worst case scenario of a 1-in-200 year event under these sea level rise projections. The landfill (as estimated by the landfill extent previously shown) is assumed to cover a chainage of 20 m with the seaward extent lying approximately where the break in slope occurs.

Overall these figures show that topography changes significantly along the length of the site, with some areas where the landfill site is higher in elevation than the immediate land behind (profiles 1, 2 and 5) and other areas where the land behind is of higher elevation (profiles 3, 4, 6 and 7). This has clear ramifications for the hinterland if the landfill site were to be removed, although due to the current land-use (recreational), it is contamination via erosion and flooding of the landfill site and not flooding of the land behind that is the main concern to the local FCERM authorities.

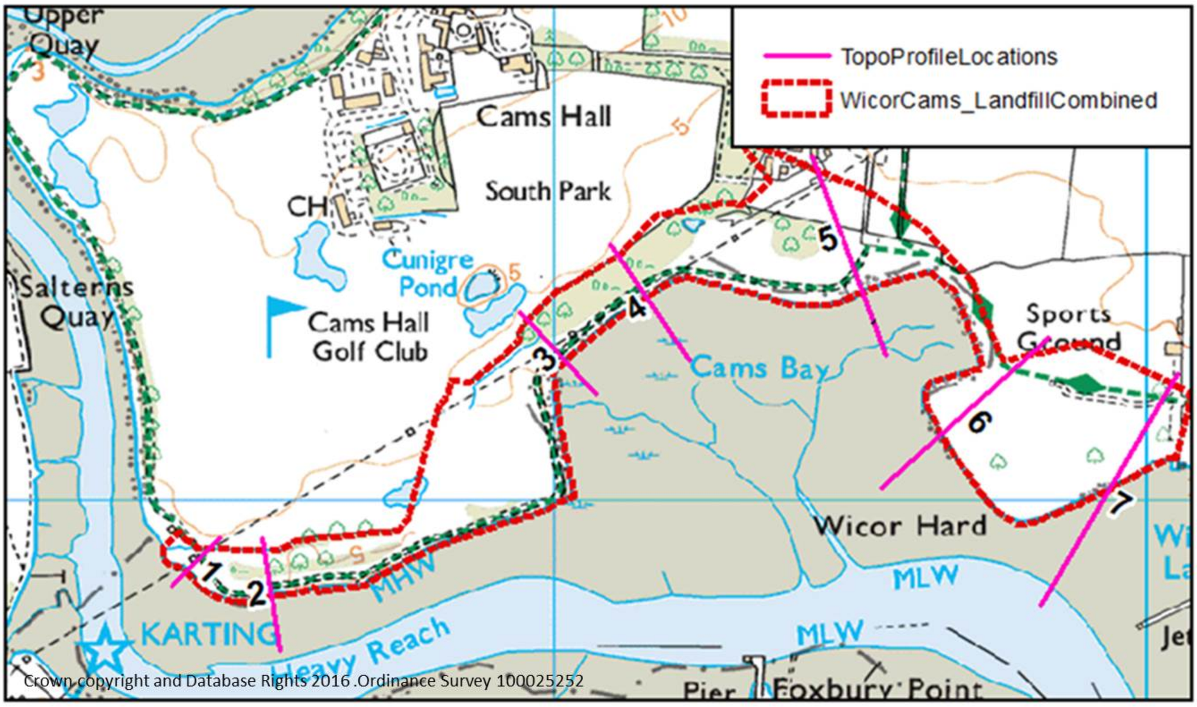

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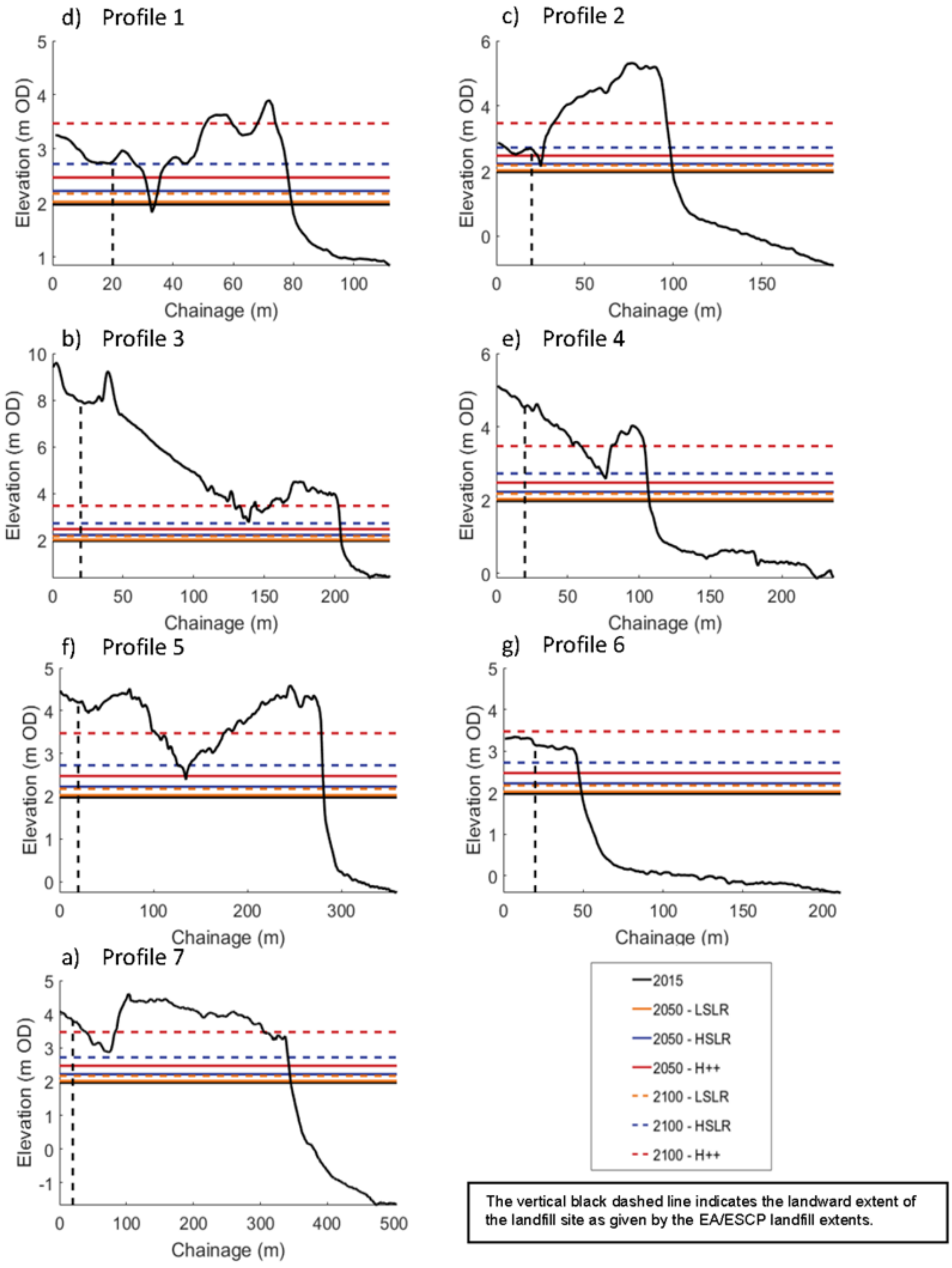
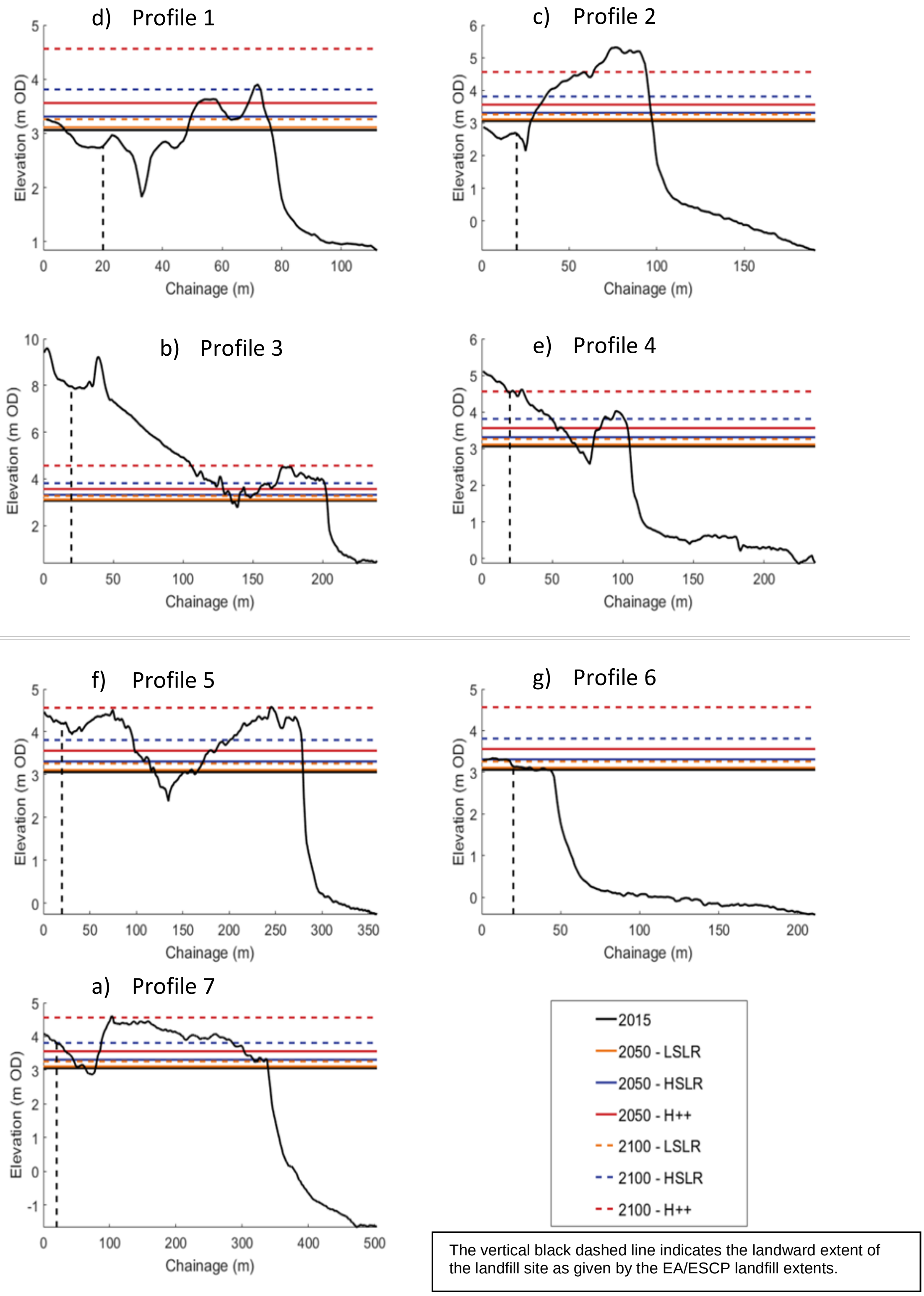
Figure 13: Locations of topographic profiles extracted from LIDAR data. (Environment Agency and ESCP databases for landfill extent).

At current MHWS, the toe of the landfill site is impacted at all cross-sections. In the future, as sea level rise occurs, ranging from 2m to almost 4 m aOD under a high end sea level rise projection, the area which may be subject to groundwater flooding and marine erosion during the tidal cycle increases.. Under a 1-in-200 year event (Figures 15 a-g) it is clear that the area of the landfill that will be subject to flooding will be much more significant. However, the duration of inundation will also have a significant impact on how detrimental this is.



The vertical black dashed line indicates the landward extent of the landfill site as given by the EA/ESCP landfill extents.

Figure 14:: High tide and the landfill. Topographic profiles extracted from LIDAR digital elevation model compared to current and future mean high water springs under a range of sea level rise scenarios. LSLR = low sea level rise; HSLR = high sea level rise; H++ Extreme sea level rise.



The vertical black dashed line indicates the landward extent of the landfill site as given by the EA/ESCP landfill extents.

Figure 15: 200 year flood level and the landfill. Topographic profiles extracted from a LIDAR digital elevation model compared to current and future 1-in 200 year extreme water level under a range of sea level rise scenarios. LSLR = low sea level rise; HSLR = high sea level rise; H++ Extreme sea level rise.

6.3 Coastal Erosion analysis

The EA gives three erosional zones for the short (2005 – 2025), medium (2025 – 2055) and long term (2055 - 2105) which are at risk of eroding. These are 1.8-8 m, 10- 20m and 40 m + wide respectively. Observing the areas at risk in Figure 16, indicates that these erosion zones would have a limited impact on the total volume of waste left in the landfill site due to the large scale of the site. Under these recession predictions it can be projected that, by 2055, approximately 1.4 – 6% of the total landfill area (estimated to be 0.31 to 1.32 ha) would have been eroded and released into the marine environment, and 6-20% (estimated to be 1.32 to 4.4 ha) by the year 2105.

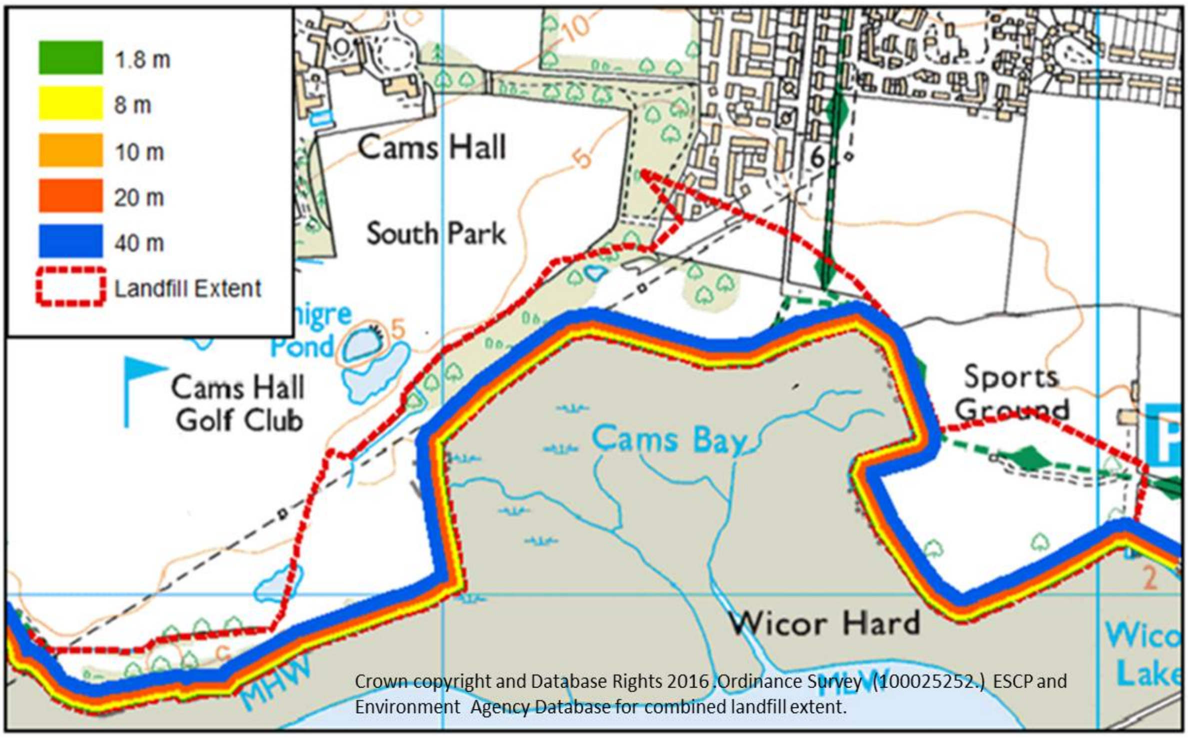


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Figure 16: Buffers showing the area at risk of erosion under EA short, medium and long term predictions.

Lower and upper potential rates of erosion (0.2 and 0.4 m/year) were derived from the EA projections. The total loss of the landfill site under these rates of erosion would not be anticipated for another 400-900 years. While this is clearly an over-simplification, as it does not account for changing physical processes over this time period (e.g. rising sea level), it demonstrates well the potential long term problem of large historic landfill sites subject to erosion. In theory the eroded volume over time could be calculated, but we have not undertaken this due to the great uncertainty in the volume of waste in the site.

Further topographic profiles collected by the Channel Coastal Observatory at the locations shown in Figure 17, have also been analysed to assess whether erosion of the landfill site is apparent within this dataset. Overall, the changes observed between 2007 and 2011 are not significant (Figure 18). The one site where consistent erosion is apparent is site A although a longer time series is needed to have confidence in any of these results. This analysis is limited by the short time period over which these profiles have been collected as well as the fact that they do not show the difference along the entire length of the site, the limited erosion is also supported by historic Ordnance Survey records showing little shoreline change (Figure 19).

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Figure 17: Location of topographic profiles (data collected by the Channel Coastal Observatory). (Environment Agency and ESCP databases for landfill extent).

During the site visit (August, 2017), evidence of erosion was observed in some locations as shown by the low vertical cliffs, sometimes revealing landfill waste (Figure 3). Equally, vegetation at the cliff base (Fig. 2d) did not suggest rapid erosion. The defences in general had a toe beach and there was no evidence of chronic erosion, although locally the rock blocks had been redistributed across the intertidal zone. On balance, the shoreline would appear to be stable or eroding slowly, The minimum rate (0.2 m/yr) used by the Environment Agency erosion zones appears to be much higher than the current rate of change.

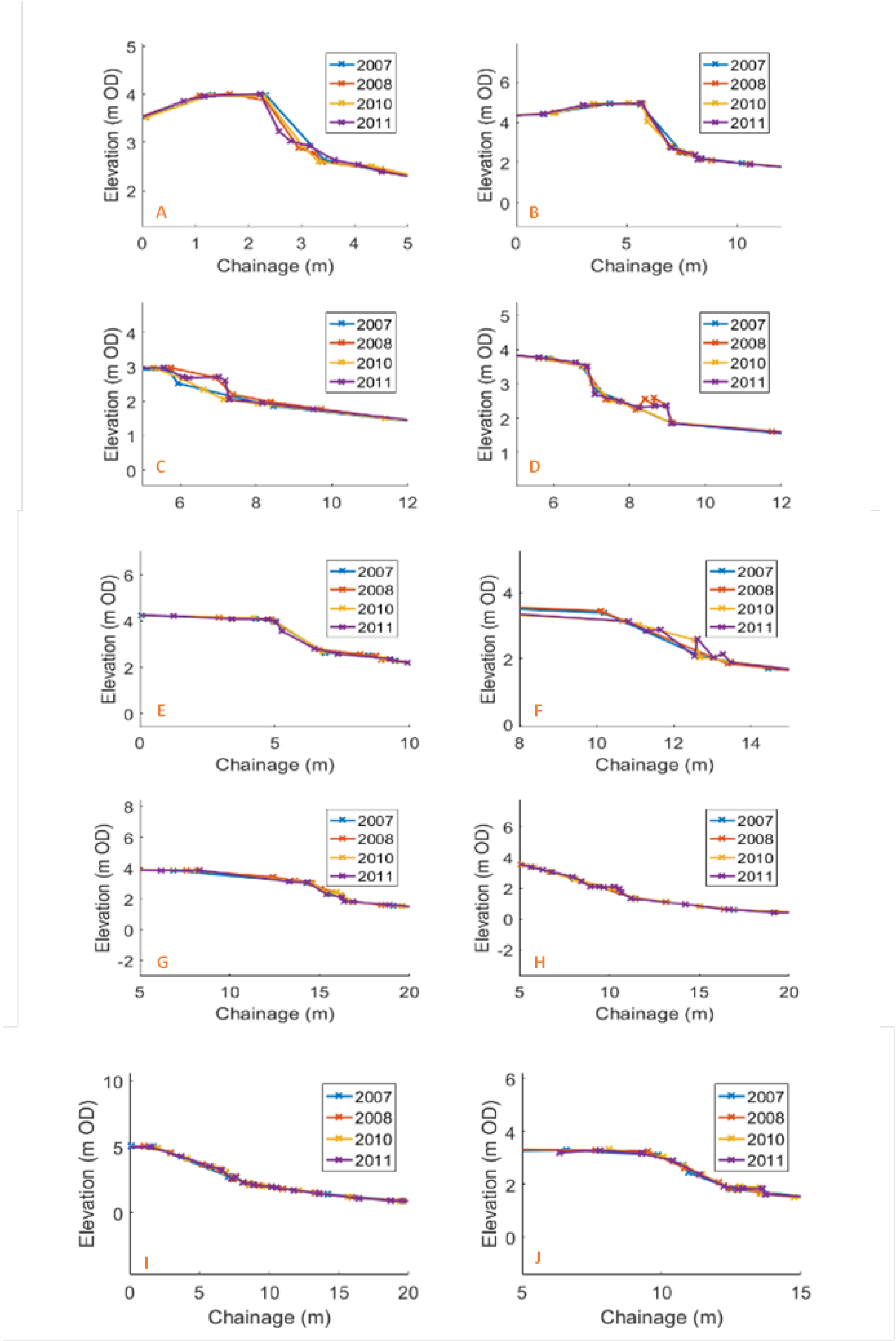

Figure 18: Comparison of topographic profiles collected by the Channel Coastal Observatory in 2007, 2008, 2010, and 2011.

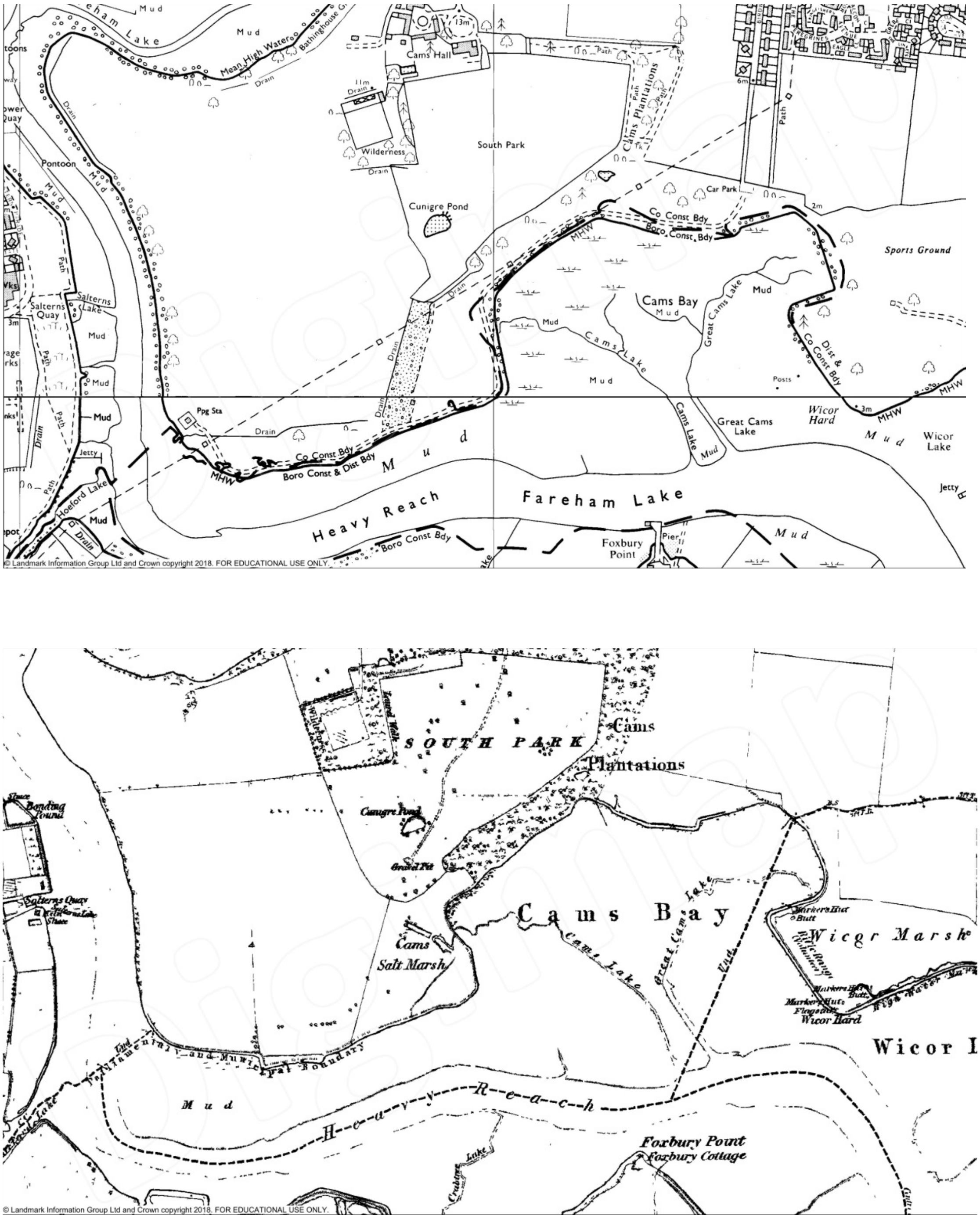

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Figure 19: Erosion over the last 120 years: a) 1870 and b) 1992.

7. Management options

7.1 Hold the line

The maximum length of coastline that fronts the waste deposits is 2.4 km. The cost of defending this part of the shoreline depends on the chosen method, but indicative costs for each are shown in Table 4. As the site is in an estuarine environment, and therefore relatively low wave energy, methods of protecting fluvial channel slope toes from erosion have been included. Geosynthetic barrier systems should be used to prevent the migration of liquids and gases from the landfill sites, together with the engineering product (e.g. rock roll) to protect and maintain the geomembrane in position. Total costs range from £100k to £1M using stone gabions, rock rolls, etc., depending on the type of protection chosen. Higher costs may be anticipated as the existing defence walls will need to be removed, and work will be carried out in a tidal environment. However, protection may not be needed along the whole length of the shoreline and a phased approach could be taken in which eroding areas are given priority.

Table 4: Cost estimations for different methods of flood protection at the Wicor Cams site.

Material	Unit Capital Cost (£/m)	Capital Cost (£ thousands)	Yearly Maintenance Cost (£ thousand)	Maintenance Costs over 50 year lifespan (£ thousand)	Total Cost (£ thousand)
Stone Gabions	250	600	6.25	313	913
Rock Rolls	46	110	1.15	58	168
Stone Rip Rap	26	62	0.65	33	95

Costs taken from Environment Agency (2015); Cost estimation for channel management – summary of evidence. Report – SC080039/R3.

7.2 Managed realignment

The policy for the area which includes the landfills is HTL. Nevertheless, alternative strategies including removal of the landfill were considered and the costs to remove the site were estimated. Costs included excavation, transport and disposal to an alternative landfill, health and safety and environmental control measures and landfill tax. Costs for characterisation of the waste prior to excavation are included. There are many uncertainties with the cost analysis, not least because the values chosen against the various categories are mostly estimates and are not based on a detailed analysis of costs. However, the analysis does give an indication of the magnitude of potential costs.

Total removal of the Wicor Hard and Cams Tip landfill sites (assumed to be a maximum of ~1.2 million tonnes – see section 5.2) to an unspecified landfill, assumed to be within 50 miles driving distance could cost in the region of £140M if all removed materials that were landfilled attracted the top rate of landfill tax (Figure 20a). In this scenario over two thirds of the costs (72%) are accounted for by landfill tax. If it is assumed that only 30% of the removed and re-landfilled material attracted the higher rate of landfill tax, the total remediation cost is halved to around £70M (Figure 20b). Given the large cost of excavation and disposal, total removal of the landfills from Wicor Cams is not considered financially viable.

Excavation and in-situ treatment of the landfilled waste with recovery of some of the material for use on site or in shoreline defences may be possible, but a comprehensive waste characterisation would be needed to determine the feasibility and cost of this approach.

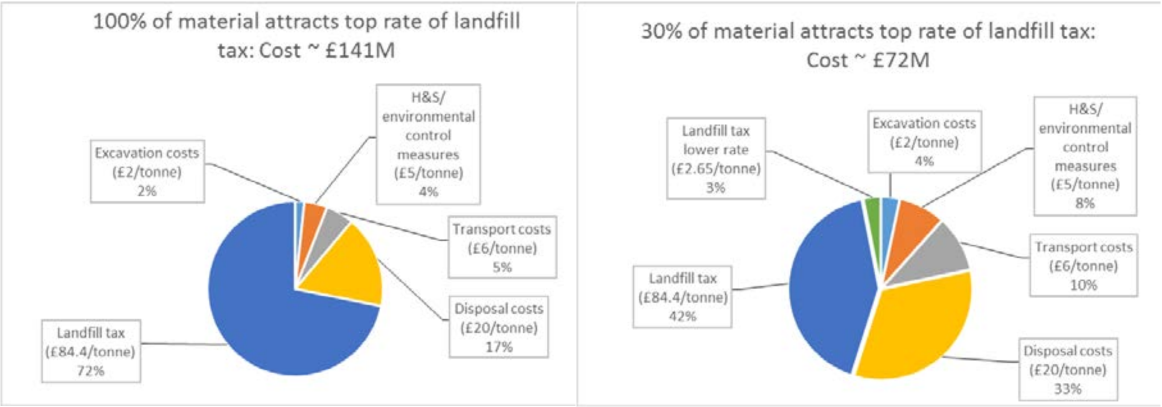

Figure 20: Possible magnitude of costs to remove Wicor Cams landfill to an alternative landfill assumed to be within 50 miles driving distance.

8. Recommendations

The "River Hamble to Portchester Coastal Flood and Erosion Risk Management Strategy" (ESCP, 2016) noted that environmental improvement of currently undefended potentially contaminated land should be planned and in the future the landfill sites should be defended. In the short term it is important that systematic monitoring of the site continues to better understand the rate of erosion and the potential for waste or leachate release from the landfills. If a HTL management strategy is followed, then work should be undertaken to repair or replace the sea defences. This is a low cost option in comparison to removing the landfill, but would need full appraisal to determine the best construction method and long term viability of the new defences. Monitoring would focus attention on where protection is most essential. The costs given for removal of the landfill in section 7.2 are based on the area of landfill estimated in 5.2, but it is noted that there is some uncertainty about the landfills' extent. Further research is needed to understand the true extent (area and depth) of the waste tips and to characterise the waste. Based on the results of new tests, the cost for excavation and removal of the waste could be reassessed, but is unlikely to change the finding that this is not a cost-effective solution for the site.

9. Acknowledgements

We would like to acknowledge funding from the Natural Environment Research Council (NERC) as part of the Environmental Risks to Infrastructure Innovation Programme. Thanks go to the members of the project steering group, especially to Dr Matthew Wadey, Eastern Solent Coastal Partnership (ESCP) and Dr Samantha Cope, ESCP and Standing Conference on Problems Associated with the Coastline (SCOPAC), for assistance with site visits and providing information relating to the landfill site.

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Appendix 1

Mean Sea Level Projection

Relative mean sea level (RMSL) projections were extracted from the latest (2009) UK Climate Impact Projections (UKCP09), using the user-interface on the UKCP web-site. The projections include sea level rise and vertical land movement components. Low, medium and high emission projections at the 5th, 50th, and 95th percentile were obtained from 1990 to 2100. RMSL projections were downloaded for the coastal grid points nearest to the three study sites and can be seen in Figures A1, A2 and A3 and are listed in Table A1 for 2050 and 2100. Given the projections are to within a cm of each other at each of the three sites, the same levels were used across the three case study sites. Relative to 1990, three suitable projections covering the UKCP09 range are 10, 25 and 40 cm for 2050 and 25, 50 and 90 cm for 2100. However, the base-year of the project is 2015 and there is a sea level rise of 5, 10 and 15 cm from 1990 to 2015. Hence, final values of 5, 15 and 25 cm for 2015 to 2050 and 20, 40 and 75 cm for 2015 to 2100 should be used in the analysis. In addition, a high-end scenario based on the H ++ range in UKCP09 is recommended with a 50 cm rise from 2015 to 2050 and a 150 cm rise from 2015 to 2100.

Extreme Sea Projections

Sea level exceedance probabilities estimated recently in a national study commissioned by the Environment Agency (EA; McMillian et al., 2011; Batstone et al., 2013) were used. The EA-commissioned study that produced these, is the latest in a number of related UK investigations from the last six decades (see Batstone et al., 2013 and Haigh et al, 2010 for a summary) that have contributed significantly to developing and refining appropriate methods for the accurate and spatially coherent estimation of extreme water levels. Exceedance probabilities, often called return periods/levels, convey information about the likelihood of rare event such as floods. For example, a 1 in 50 year return level is where there is a 1 in 50 chance of that level being exceeded in a year. In the EA study, a method, called the Skew Surge Joint Probability Method (SSJPM), was developed and used to estimate sea level exceedance probabilities at the 40 national tide gauge sites on the English, Scottish and Welsh coasts (and five additional sites where long records were available). A multi-decadal hydrodynamic model hindcast was used to interpolate these estimates around the coastlines at 12 km resolution. The exceedance probabilities for the grid points nearest to the three study sites were extracted. The base-year for these projections is 2008. Considering the scope of our work, we have assumed that this is close enough to the project base-year (2015) that alterations to these values are therefore not required.

Wave projection

We assumed that wave set-up would be equivalent to 10% of the wave height at each of the three sites. We also assumed that if the chosen extreme sea level reaches 0.5 m from the top of the sea wall there would be over-topping.

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Table A1: UKCP09 relative mean sea level projections at the three study sites in metres, relative to the year 1990.

Lyme Regis

Year	5%	50%	95%	Projection
2050	0.104	0.191	0.277	**Low**
2050	0.111	0.224	0.337	**Medium**
2050	0.122	0.266	0.409	**High**
2100	0.214	0.409	0.603	**Low**
2100	0.230	0.484	0.739	**Medium**
2100	0.254	0.577	0.900	**High**

Pennington

Year	5%	50%	95%	Projection
2050	0.100	0.186	0.273	**Low**
2050	0.107	0.220	0.333	**Medium**
2050	0.118	0.261	0.405	**High**
2100	0.206	0.401	0.595	**Low**
2100	0.222	0.476	0.731	**Medium**
2100	0.246	0.569	0.892	**High**

Wicor Cams

Year	5%	50%	95%	Projection
2050	0.099	0.185	0.271	**Low**
2050	0.106	0.219	0.332	**Medium**
2050	0.117	0.260	0.403	**High**
2100	0.204	0.399	0.593	**Low**
2100	0.220	0.474	0.728	**Medium**
2100	0.244	0.567	0.890	**High**

Table A2: Sea level exceedance probabilities, in metres relative to the base year 2008 from McMillian et al. (2011).

Return Period (years)	Lyme Regis	Pennington	Wicor Cams
1	2.57	1.71	2.56
2	2.63	1.8	2.64
5	2.73	1.89	2.73
10	2.8	1.97	2.81
20	2.88	2.04	2.88
25	2.9	2.06	2.9
50	2.97	2.12	2.98
75	3	2.16	3.02
100	3.04	2.18	3.05
150	3.08	2.22	3.09
200	3.11	2.24	3.12
250	3.13	2.26	3.14
300	3.15	2.28	3.16
500	3.21	2.32	3.21
1000	3.29	2.37	3.28
10000	3.55	2.55	3.5

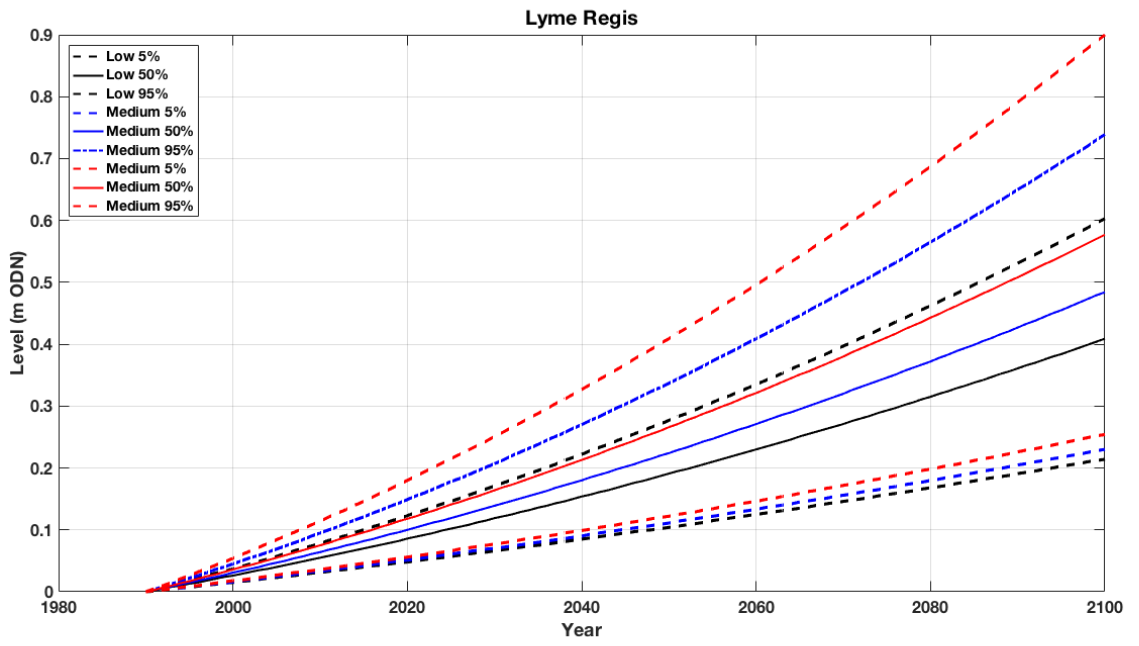

Figure A1: UKCP09 relative mean sea level projections at Lyme Regis

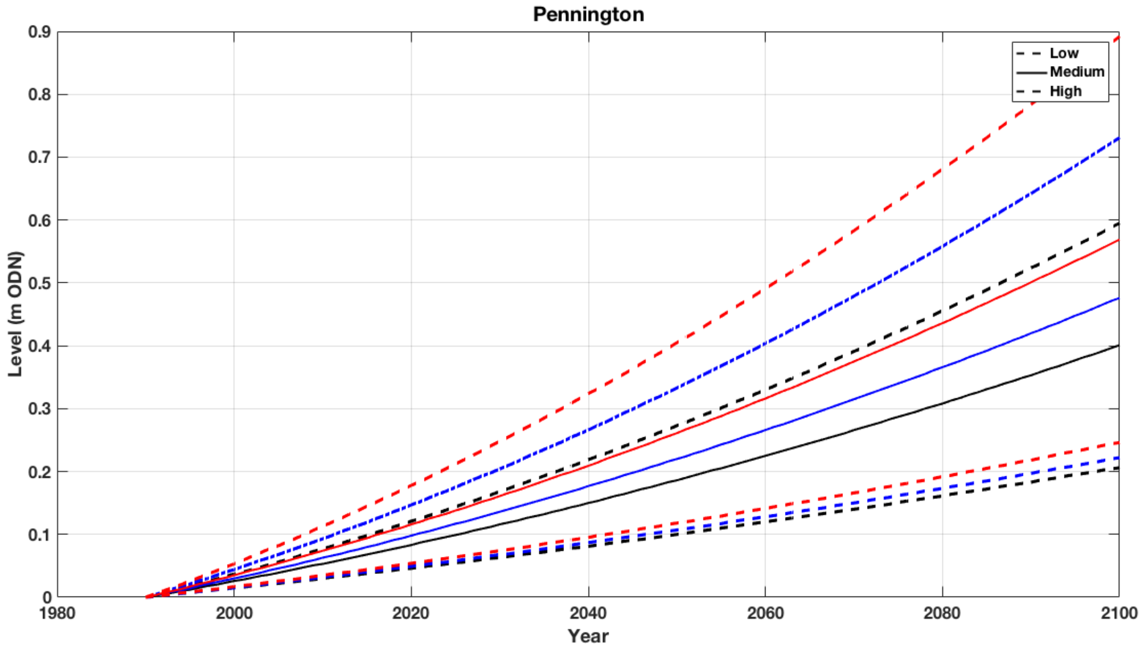

Figure A2: UKCP09 relative mean sea level projections at Pennington.

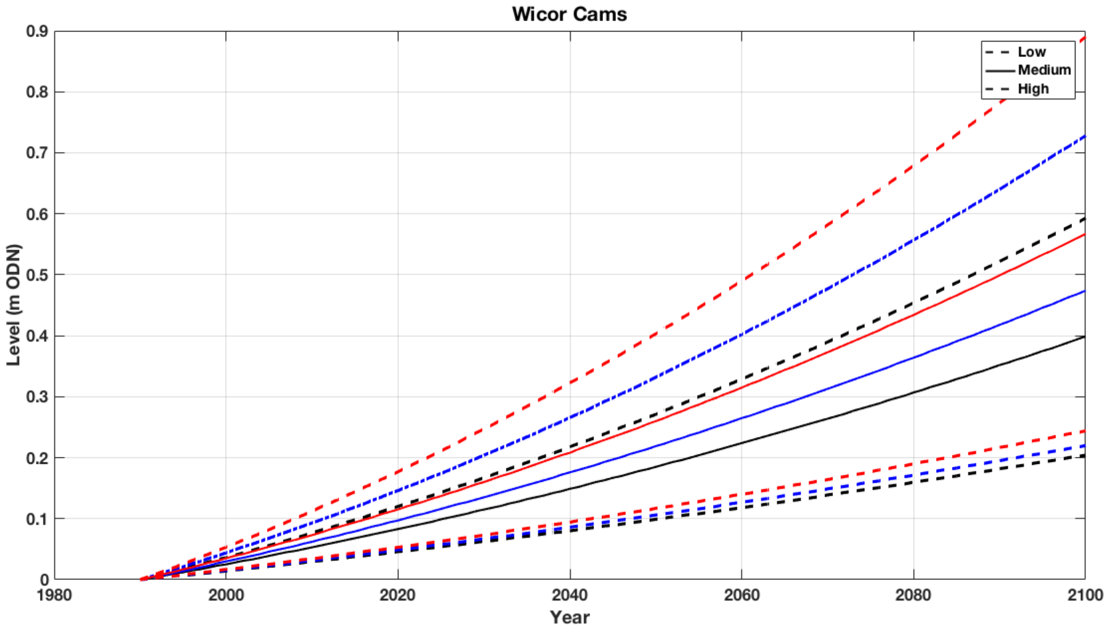

Figure A3: UKCP09 relative mean sea level projections at Wicor Cams.

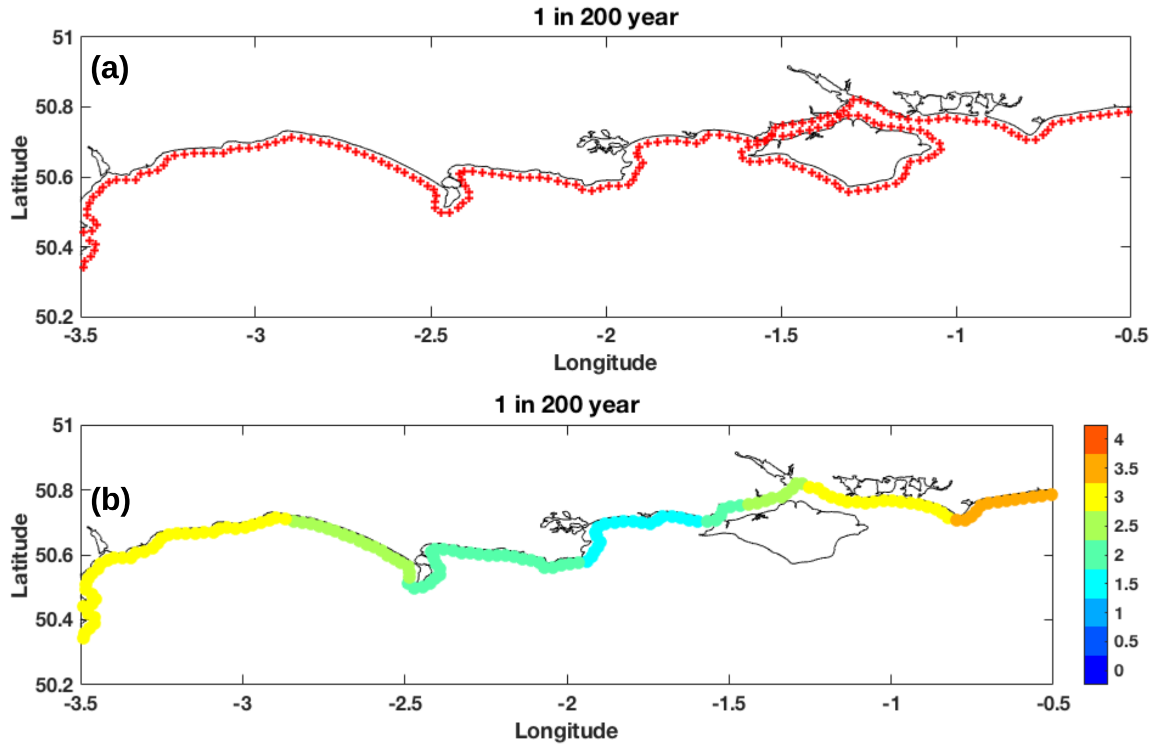

Figure A4: (a) Coastal grid points where sea level exceedance probabilities are available; and (b) the 1 in 200 year return level, across the south coast.

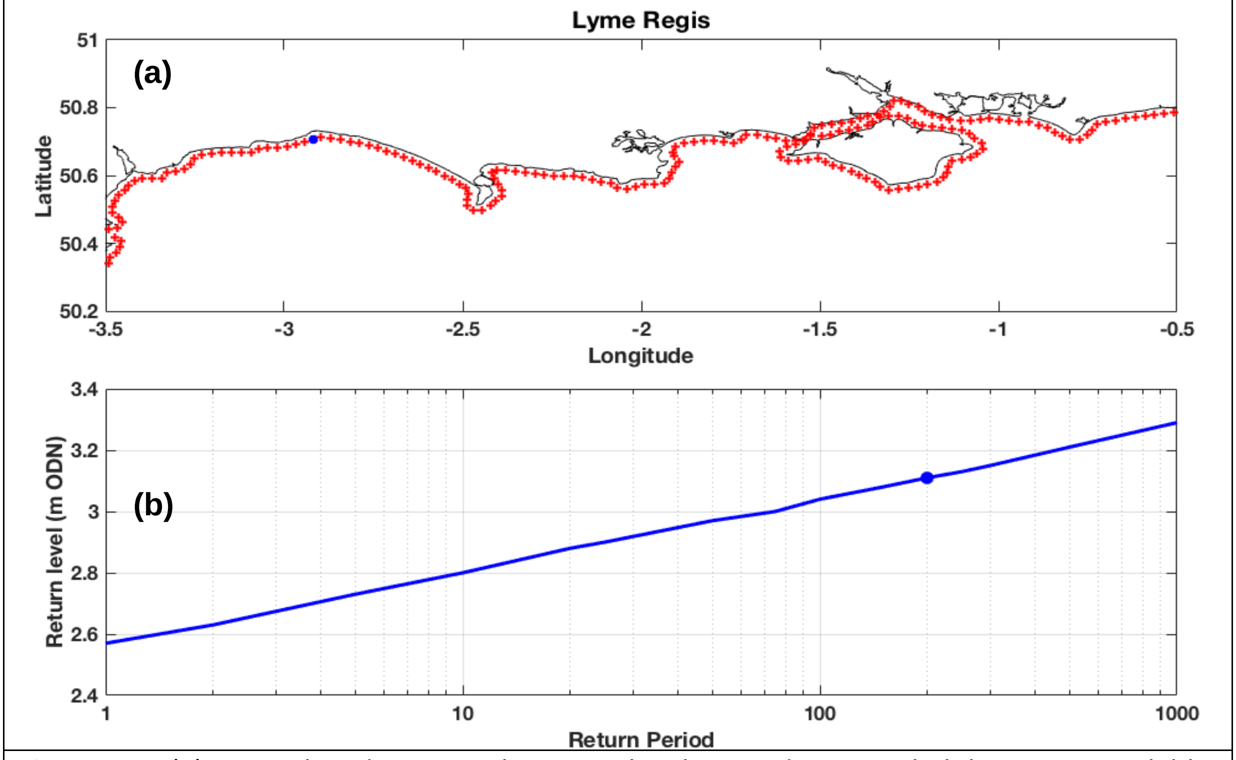

Figure A5: (a) Coastal grid points where sea level exceedance probabilities are available, with the Lyme Regis extraction point shown in blue; and (b) the return period curve at Lyme Regis.

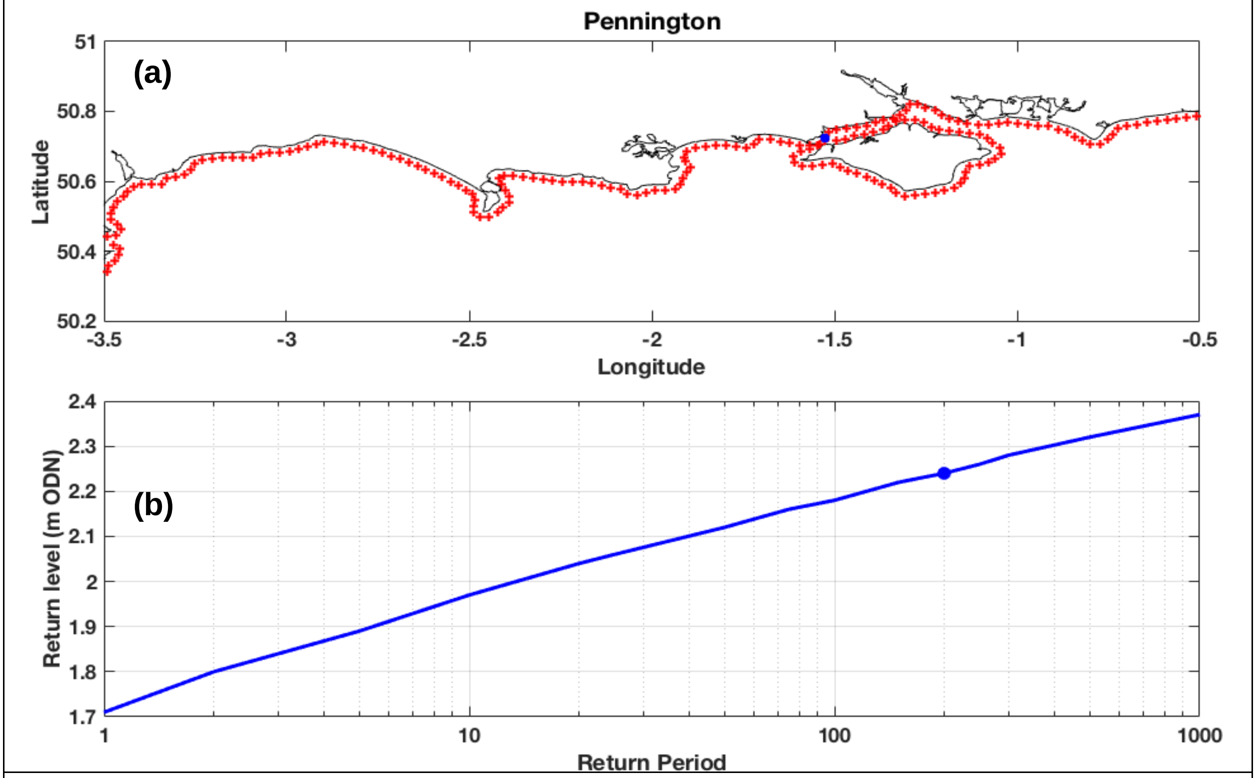

Figure A6: (a) Coastal grid points where sea level exceedance probabilities are available, with the Pennington extraction point shown in blue; and (b) the return period curve at Pennington.

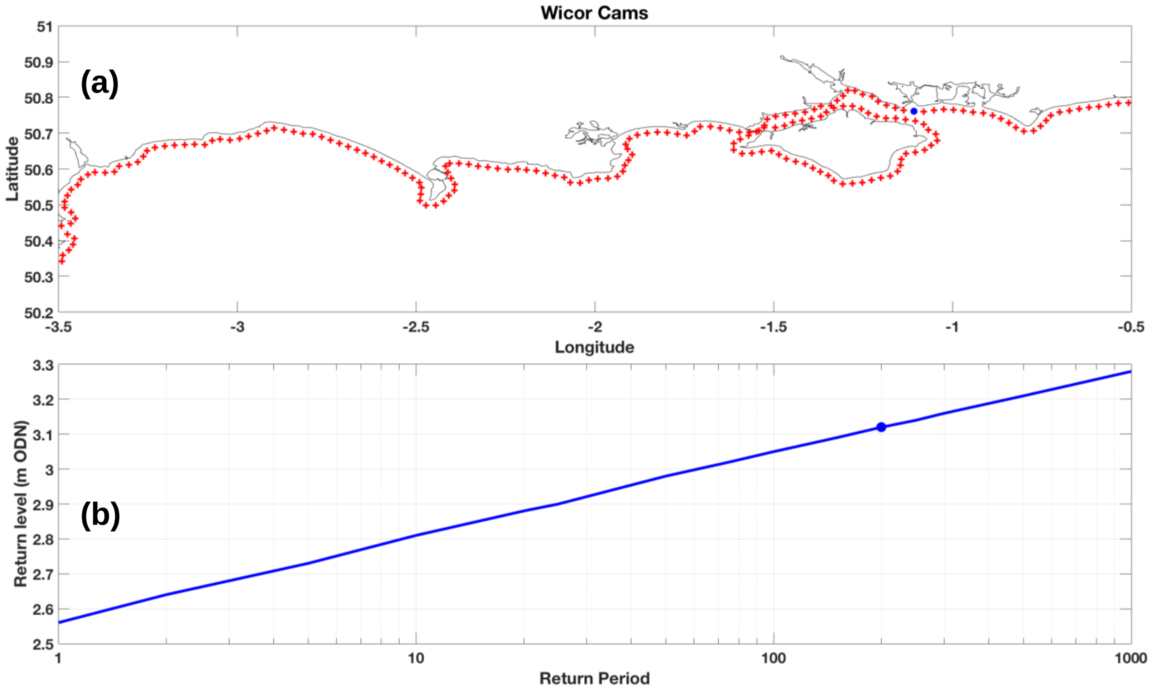

Figure A7: (a) Coastal grid points where sea level exceedance probabilities are available, with the Wicor Cams extraction point shown in blue; and (b) the return period curve at Wicor Cams.