NERC Environmental Risk to Infrastructure Innovation Programme (ERIIP)

Coastal Landfill and Shoreline Management: Implications for Coastal Adaptation Infrastructure

Case Study: **Lyme Regis**

Prepared by: R.P. Beaven, A.S. Kebede, R.J. Nicholls, I.D. Haigh, J. Watts, A. Stringfellow

I were better to be eaten to death with a rust,
than to be scoured to nothing with perpetual motion.

Shakespeare. Second part of King Henry the Fourth Act I, Scene 2

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 —Lyme Regis Case Study. Report for Natural Environment Research Council. 32pp.

Cover photograph, courtesy of Jenny Watts, University of Southampton. View southwards from Spittles Lane Landfill site. (January 2017).

Table of Contents:

List of Tables

List of Figures

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 therefore 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 gave the project partners a better understanding of the impacts these landfills have on shoreline management plan strategic options under different climate change scenarios. The three landfills selected are located on the south coast of England: (1) Lyme Regis, Dorset, (2) Wicor Cams near Fareham, Hampshire (University of Southampton, 2018a) and (3) Pennington near Lymington, Hampshire (University of Southampton, 2018b).

2. Background

2.1 Study Area: Lyme Regis

The geographic location of the study area in Lyme Regis is shown in Figure 1. Lyme Regis is an important coastal town with a population of 3,671 (2011 census)[1]. The town is located in Lyme Bay on the English Channel coast, in the west of the county of Dorset at the Dorset–Devon border in South West England. The area is known for its archaeological significance due to its geological exposures, the fossils found in the surrounding cliffs and beaches, and its coastal geomorphology, which are part of the coastline designated as Heritage Coast. The area contributes to the tourism industry in the region and is known as the Jurassic Coast World Heritage Site[2]; it is also considered as an important educational resource.

The cliffs and foreshore between Lyme Regis and Charmouth are actively eroding and are particularly prone to coastal erosion and large-scale landslides. These processes are mainly due to the geology and soft rock of the cliffs that are prone to weathering, and to surface and toe erosion.

[1] Joint local plan review for West Dorset, Weymouth and Portland: Lyme Regis Background Paper, 2017. West Dorset District Council.
[2] See: https://en.wikipedia.org/wiki/Lyme_Regis

Over the last 100 years these issues have resulted in erosion of the foreshore, loss of and damage to properties and other infrastructure (e.g., roads and gas works), loss of farmland and major seawall breaches, etc.

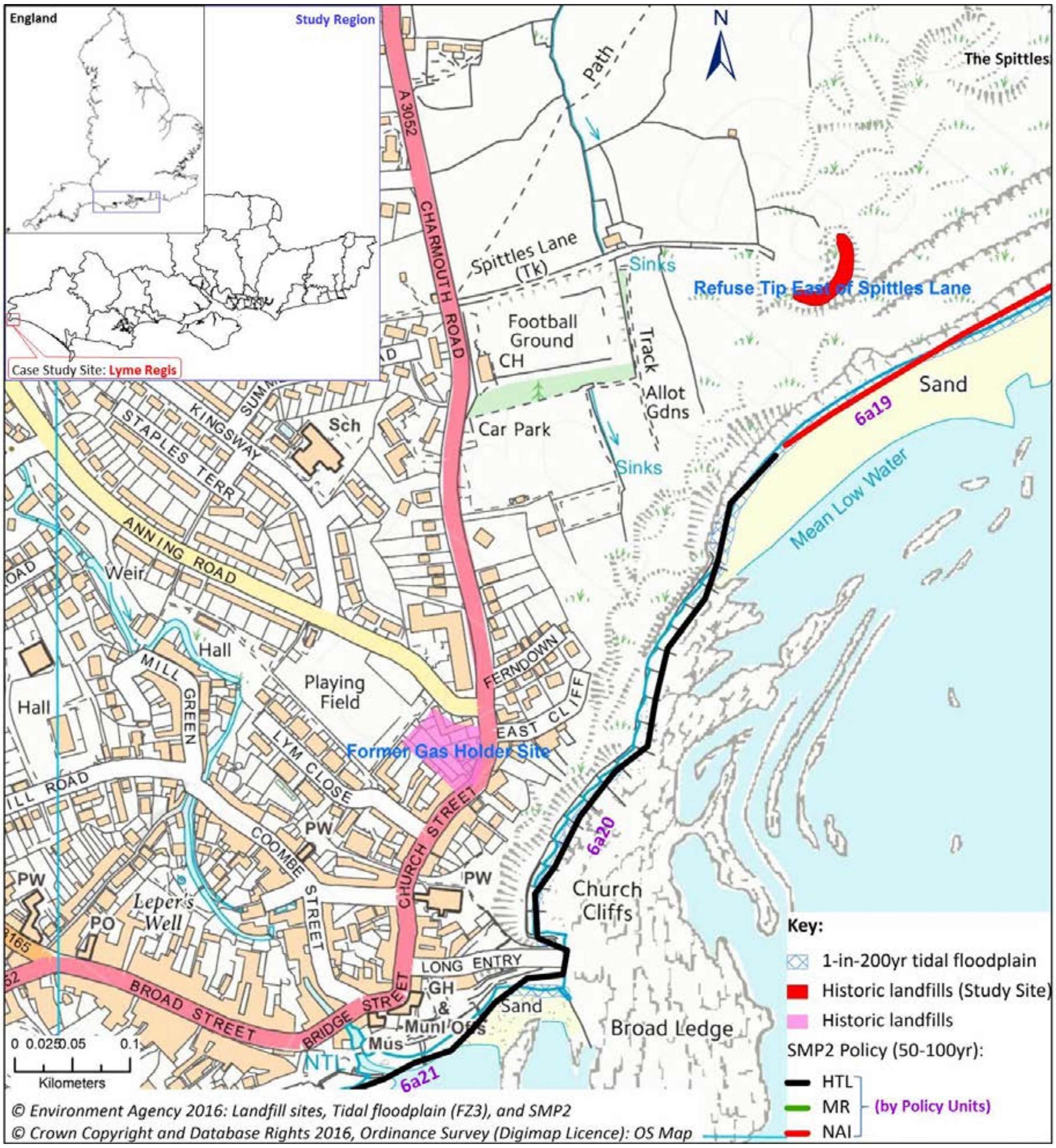

Figure 1: Lyme Regis: Geographic location of the study area and the landfill sites. Map scale: 1:5,000.

More than 400 metres of the cliff along the coastal stretch just to the east of Lyme Regis collapsed in the evening of 6th May 2008, after a prolonged period of rainfall. The landslide was described as 'the worst for 100 years', and destroyed part of the heritage coastline (BBC News, 2008). The landslip site is <300m distance from the Lyme Regis built-up area (Gallois, 2009) and about 120m from the end of the seawall at the foot of the eastern margins of East Cliff (HPR, 2009). The landslipping also exposed 'potentially hazardous' waste material (e.g., glass, metal, other old household wastes and possible pollutants) from an old landfill site, the Refuse Tip East of Spittles Lane (located on the top of the cliffs; Figure 1) (Gallois, 2009). This immediately led to emergency administrative and study responses such as waste and water sampling, initial geotechnical inspections, etc. (see HPR, 2009; Cooper *et al*., 2012). The landslip raised significant concerns about potential threats posed by the release of landfilled waste to public health and the environment (e.g. Pope *et al*., 2011).

2.2 Shoreline Management Plans

A SMP[3] policy 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. It is a high-level, non-statutory policy document that provides guidance aiming to balance flood and erosion risks with natural processes and the potential implications of future climate change. The choice of a preferred policy option 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 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[4]:

(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*".

Table 1 presents the proposed short, medium and long-term SMP policies for the three policy units identified for the stretch of coastline between Charmouth and Lyme Regis.

Table 1: Shoreline management plan (SMP) policies for the coastal stretch between Charmouth and Lyme Regis

Location	**SMP Policy Unit** (see *Fig. 1*)	**Preferred SMP2[3] policies for the three epochs**		
		Short-term (0–20 years)	Medium-term (20–50 years)	Long-term (50–100 years)
Charmouth (West) to East Cliff (Lyme Regis)	6a19	*NAI*	*NAI*	*NAI*
East Cliff to Broad Ledge (Lyme Regis)	6a20	*HTL*	*HTL*	*HTL*
Broad Ledge to The Cobb (Lyme Regis)	6a21	*HTL*	*HTL*	*HTL*

Note: *NAI – No active intervention and HTL – Hold the (existing defence) line*.

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

The management strategy for the coastal stretch between Church Cliff and East Cliff (i.e., 6a20 policy unit) is to hold the line, with the main town frontage of Lyme Regis protected by coastal protection and cliff stabilisation works. Following the landslip in 2008, major improvements to Lyme Regis' coastal defence were completed in 2016 as shown in Figure 2 (BBC News 2014, 2015). However, the SMP policy for the stretch of the coastline in front of the Spittles Lane landfill site (i.e. 6a19) is NAI (no active intervention) in order to allow natural processes to occur (e.g., BBC News 2012).

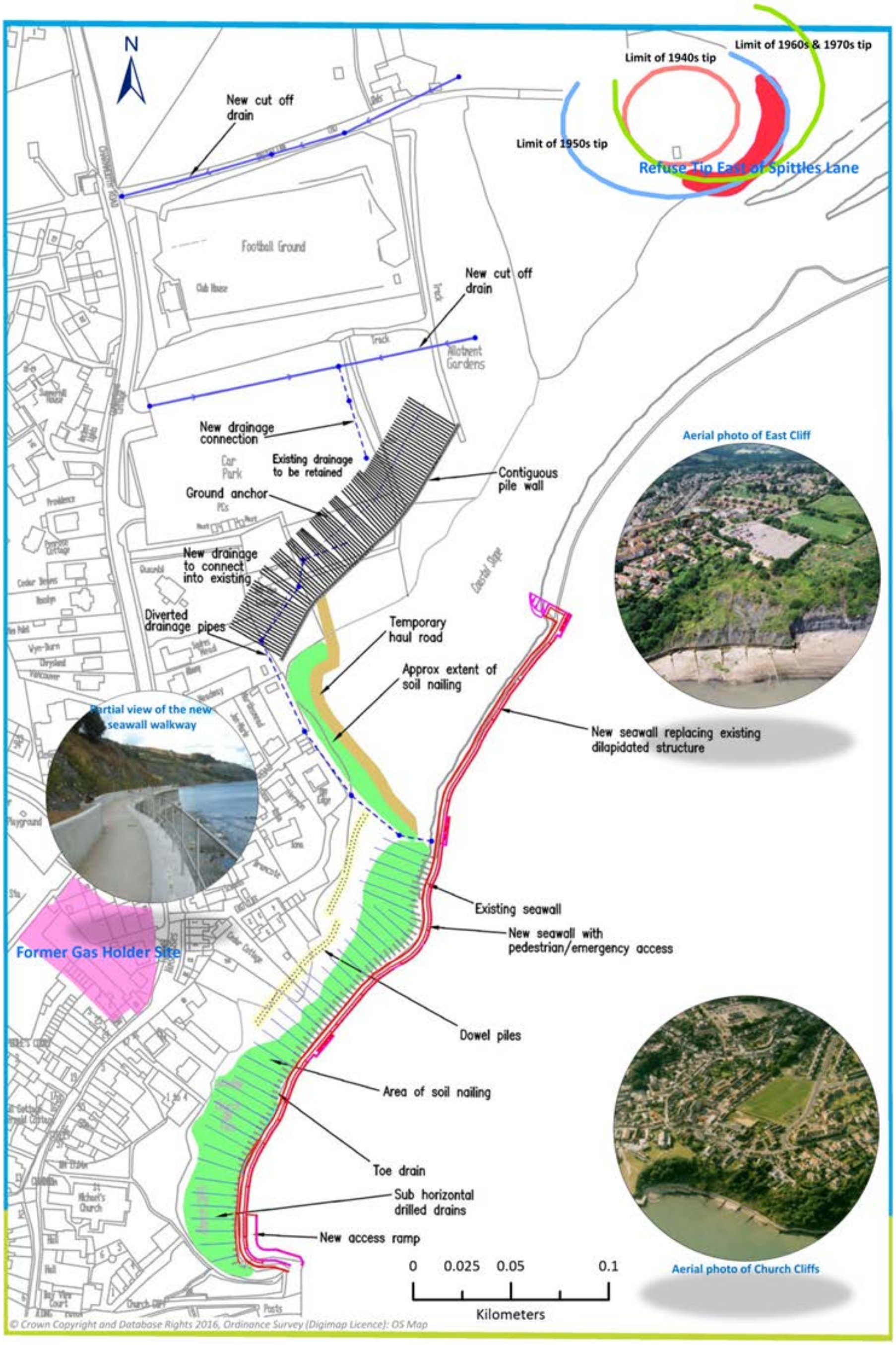

Figure 2: Drawing outlining the locations of the landfill sites (including the historic limits of the study site) and the new coastal stabilization (Phase IV) works in Lyme Regis[5].

[5] Adapted from WDDC (2014). See BBC (2014, 2015) for photos of the new seawall walkway and WDDC (2005) for the Church and East Cliffs.

3. Method

3.1 Landfill site assessment

This study focusses on the Spittles Lane landfill (SL) to better understand the potential future shoreline and environmental management challenges affecting this site, and explores a range of possible management response options. The analysis presented in this report used publicly available data as well as values and observations in published literature. Geographical models were created using ArcGIS software. Descriptions of the data used, its use in these analyses, and relevant sources/citations are provided in Table 2.

The Environment Agency's "What's in Your Backyard" landfill database[6] was consulted to investigate the history and ownership of the landfill sites at Lyme Regis. Literature searches were carried out to find information relevant to the landfill sites and to shoreline management plans for this area. Site visits were carried out on 13th January 2017 and 18th January, 2018. The full extent of the landfill was not clear due to the dense vegetation covering the site. Because of safety concerns, and because ground conditions and vegetation made access difficult, it was not possible to determine the extent of the landfill. Contact was made with a local historian, Ken Gollop, who had collated information about the Spittles Lane landfill for an exhibition display in 1990.

The methodology for the analysis of the dimensions of the SL landfill site is largely conceptual due to the complexity of the land-sliding processes. As well as a tool for visualization, ArcGIS has been used to conduct simple analysis using the described data. The surface area of the existing SL landfill site was estimated from data in the EA's historic landfill database and other sources, including the larger footprint of the landfill reported by Bennett (2007), and the site visit. The volume of the site was calculated from these areas together with estimations of the depth of the landfill in the literature (section 5.2.1). Aerial photography was also used to estimate the volume of waste released from the landfill site during the May 2008 landslide event.

[6] 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

Table 2: Data description and usage for the Lyme Regis study area.

Data Description	Usage	Source/Citation
Ordnance Survey Maps	1920s, 50s, 60s, & 80s Maps	Digimap
Aerial Photographs (1962, 2006, 2009, 2013) of the site.	1962 aerial photograph showing Spittles Lane Landfill Time-line of 'slippage' of the landfill site following the 2008 landslide Digitisation of the landward extent of erosion of the landfill site, used to calculate historic eroded volumes of waste and potential volumes at risk over time.	Bennett (2007) Plymouth Coastal Observatory (Downloaded via www.channelcoast.org). Plymouth Coastal Observatory, (2006, 2009, 2013).
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). Bennett, 2007
Digital Elevation Model (DEM) consisting of multiple LiDAR tiles with a 2m resolution mosaicked in to a single dataset. Collected in 2014.		Environment Agency, 2014.
NCERM[7] **Baseline** shapefile which identifies the 'complex cliff' area.	Visualisation of the area of risk of land-sliding and rapid erosion.	National Coastal Erosion Risk Map
Historic Rates of Erosion in m^3/yr.	Calculation of potential eroded area and volume of waste in the future over time. Examination of the impact of sea level rise on future erosive rates affecting the landfill site.	Brunsden (1996) High-Point Rendel Ltd (2000)
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.	Examination of the impact of sea level rise on future erosive rates affecting the landfill site.	UKCIP09 relative projections (sea level rise and land subsidence) (Lowe *et al.*, 2009)

3.2 Coastal erosion

The SL landfill site is at risk from erosion from the sea and subsequent landsliding events, with potential acceleration of these processes as a result of sea level rise and changing local wave climate. To assess these risks in the present and over the next 100 years, a simple assessment using GIS was applied using existing predictions of erosion at the site (see Table 2) together with simple analyses using historic rates of erosion obtained from the literature. The impact of the landslide has been described qualitatively making use of probabilistic analysis of future landsliding events taken from the literature.

A simple model of soft-cliff erosion is used to examine the impact of rising sea levels on the rate of erosion of the landfill site. Walkden and Dickson (2006) (equation 1) gives a relationship between historic and future rates of erosion (R_1, R_2), and historic and future rates of sea level rise (S1, S2).

[7] NCERM = National Coastal Erosion Risk Map https://data.gov.uk/dataset/national-coastal-erosion-risk-mapping-ncerm-smp17-rame-head-to-hartland-point

Historic rates of erosion are taken from the literature, while historic and future rates of sea level rise are derived from extracted predictions of total sea level rise.

Equation 1: The Walkden and Dickson equation for soft cliff-erosion.

$$R_2 = \sqrt{R_1\left(\frac{S_1}{S_2}\right)}$$

There are, however, a number of limitations to the application of this equation. Firstly, the fronting beach to the cliffs must be assumed to be relatively narrow. Secondly, the final 'future' rate of erosion predicted does not represent the actual rate that will be occurring, but more the equilibrium rate that the system will be aiming for. As such, it is useful as a guide to how rates will change at this site but does not provide a definitive numeric value of the eroded distance that will have occurred by the years 2050 and 2100. Importantly, erosion is episodic and long periods of relative stability may be punctuated by short periods of high instability and release of landfill material into landslides.

4. Landfill assessment

4.1 Landfill Sites

The Environment Agency's database "What's in your Backyard" identified two historic[8] "landfill sites" located within the study area in Lyme Regis as shown in Figures 1 and 2: (i) the Former Gas Holder Site (shown in pink polygon, situated at the junction between Anning Rd and Church St - centre coordinates at Easting 334341, Northing 92341) and (ii) the Refuse Tip East of Spittles Lane (shown in red polygon, situated within the landslip zone – centre coordinates approximately at 334678, 92757).

The Former Gas Holder site is now a developed area with houses and nearby playing field, and is fronted by a protected coastline (represented by the 6a20 policy unit[9] as shown in Figure 1). In addition, the coastal stretch in front of the site has 'HTL' (i.e., hold the existing defence line) as the preferred shoreline management plan (SMP) policy for all the three epochs: i.e. short (2005–2025), medium (2025–2055) and long-term (2055–2105)[10]. The sea defences along this coastline have been upgraded recently (with the Phase IV coastal stabilisation scheme officially opened on 17 June 2015[11]). The work involved a £19.5 million[12] investment on major land stabilisation and coastal protection measures, including a 390m long seawall walkway between Church Cliff and East Cliff, stabilising piles, and soil nailing and drainage systems (see Figure 2). The seawall and promenade also provides access to the town and protects up to 480 homes, roads and other infrastructure (e.g., Charmouth Road Car Park and major utility pipes and cables) from the effects of coastal erosion and landslips for the next 50 years (e.g., BBC News 2014, 2015; West Dorset District Council (WDDC 2014). The Former Gas Holder site will remain protected from potential risks of coastal erosion and flooding until 2100, and hence was not considered for further investigation within the project.

[8] The EA defines historic (closed) landfill site as: "*...one where there is no PPC permit or waste management licence currently in force. This includes sites that existed before the waste licensing regime, if a site has been licensed in the past, and this licence has been revoked, ceased to exist or surrendered and a certificate of completion has been issued*". **Note**: PPC permit – a permit issued under the Pollution Prevention and Control Act 1999. Under the Environmental Protection Act 1990, the EA "*do not monitor historic landfill sites*".

[9] See Section 3.3

[10] See: http://www.sdadcag.org/docs/SMP/Policy_Statements/19.pdf

[11] See: https://www.dorsetforyou.gov.uk/article/340944/Phase-IV---multi-million-coast-work

[12] With funding contributions of: £14.6 million (Defra), £4.27 million (Dorset County Council), and £0.6 million (West Dorset District Council).

Figure 1 shows the Refuse Tip East of Spittles Lane (SL) landfill's boundary as currently identified within the Environment Agency's (EA) database (as shown in the red-crescent polygon). Figure 2 shows historic evolutions of potential boundary/limits of the site shown by the three lines of different colour, as identified by Bennett (2007) from aerial photographs, discussed further below. The SL tip is located on sloping land directly behind the cliff-edge at an approximate elevation of ~55 to 65maOD, with part of it already within the landslip zone along the Spittles and Black Ven landslide complex (see Figure 3). Figure 4 is a schematic drawing showing the various features and principal landslide mechanisms of the complex cliff of the coastal stretch between Lyme Regis and Charmouth. The site is already experiencing issues of coastal cliff erosion, including the major landslip of 2008 (section 2.1) which resulted in the SE corner of the landfill being undercut (Figure 5). Average erosion rates are estimated at ~0.6m/year between 1995 and 2005 based on photogrammetry in 1995 and a digital elevation model generated from Lidar data in 2005; Bennett 2007). The overall landslip area is a protected UNESCO World Heritage Site (and designated as an AONB (Area of Outstanding Natural Beauty), SSSI (Sites of Special Scientific Interest) and SAC (Special Areas of Conservation) sites; see Figure 3 and Cooper *et al*., 2012).

In May 2008, the landslip exposed old waste materials from the SL landfill site, spreading them over the cliff face and the beaches below. A number of tiered steps/benches were present in the landslip zone below the landfill containing loose soil and waste materials. WPA consultants observed the evolution of these benches in a series of reports between 2009 and 2013. In WPA's 2012 report it was noted that the original footprint of the lower tier at the back of the beach was considerably reduced due to erosion. Soft soil-like material had been eroded leaving behind larger boulders of sandstone, mudstone and the heavier fraction of waste materials, such as storage tanks and hard core. The beach area to the west of the landslide toe was reported to contain frequent fragments of glass, hard core and suspected asbestos containing material. In 2012, the steepness of an upper tier of land-slipped material had lessened to the extent that pedestrian access was possible for the first time.

The landslip of parts of the SL landfill raised concerns related to contaminant leakage into the sea with potential environmental risks to local ecosystems and shellfish (e.g., Marshal, 2008; Pope *et al*., 2011) and prompted an assessment as a potential Part 2A contaminated land site by West Dorset District Council (further details in section 5.2.4).

The recent coastal stabilisation work does not include the coastal stretch in front of the SL landfill site (see Figure 2). The current and future shoreline management plans for this part of the coast consider the NAI (i.e., no active intervention) policy as the preferred option for all the three epochs (see above). This highlights the potential future risks of further waste materials being exposed and released to the environment, possibly due to direct physical erosion and/or potential leachate release, if the landslip is allowed to continue. These issues will only be exacerbated due to the changing future climate and rising sea levels (Section 6.2).

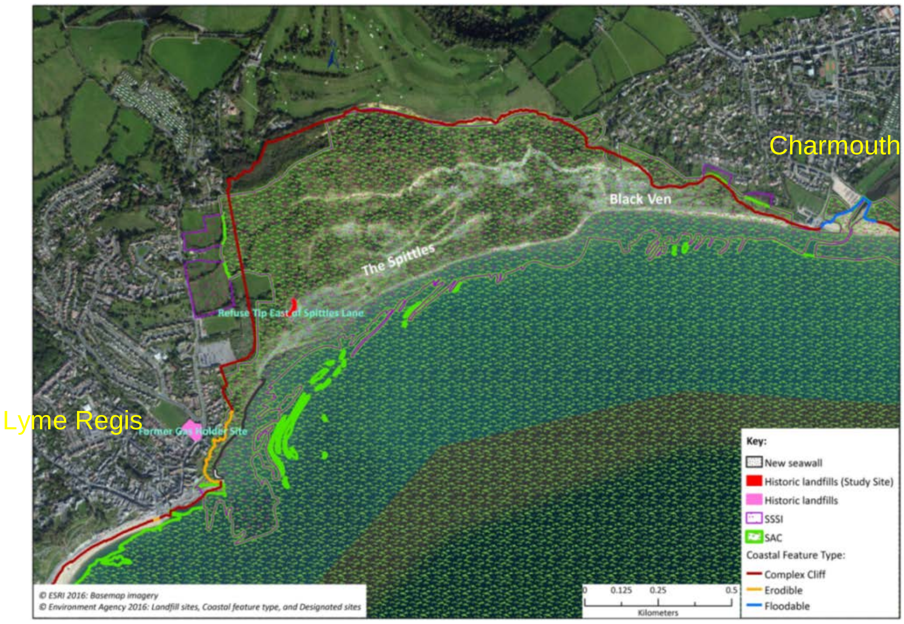

Figure 3: Lyme Regis: Location of the new seawall and the designated sites at the study site. Map scale: 1:10,000.

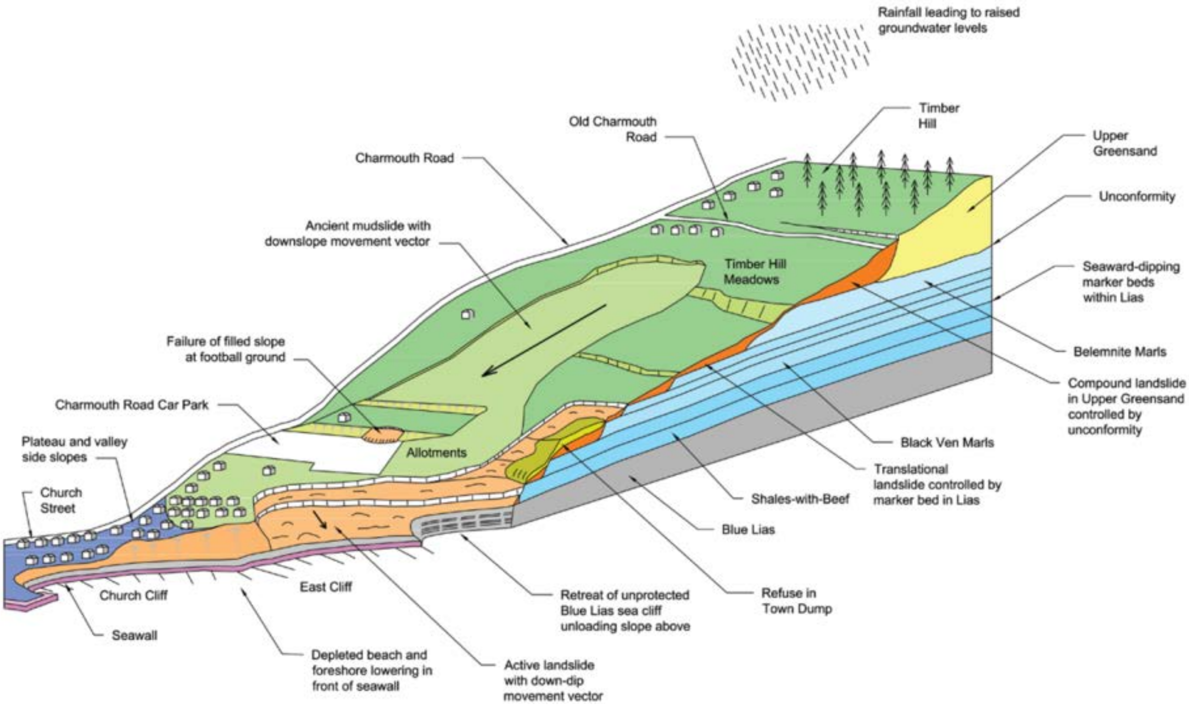

Figure 4: Schematics of the principal landslide mechanisms along the coastal stretch between Lyme Regis and Charmouth (Source: WDDC (2014)).

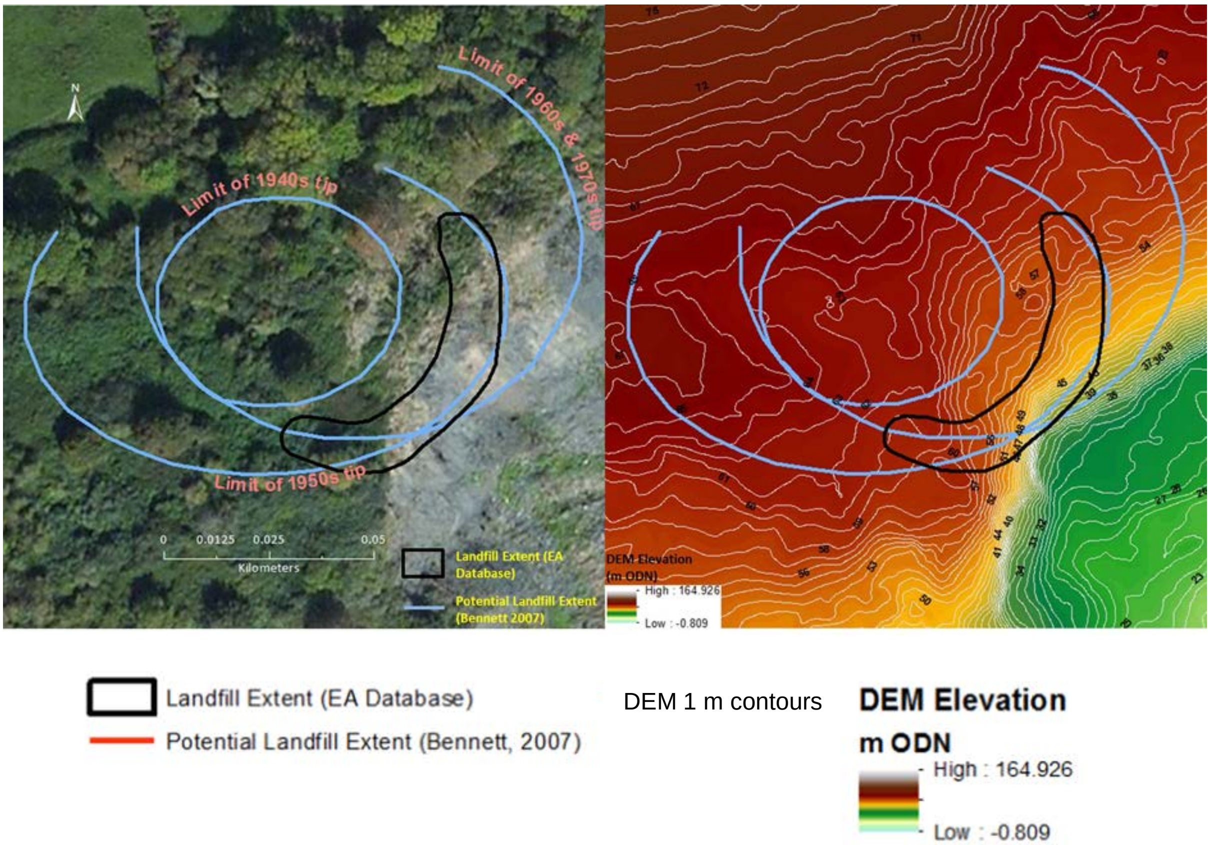

Figure 5: DEM elevations for the Lyme Regis Spittles Lane landfill site. (source: Plymouth Coastal Observatory).

4.2 Site visits

The SL site was accessed from Spittles Lane which runs to the north of a football ground and allotments. Beyond the allotments, Spittles Lane becomes a track and then an overgrown footpath, with the identified landfill lying to the south. The western boundary of the landfill as identified by Bennett (2007) lies ~ 50 metre from the eastern boundary of the allotments. However, the morphology of the land just to east of the allotments looked like “made ground” (Figure 6) which corresponds to the evidence provided by local historian Ken Gollop that waste had originally been tipped up to the boundary of the allotment site. Access to much of the waste tip was impeded by the presence of dense vegetation, including bramble briers, hawthorne and hazel bushes interspersed with more mature trees. Parts of the original asphalt haul road were still visible, leading to the cliff edge where the tip had collapsed (Figure 7). Large items of waste were observed, including kitchen sinks and car parts: only single items of waste were seen rather than extensive areas of tipped waste.

Waste was observed both at the top and bottom of the cliff. Sections of the top edge of the cliff showed evidence of waste at depths of up to 1.5 m. In areas where the slip occurred and ground had been unearthed from below, there was no evidence of landfill. It is clear that there was significant waste in the active section of the landfill, however due to landslip mechanisms, such as rotation, this is distributed throughout the landslide both horizontally and vertically. This made estimating the volume of waste in this section difficult. Figure 8 shows a view from the foreshore looking towards the waste tip; it is not possible to identify the exact position or extent of the original site from this location. Waste can be seen distributed on the benches formed during the landslip and in the landslip toe area.

There were significant amounts of waste(which were presumed to come from the tip due to the age of the material) spread over approximately 400 m of foreshore below the waste tip (between waste locations 1 and 2 in Figure 9). This material was predominantly metal, with some glass and ceramics, and occasional pieces of plastic (Figure 10). At the western end of the 400m of foreshore, individual items of waste material were spaced no more than 1 metre apart. Some of the metal waste had been collected and piled up (Figure 11). A local resident who was on the beach at the time of the visit said that this collection of metal had been undertaken by a member of the public rather than a local authority, but this was not confirmed.

Figure 6: View southwards from Spittles Lane track, from eastern boundary of allotments (January 2018 site visit).

Figure 7: View from the landfill site at Spittles lane, showing waste on the cliff face (January 2017 site visit).

Figure 8: View from the beach below Spittle Lane waste tip, showing benches (dashed red lines) formed during the landslip and some waste material on the benches (January 2018 site visit). Arrow shows the approximate position of waste tip.

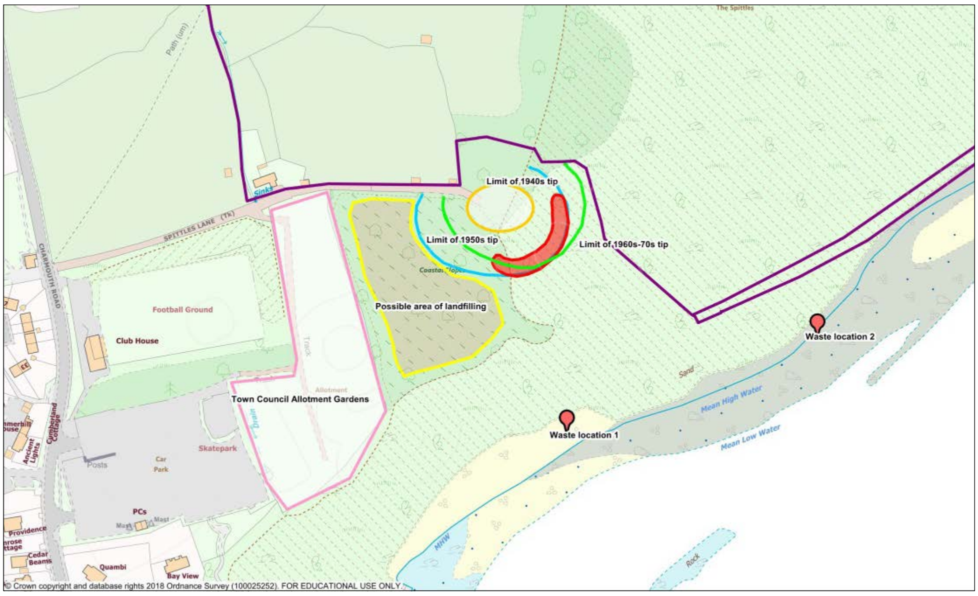

Figure 9: Map of Spittles Lane site location, showing extent of waste on foreshore between locations 1 and 2 (January 2018). The landfill boundaries (EA database, and boundaries adapted from Bennett, 2007) are shown together with adjacent land ownership (from The National Trust Land Map website).

Figure 10: Metal and glass on the beach from Spittles Lane waste tip (January 2018 site visit; pen for scale in right hand picture).

Figure 11: Collection of metal waste on the beach below Spittle Lane waste tip (January 2018 site visit).

5. Landfilling: History and Characteristics

Table 3 presents a summary of the landfilling history for the SL site, as well as characteristics in terms of the types, age, and volume of waste material involved within the case study site, which are then discussed in more detail in the subsequent sections.

The ownership of the site was not confirmed. In discussions with the WDDC, it was suggested that the land on which the SL tip is situated belongs to the town council, but it is unclear if the site was transferred to new ownership when the borough councils were amalgamated to form the district council in 1972. Lyme Regis town council owns the allotments to the west of the SL site (Figure 9). The eastern side of the tip in the 1960s and 70s extended up to the boundary on land acquired by the National Trust in 1974 (Land Registry and The National Trust Land Map website). The boundary of the National Trust land follows the hedge behind the SL landfill and runs down to a point above mean high water on the foreshore (Figure 9).

A further matter for consideration is whether any of the land-slipped waste material had entered onto adjacent landowners' land. The waste material on the beach below MHWL could potentially belong to the Crown Estate. However, checking The Crown Estate Foreshore and Estuary Map indicated that the Crown Estate owns the foreshore (below MHWL) of Lyme Regis, up to 30 metre north-east of the end of the new seawall whereas the National Trust owns the Foreshore (but above MHWL) approximately 200 m to the east of the Crown Estate land, and it is assumed (but not confirmed) that the Local Authority owns the intervening land. During the site visit waste materials were observed along approximately 400 metres of beach, 100 metres of which were directly below National Trust foreshore land. Consequently it is highly likely that waste materials within the land-slipped tumble zone have encroached onto National Trust land.

Table 3: Key characteristics summary of the Refuse Tip East of Spittle Lane in Lyme Regis.

	General Information and Landfill Characteristics	**Additional Remark/Sources**
Site name	*Refuse Tip East of Spittles Lane*	*EA's landfill database*
Site address	*Lyme Regis, Dorset*	*EA's landfill database*
Site operator	*Lyme Regis Borough Council*	*EA's landfill database*
Land owner	*Not confirmed*	*Land Registry. WDDC.*
Waste type	*Inert, industrial, commercial, and household*	*EA's landfill database*
Date of landfilling	*1929 -* *1940 – 1978* *31/12/1974 (first input) – 31/12/1990 (last input)*	*OS Maps* *From aerial photographs Bennett (2007)* *EA's landfill database*
Current surface area (*A*)	*1,050 m^2 (0.11 ha)* *~8,000 m^2 (0.8 ha)* *~14,000 m^2 (1.4 ha)*	*Based on EA's landfill polygon* *Based on landfill areas from Bennett (2007)* *Including area of land next to allotments*
Ground elevation ranges	*55-65m*	*EA's LIDAR DTM data*
Depth (*d*) of fill material	*Greater than ~0.75, possibly up to ~3.0m on average*	*HPR (2009)*
Volume (*V*) of waste remaining	*12,000 m^3 (assuming an average depth of 1.5 m)*	*Estimated based on 'd' & 'A'*

5.1 Filling History and Waste Types

Landfilling at Spittles Lane probably started in the 1910s or early 1920s. Evidence of waste deposits is recorded on the 1929 1:2500 OS map, but not on the equivalent 1903 map. Pope et al 2011 report that *"…the landfill is believed to date back to shortly after [….] 1908".* Historic aerial photographs (Bennett, 2007) also show the presence of landfilling from the 1940s through to the

1970s; photographs from March 1978 suggest that the site had been decommissioned. A Lyme Regis historian, Mr Ken Gollop, stated that the tip had been open in the 1920s and was operated at that time by Lyme Borough Council. The District Council then took on the operation of the site which was closed in 1974. During the early period of operation, the waste had been burned at the site, and also tipped into ravines from the cliff top. Building waste had been accepted at the site and used to form a haul road. Mr Gollop thought that waste had been tipped up to the boundary of the allotment site; this area is currently overgrown so landfilling in this area could not be confirmed during the site visit (January 2018). Mr Gollop also thought that a considerable amount of the waste on the foreshore had been washed away by the sea.

This information is not reflected in the EA database, which only records the site having received waste materials between 31st December 1974 (first input) and 31st December 1990 (last input). Lyme Regis Borough Council is identified as the site operator during this period. The types of waste materials deposited at the site were identified in the EA database as "*inert*, *industrial*, *commercial* and *household"* wastes[13]. Bennett (2007) highlighted that "*the landfill was on a subsiding cliff from the start*"; and the relatively unchanged extent of the waste, bearing in mind the tip's age, could be a potential sign that either landfilling input was modest or waste reduction measures were conducted on the site (e.g. burning and scrap metal extraction measures; based on local residents' anecdotal evidence).

5.2 Landfill Characteristics

5.2.1 Area, Depth, and Volume of Waste

The surface area of the landfill site based on the size of the crescent-shaped polygon currently recorded in the EA's historic landfill database was estimated at approximately 1051 sq. m (~0.11 ha). However, the area of the site could be much greater than this estimate, as there are signs of a larger footprint of the landfill as shown in Figures 2 and 5 by the historic time-line of the tip reported by Bennett (2007). In addition, reinterpretation of the 1962 aerial photo in Bennett (2007) indicates that there was an additional area of ~ 0.6ha landfilled adjacent to the allotments not previously reported. Combined, these data sources indicate that the footprint of the historic tip may originally have covered an area nearer to 1.6 ha. This area may have been reduced (to ~1.4 ha) due to the landslips and the erosion of the seaward parts of the landfill into a tumble zone of landslides and onwards to the beach.

There are few credible data that relate to the depth of waste at the site. Bennett (2007) did not deduce any specific depth information from aerial photography. In 1956 there was evidence of two tiers of waste, which from practical experience were unlikely to have been less than ~2m deep each. Shallow 1m deep hand-augured gas wells installed in 2006 (Bennett, 2007) did not reach the bottom of the waste pile. Figure 13 in Bennett (2007) depicts a cross-section through the landfill showing a waste depth of 3–4 metres, but as this is a conceptual diagram little confidence should be attributed to the depths shown. A site inspection report (HPR, 2009) following a major coastal landslide on 6th May 2008 which undercut and truncated part of the SL landfill observed that the thickness of fill material within "*the exposed tip at its' eastern area was approximately 0.75m thick and increase westwards up to approximately 2m"*. HPR (2009) commented that "*the relatively thin thickness of tip material exposed could indicate that the back scar regression has not yet intersected the main tip*".

With little basis for a reliable estimate of average waste depth, it is difficult to be confident about the volumes of waste in the landfill. However, it is probable that between 14,000 and 42,000 m^3 of

[13] The EA defines these as: ***Inert****: waste which remains largely unaltered once buried, e.g., glass, concrete, bricks, tiles, soil and stones;* ***Industrial****: waste from a factory or industrial process, excluding waste from mines, quarries and agricultural wastes;* ***Commercial****: waste from premises used wholly or mainly for trade, business, sport, recreation or entertainment, excluding household and industrial waste;* ***Household****: waste from dwellings of various types including houses, caravans, houseboats, campsites, prisons and from schools, colleges and universities.*

material remains on the site assuming an average waste depth of between 1m and 3m and an area (following some loss through landslips) of 1.4 ha. 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 50,000 tonnes.

Figure 12 shows aerial imagery of the study site in a) 2006 (pre-landslide), b) 2009, and c) 2012. Assuming a waste depth of 1 m in the landfill, it can be estimated that 500 - 1100 m^3 of waste material was released from the cliff-top site between 2006 and 2009 (depending on the chosen landfill extent). Since 2009, a further 160 - 200 m^3 waste is estimated to have been released and is either still present in the landslide zone or in the wider environment.

Figure 12: Aerial imagery showing the landfill site and progression of the Spittles landslip complex in (a) 2006, (b) 2009 and (c) 2012. (source: Plymouth Coastal Observatory).

5.2.2 Underlying geology

The geology of the area consists of Lias sediments of Lower Jurassic age (Figure 4). Layers of mudstones alternate with harder limestones which dip approximately 2 -3° to the south east and create the ingredients for the frequent slope failures that are typical of this section of coast. The harder more competent limestone resists erosion, creates perched water-tables and forms benches on which superficial deposits of mudslide debris form from the eroding mudstones. There is a seasonal flow of mudslide debris down the slope from one bench to another. Actual landslides are controlled by the steepening of slope angle and pore water pressures, which increase during wet years.

Landslides of the surrounding and underlying Lias beds to the landfill have already occurred, as the site is located on the western edge of a large well-known coastal landslip complex known as Black Ven and Spittles. From photographic evidence, Bennett (2007) reports that, by 1951, tension cracks had developed to the north and east of the site, which are currently still visible. A cliff/landfill slump with waste falling down the cliff was visible in 1956 and further cliff slumps were evident in 1965 and 1971 as a precursor to the more recent one in 2008. Gullying occurs from the centre of the landfill to the beach; a potential pollutant pathway. Further slope failures are to be anticipated.

5.2.3 Landfill Engineering: Lining/Capping

There is no evidence that landfill engineering was carried out at the site. Waste was placed directly onto original ground, involving "*direct dumping onto an active coastal slope*" (Bennett 2007). There is no indication that any significant waste compaction occurred at the site, so it can be assumed that waste was loosely placed and any compaction would have been achieved through self-weight of any material placed above.

There is evidence that a thin layer of soil forming materials was placed as a cover to the site on de-commissioning. The 2006 site investigation (Bennett 2007) reported a 300 mm thick top layer comprising gravelly sandy clayey material with rounded gravel and cobbles.

5.2.4 Soil/Waste Quality Analysis

There are a limited number of waste quality analyses undertaken by Bennett (2007). A total of 12 shallow (<50cm deep) soil samples were obtained from monitoring locations to the east and west of the site, two on the 1960-70 site boundary and one on the 1950s site boundary. Analyses indicated that the only contaminants of potential concern were poly-aromatic hydrocarbons (PAHs), nickel and arsenic for which the concentrations were close to 'soil guideline values for residential land use with potential for plant uptake' (for example, consumption of wild produce e.g. blackberries).

These analyses cannot be taken to be representative of the whole site, but nevertheless are consistent with the materials known to be deposited at the site. A report into the 2008 landslip (HPR, 2009) identified a mixture of metal, intact and broken glass bottles and jars, metal tanks and construction waste. There was significant evidence of burning, together with melted glass.

Pope *et al*. (2011) studied the concentration of metals in sediments and aquatic life in the vicinity of the Lyme Regis 2008 landslip, and attempted to link results to the presence of waste deposited on the beach from the landfill. Although elevated concentrations of certain metals in sediments and intertidal biota were found, the evidence that this was directly caused by the waste is weak; a geogenic source from the local geology seems plausible.

WDDC commissioned a number of site investigations and reports under Part 2A of EPA (1990); six rounds of sampling were undertaken between 2009 and 2013 (WPA Consultants, 2010, 2013). Descriptions of waste samples included the presence of brick, concrete, pottery, metal, glass, plastic and asbestos containing materials (e.g. cement sheets and tiles; (chrysotile) fibres were identified) in a predominantly soil matrix. The 2010 report indicated that lead concentrations were greater than soil guidance values in beach and landslip toe samples, and arsenic and nickel exceeded SGVs in some of the landslip toe samples. Polyaromatic hydrocarbons also exceeded guidance values in beach and toe samples. The 2013 report also identified lead as exceeding assessment criteria in soil samples from the toe, but not from the beach; benzo(a)pyrene and asbestos were found in both sites. Concentrations of certain metals and organics from soil samples taken from the toe of the landfill are summarised in Table 4.

Table 4: Elemental concentrations from soil samples[#] taken from the toe of Spittles Lane landfill

Species		Average	Maximum	GAC*
Arsenic	mg/kg	14.8	62	20
Cadmium	mg/kg	3.4	40	2
Chromium	mg/kg	42	129	130
Copper	mg/kg	213	1300	190
Lead	mg/kg	614	3351	450
Nickel	mg/kg	105	790	
Zinc	mg/kg	509	1500	720
PAH Total	mg/kg	26	95	40
Benzo[a]pyrene	mg/kg	1.5	11.4	

[#] Based on samples taken: March 2009; June 2009; Feb 2010; May 2012 and Sep 2013. Data not available for monitoring of May 2012

*GAC -generic assessment criteria based on Soil Guideline Values for 'residential land use plant uptake"

5.2.5 Landfill Gas

Limited landfill gas monitoring at the site was undertaken by Bennet (2007). No methane or elevated concentrations of carbon dioxide were found.

5.2.6 Water/Leachate Levels

There are no quantitative data on leachate / water levels in the site. Bennett (2007) reported a surface water logged zone to the north of Spittles lane, and the presence of seasonal springs on the south east flank of the site. The assumed loosely compacted nature of the waste, evidence of gullying in the underlying formation on which waste was placed, and seepages in the cliff face below the site suggest that any perching of water/ leachate in the site is likely to be minimal.

5.2.7 Leachate Quality Analysis

There are limited numbers of samples of water/leachate taken from seasonal seeps. Bennett, (2007) reports results for two samples. The reported units of µg/l are assumed to be mg/l. The samples exhibited none of the characteristics of MSW leachate, even in a dilute form. There was no ammoniacal nitrogen detected; organic carbon was not analysed, but values for BOD were low. Almost all other inorganic parameters including heavy metals were at concentrations that did not indicate contamination. Concentrations of sulphate were elevated compared to many landfill leachates, and while this could be indicative of contamination from industrial wastes (e.g. plasterboard) in the site, it may be related to the Lias sequence of mudstones (section 5.2.2). WPA consultants also analysed two surface water samples collected in October 2009 from spring water emerging from the waste and ponding on waste filled depressions. Concentrations of cadmium, copper and lead were below the Environmental Quality Standard (EQS) for saline waters. Monitored concentrations of zinc at 0.06 mg/l were reported at the analytical limit of detection which was 50% above the saline EQS.

Six leaching tests on waste/soil samples taken during 2009 were also undertaken and reported in WPA 2010. Leaching protocols were not specified. In four out of the six samples, direct analysis of the leachant resulted in one or more exceedances of the saline EQS for cadmium (2.5), copper (7), lead (7) and zinc (31). The numbers in brackets indicate the factors of dilution required to reduce the maximum concentrations detected to the respective EQS limits.

The relatively shallow waste depth and the uncapped nature of the site suggest that the landfilled waste has been exposed to relatively high levels of flushing through precipitation and possible upstream groundwater flows and seepages. A useful measure of how well flushed and stabilised waste is likely to be is the Liquid-Solid ratio (LS), which is the ratio of clean water that has passed through a unit dry mass of waste. A LS value of 10 indicates very high degrees of flushing and clean-up, whereas values significantly less than 0.5 are typical of most modern “engineered landfills”. An LS ratio of 22.5 was calculated for the site assuming an average waste depth of 1 metre, a dry density of 0.8 t/m^3 and effective rainfall of 450mm/year acting over a 40 year duration.

6. Erosion Risk analysis

The issues of coastal erosion and landslipping raise important shoreline management challenges, as a balance needs to be achieved “between allowing the Dorset coast to erode naturally and safeguarding people’s lives” (BBC News 2012). This raises a dilemma between “protecting the coast from erosion” (in order to reduce potential risks to people and properties in the area) and “protecting the coast from coastal protection” (in order to allow natural coastal evolution to continue and preserve the natural conditions of the area as a designated World Heritage Site). With rising sea levels and increased winter rainfall, the potential future cliff recession rates and landslide event frequencies could be significantly greater than experienced in the past. These potentially could threaten the urban areas of Lyme Regis and Charmouth and the surrounding environment. Moreover, although it is uncertain by how much, increased precipitation could also have additional implications for the cliffs due to associated potential future changes in groundwater conditions.

There are concerns about the potential current and future implications of the old landfill site to human health and the environment associated with further westward expansion of the landslip zone. It is not clear whether this has been taken into account in the shoreline management plan policy decisions, for example, in terms of what the potential future implications of the landfill would be under the NAI policy for the coastal stretch fronting the landfill site. However, if the landslip is allowed to continue to expand (especially west-ward) the presence of the old landfill site in the area presents additional challenges in future land use, environmental, as well as shoreline and coastal management planning.

The future impact of climate change on erosion on this site is difficult to quantify. However, an assessment can be made based on an understanding of the mechanisms that cause landslip events at the study site. The landslips are controlled by the underlying geology. There are a number of factors that can trigger landslip events. These include increases in groundwater (either via increased rainfall or large storm events), erosion and undercutting of the cliffs. All of these are likely to be affected by climate change.

6.1 Coastal erosion

The undefended coastal stretch at the study area (i.e., represented by the 6a19 policy unit) is expected to continue to erode, depending on the time and form of landslide events. The SMP and National Coastal Erosion Risk Map (NCERM) predictions of erosion over time along this section of coastline are estimates for the movement of the *back* of the complex cliff zone shown in Figure 13. As a result this gives little insight into how the landfill site itself will be impacted over time. Nevertheless, these projections show that in the short-term (i.e., 2005–2025), the coastal cliffs at the Spittles are projected to erode on average by 10m due to sea-level rise. By 2055 (i.e., in the medium-term), erosion is expected to grow to 25 to 50m due to rising sea-levels and associated submergence of the beaches and shore platforms in front of the cliffs. The cliff recession is projected to be 50m or more in the long-term (i.e., 50–100 years from present day).

The low frequency, high magnitude erosional events caused by landslides mean that an accurate linear rate of erosion for the 'cliff edge' which intersects the landfill site cannot be determined with any certainty. Historic rates of cliff undercut erosion at the site quoted in the literature vary. Brunsden (1996) quotes average erosion rates for the basal Lias of between 0.3 and 3.0 m per year. A report by HPR Ltd (2000) reported in Bennett (2007) quotes recession rates of 0.5, 0.8 and 1.3 m per year for areas of East Cliff prior to the construction of the defences.

To determine event probabilities in terms of future landslide events, a reliable historical landslide frequency is required and that the direct relationship between landslide activity and environmental factors (e.g. rainfall) has remained constant over the record period. However, at Lyme Regis conditions have deteriorated over time and there is no recent historical precedent for the scale of events that could occur in the future (HPR, 2009). It is almost certain that without intervention the whole of the landfill will be eroded into the sea. The timeframe over which the whole landfill will be undercut and enter the tumble zone is estimated to be between 50 and 500 years.

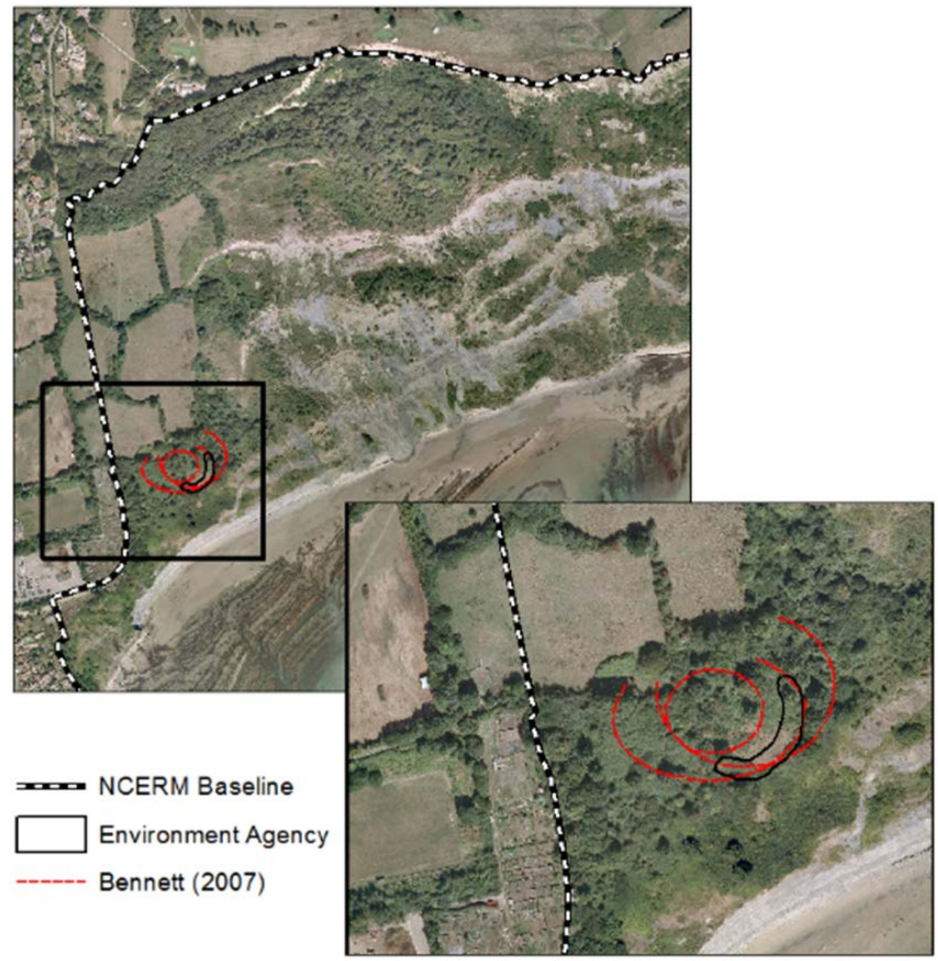

Figure 13: SMP and NCERM predictions of erosion applied to the area of the landfill site. The baseline is the black and white line.

6.2 Impact of sea level rise on erosion rates

Sea level rise promotes marine erosion, which in turn can trigger landslide events. Future rates of erosion in response to a range of sea-level rise rates were estimated using equation 1 (Walkden and Dickson, 2006) (Section 3.2). The method applies to soft cliffs fronted by small, low volume beach. Estimates of beach volume in front of the cliffs were not possible as the site is not a coastal unit which is surveyed by the South West Coastal Monitoring Scheme. Therefore, this analysis should be viewed with caution. Table 5 shows different predicted rates of erosion in the future under the four sea level scenarios for a range of estimated historic rates of erosion observed at the site. It must be noted that the estimate of 3 m/yr (Brunsden, 1996) is very high and takes into account landslide activity which would not occur consistently over time. Nevertheless, these values indicate that under low sea level rise by 2050, the future rate of erosion may not change significantly. However, by 2100 under low sea level rise, rates could increase by a third. As the projected rate of sea level rise increases, the future rate of erosion increases. By 2100 under an H++ scenario erosion could have quadrupled. It must be noted that these rates do not depict what will necessary be happening by this time period, but indicate the impact sea level rise could have on accelerating rates of erosion; in reality the stabilization period would be much longer.

While less certain than sea level rise, changes in storms, weather patterns, and regional wave climate (e.g., wave heights) are expected due to future climate change. By 2080, a two degree shift in mean wave direction and potentially reversed longshore drift direction is projected in Lyme Bay (Halcrow, 2001). These changes have additional potential implications on the cliffs and foreshore at the site, i.e. they add to the uncertainty.

Table 5: Potential future rates of erosion under different rates of sea level rise.

Historic Rate of Erosion (m/yr)	**Source**	**Sea Level Rise Scenario**							
		Low		Medium		High		H++	
		Potential Future Rate of Erosion (m/yr)*							
		2050	2100	2050	2100	2050	2100	2050	2100
0.3	Brunsden (1996)	0.3	0.4	0.5	0.5	0.6	0.7	0.8	1.0
0.8	HPR (2000)	0.7	1.0	1.2	1.3	1.6	1.8	2.2	2.6
3	Brunsden (1996)	2.6	3.8	4.6	4.9	5.9	6.9	8.3	9.7

*Based on Walkden and Dickson (2006)

6.3 Landsliding

The UKCIPO2 climate change scenarios (Hulme et al., 2002) give estimates of future potential change to mean precipitation and temperature for 50km x 50 km grid cells covering the UK. In 2009 the probability of a wet year (c.380 mm of winter rainfall) on the West Dorset coast was around 0.1 (1:10 years). The frequency of this event is predicted to rise to 0.25 for a low scenario (1:4 years) and 0.5 (1:2 years) under a high scenario. Reactivation can occur in response to the progressive effects of repeated unloading or loading after a single initiating event (e.g. a wet year sequence). The response to unloading or loading of a unit will be delayed. It is expected that reactivation of a particular landslide unit will be conditional on the occurrence of a wet year and high groundwater levels. It is assumed that a number of wet year sequences will need to have occurred before the response is fully developed. HPR Ltd (2009) indicated that there was a 95% chance that any part of the study area may be affected by landsliding within the relatively near future, over an approximate timescale of the next 10 to 28 years (baseline 2009). Landsliding could happen at any time in this period. This short timescale for all of the study area reflects the historical precedence of rapid landslide expansion in adjacent areas (for example the Spittles in the 1980s) and the sensitivity of the area to ground movement at the present day, as indicated by the results of ground monitoring.

7. Landfill management options

Waste materials released from the landfill site pose potential risks to beach users as well as the surrounding ecosystems. The direct release of waste materials to coastal waters is an offence under the Environmental Permitting (England and Wales) Regulations 2010, unless specifically authorised by an Environmental Permit.

In a series of reports commissioned by WDDC under their obligations from Part IIA of the Environmental Protection Act 1990, WPA consultants considered the risk to human health of waste on the beach and in the Spittles Lane landslip. In the most recent investigation (WPA, 2013) the site was assessed to be category 3 or 4: Human Health under Part 2A Contaminated Land Guidance (Defra, 2012). Under this guidance, category 3: Human Health indicates the land does not present a significant possibility of significant harm to human health. Such land may present risks, but the local authority does not consider that a regulatory intervention is warranted. For, Category 4: Human

Health, land is assumed not to pose a significant possibility of significant harm. However, the investigation report (WPA, 2013) stated that a full review of all data pertaining to the site was necessary for a formal classification. It was also pointed out in the report that further landslips affecting the site and erosion of the toe could change the category status.

Additional risks due to the waste have been identified, including: (i) direct physical risks to the public from further falling debris, of cuts from glass, tanks and jagged shards of metal, and from trips and falls over debris, and (ii) potential effects on marine life, such as limpets and periwinkles, identified from the metals present (see Cooper et al., 2012; p164).

The only viable shoreline management option at the SL site is No Active Intervention. This reflects two main factors: (1) the area is designated as a SSSI, and (2) the lack of a viable economic case to hold the line at this site.

Cooper et al., (2012) also assessed this site and considered three management options as potential response measures to the risks identified at the site and "based on knowledge of the waste materials to date".

- Stabilise: This was considered impractical from safety, economic and environmental viewpoints to further stabilise the landslip complex,
- Remove: Considered impractical from safety, economic and environmental viewpoints to remove waste from either the existing unaffected landfill area or, once disturbed, from within the landslip complex before it reaches the foreshore, and
- Manage *in situ*: This would involve monitoring the landslide for further movement and sampling the waste composition to continually update the site-specific risk assessment.

Managing the site *in situ* was identified as the preferred approach. Various intermittent and continuous activities have been identified in delivering this management option as discussed in Cooper et al. (2012; p164). Current management at this study site is discussed below (7.1) and potential management options for the landfill and released waste in the light of this new analysis are explored in section 7.2.

7.1 Current management

The landslide complex is in a section of coast that is internationally designated which will be allowed to evolve naturally. Furthermore, the complexity of the landslips in this section of coast and the low number of properties behind the cliff mean that obtaining funding for other courses of action would be difficult.

Following the large landslide event in May 2008, the immediate management plan was for weekly, monthly and quarterly inspections to take place, with a provision of £100,000 for the removal of waste on the foreshore. A series of site investigations and risk assessments were also commissioned, as part of West Dorset District Council's obligations under Part IIA of the Environmental Protection Act 1990, to investigate the risks to human health and controlled waters of potentially contaminated land. Regular beach inspections would be undertaken in response to landslide activity and other triggers including storms, high rainfall, high tides and large swells as well as prior to main holiday periods and following reports from members on the public. To date it is estimated that around £60,000 of this funding has been used for the removal of waste and post-monitoring of the site (Clarke, 2017, p.comm), although no waste removal has occurred since 2012.

A notice is displayed at the steps leading from the new sea wall down to foreshore below the landslip. The notice warns beach users that there is hazardous material on the beach (metals and glass) resulting from coastal erosion of an old rubbish tip and advises care should be taken.

In 2016, a review of the Spittles Lane Management Plan determined that weekly inspections would no longer be undertaken on the basis that waste materials being found on the beach had dramatically reduced. Inspections had not been carried out for 12-14 months, due to WDDC resource issues, until the final inspection on 5th May 2016. On this occasion only one small piece of asbestos was found (approx. 3"x2" and smooth from the sea). Pieces of metal were found present on the beach area and above the toe area of the slipped land, but there was nothing of any note to warrant removal. However, this is made on the basis of a decision regarding what is an 'acceptable' level of waste entering the marine environment. This threshold is not universally defined and, as a result, is inherently ambiguous. This is a key issue identified within this research study.

The use of local communities to monitor waste volumes on the beach could be important in flagging up whether the relevant authority (Lyme Regis Town Council (LRTC) or WDDC) needs to send in contractors to clean the beach. There are also many non-government organisations (NGOs) interested in beach cleaning activities in the region. These include, but are not limited to: The National Trust, The Marine Conservation Society (MCS), Litter Free Coast, Sea and Surfers Against Sewage. All of these organisations have been involved in beach cleaning and litter collection activities in Dorset in past years. In September 2016, MCS ran a beach activity on Monmouth Beach in Lyme Regis, to the west of the town. If the materials are deemed unsafe to collect, volunteers could monitor the waste on the foreshore and landslide area, providing useful information to relevant authorities to ensure action is taken when necessary. By using NGOs or community-based initiatives the cost of this landfill management option will be minimal, while being as effective as this strategy can be. This is important as arrival of waste on the shore is likely to be episodic with discrete influxes of waste arriving and being redistributed, broken up and washed away by marine processes. A monitoring approach can detect such influxes of waste arriving in the future.

7.2 Removal of waste

Bearing in mind the likely loss of the remaining landfill due to future coastal erosion, alternative strategies were considered in this study. The options considered involve removal of the waste tip and removal of the waste on the foreshore and in the toe of the landslip. However, the latter is not recommended on safety and environmental grounds, as excavation to remove waste from the toe is likely to destabilise the slope behind it.

Removal of the waste tip has been previously examined and ruled out on the basis of economic, environmental and safety concerns. This is understandable as the site is inaccessible, vegetated and is covered by a number of designations. Human activity is already believed to have influenced the development of the slip (Bennett, 2007). Engineers working on the landslide determined that removal of the waste tip was not an option due to the safety concerns regarding changes in loading at the top of the landslide complex. This is both in terms of the additional of mass caused by construction vehicles during removal, and the loss of mass once the waste material has been removed which could destabilise the slope behind the waste tip. The mass lost would need to be replaced using a fill material. As the site is highly designated and falls within a world heritage site, the selection of an appropriate fill material is likely to be complicated. Most commonly used materials would be unlikely to pass Environmental Impact Assessments.

Nevertheless, an indicative assessment of the cost of removing the remaining material in the site was calculated. Costs included excavation, transport and disposal to an alternative landfill, health and safety and geotechnical and environmental control measures and landfill tax. There are many uncertainties with the cost analysis, not least because the values chosen against the various categories (especially geotechnical stability measures) 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. Needless to say, a thorough geotechnical assessment would need to be made to understand the risks involved before carrying out this work and the cost of such an assessment has not been included in the costings. It is assumed that there is 50,000 tonnes of waste on site (section 5.2.1) and the waste will be transported to the nearest available landfill site, which is currently thought to be Kennford landfill near Exeter involving a 65 mile round trip. The disposal of the waste to landfill will be liable to landfill tax charges, although a judgement would need to be made to determine whether the waste is subject to the full tax charges (currently £84.40/tonne) or at the lower rate for inactive waste (£2.65/tonne). Two scenarios were costed, scenario A assuming that all the waste is subject to the full landfill tax rate, and scenario B where only 30% of the waste is subject to this rate and the rest at the lower rate. The full cost for scenario A is £6.8 million (Figure 14a), and for scenario B, £3.9 million (Figure 14b).

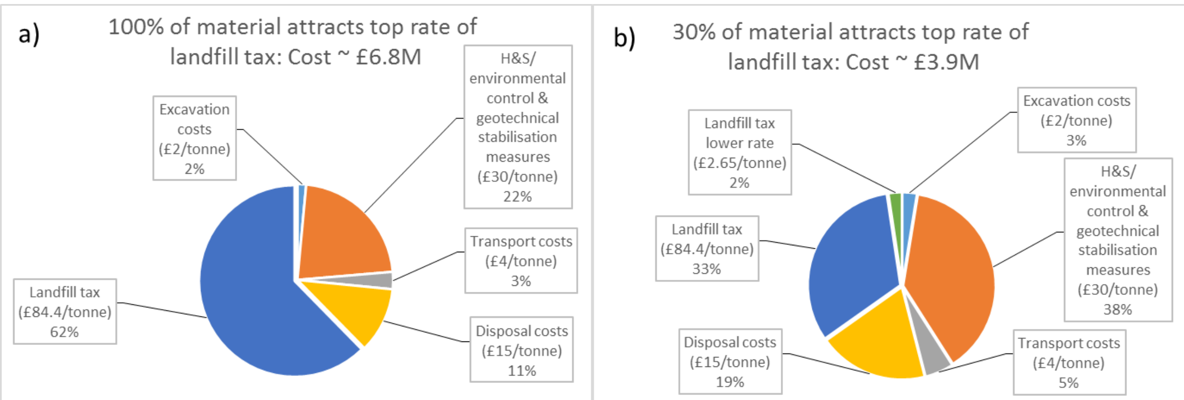

Figure 14: Possible magnitude of costs to remove Spittles Road landfill to an alternative landfill assumed to be approximately 32 miles driving distance (a) 100% of waste at top rate of landfilll tax (2018)(b) 30% of waste at top rate of landfill tax (2018).

7.3 Recommendations on long-term management of the landfill

In practical terms, following a landslip of waste material, it is difficult to envisage an alternative management plan to that enacted by WDDC and LRTC. Once waste has entered the tumble zone and is mixed into soil material in a series of benches below the cliff top, then any disturbance of this material is likely to destabilise the back slope and increase the risk of further landslips. There could be an argument that the benches of material could be dug out, processed on-site to remove wastes and then immediately replaced, but this would be highly expensive and difficult to accomplish. Hence, this report has not evaluated this option.

Natural erosional forces will result in the benches of land-slipped soil and waste being washed into the sea. This has already happened to the lower bench of material which formed on the beach following the last major landslip in 2008. The wastes that have been left behind on the beach are materials of sufficient size and density (mainly metals) to resist the erosional forces of the sea. Consequently the visible waste reflects only a small proportion (probably considerably less than 5%) of the material that has been washed out to sea.

Contaminated land assessment reports have generally concluded that the risks to human health from wastes on the beaches and contained in the land slip of fallen material do not warrant further action other than that currently agreed *(i.e. "...continuation of the ongoing visual checks of the beach and the waste for the purpose of the removal of objects that pose a risk of physical harm […] and asbestos pick up collections being undertaken by suitably trained operators when asbestos is exposed*"). Concerns remain about the potential for asbestos, and asbestos containing material, to be broken down by wave action and to become airborne, especially as there is no methodology that relates the concentration of asbestos in air to a given concentration in a source. Elevated concentrations of some contaminants, particularly lead, were also identified in individual soil samples taken from the beach and landslip but the average concentrations of all contaminants of concern do not exceed site specific assessment criteria. It is recognised that further landslip and erosion events could change this status.

The risk assessment relating to contamination of controlled waters identified the potential for the solid waste on the beach and in the landslide to leach contaminants. However, it was concluded that any point (local) exceedances of environmental quality standards arising from the leaching of wastes would be rapidly diluted within the *"volume of water in Lyme Regis Bay and the tidal flow"* and is *" not regarded as being likely to pose demonstrable pollution of controlled waters."*

What these risk assessments do not address is the direct impact of solid waste on marine life. During 2017 the prevalence and problems caused by plastics in the oceans gained widespread political and public traction in the UK, and more widely, but the effect of other waste materials are not understood. Pope *et al*. (2011) identified elevated concentrations of certain metals in sediments and intertidal biota in the Lyme Regis bay. Although direct evidence that this was caused by the erosion of waste is weak, it does highlight the need for further research and understanding in this area.

The legal framework regarding release of waste into receiving waters must be considered. It is a direct offence under section 12.(1) of the Environmental Permitting (England and Wales) Regulations 2010 to allow waste matter to enter coastal waters in the absence of an environmental permit authorising such activity. This is irrespective of whether the waste is considered to be polluting or not, and hence is an additional requirement to any obligations under EPA Part IIA. Over time and without further action to deal with the source of this "waste matter" the vast majority of the waste in Spittles Lane Landfill will end up in Lyme Bay. The current estimate is that there may be 50,000 t of such waste material on site at risk.

The other aspect that has not hitherto been recognised is that the landslip of waste material may have resulted in waste migrating onto adjacent landowner's (The National Trust) land and into protected areas (including World Heritage Site, SSSI, SPA, and ANOB designations), and marine sites such as Lyme Bay and Torbay candidate Special Area of Conservation (cSAC).

Our recommendations are that:

1. A view should be obtained from the Environment Agency about their interpretation of section 12.(1) of the Environmental Permitting (England and Wales) Regulations 2010 regarding the inevitable and largely uncontrolled release of waste into Lyme Bay. It is probable that an environmental permit would be required to authorise the current discharge of waste material.
2. A detailed survey / site investigation is undertaken to ascertain the full aerial and volumetric extent of the waste at the site, and to obtain a better waste characterisation. This information is likely to be needed whatever the outcome of the Environment Agency's deliberations relating to recommendation 1.
3. A detailed survey will necessitate improved access to parts of the site and will require removal of vegetation. The whole site would not need to be cleared for the purpose of a site investigation: potentially a number of access tracks could be cut across the site to allow investigation boreholes or trial pits to be dug to establish the depth of waste and recover samples for compositional and chemical analysis.
4. A specialist geotechnical assessment should be undertaken to assess and help mitigate the risks of any site investigation work causing slope failure. A specialist geotechnical assessment is undertaken to assess the feasibility and cost of removing part or all of the remaining waste in the Spittles Lane landfill.
5. Discussions should be held with the National Trust, private landowners, and relevant authorities regarding the future of the landfill site and the impact of waste on the foreshore in response to future erosion events.

8. 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, to Robert Clarke at WDDC for assistance with site visits and providing information relating to the landfill site, and to Ken Gollop for insights into the early history of the landfill site.

9. References

BBC News (2008). Landslip is 'worst in 100 years'. http://news.bbc.co.uk/1/hi/england/dorset/7386923.stm. Accessed 05 April 2016

BBC News (2012). *Jurassic Coast: Safeguarding Dorset's eroding coastline. http://www.bbc.co.uk/news/uk-england-dorset-19814685. Accessed 07 June 2016*

BBC News (2014). *Lyme Regis walkway opens as sea defences finished. http://www.bbc.co.uk/news/uk-england-dorset-28898711. Accessed 16 May 2016*

BBC News (2015). *Eastern Lyme coastal protection complete*. *http://www.bbc.co.uk/news/uk-england-dorset-33060524. Accessed 23 June 2016*

Bennett M (2007). *Site investigation of Spittle Lane landfill, Lyme Regis*. Report of Landscan Investigations, March 2007, Bournemouth University, 39pp.

Brunsden, D. (1996). The landslides of the Dorset Coast: some unresolved questions. Proceedings of the Ussher Society, 9, 1–7.

Burgess, K., Jay, H., Hosking, A., (2004). Futurecoast: Predicting the future coastal evolution of England and Wales. J. Coastal Conservation, 10: 65-71.

Cooper NJ, Bower G, Tyson R *et al*. (2012) Guidance on the management of landfill sites and land contamination or eroding or low-lying coastlines. CIRIA C718, London (ISBN: 978-0-86017-721-0), 174pp.

Gallois, R.W., (2009). A recent large landslide at The Spittles, Lyme Regis, Dorset and its implications for the stability of the adjacent urban area. *Geoscience in South-West England*, 12:101–108.

Halcrow Ltd., (2001). *Preparing for the impacts of climate change*. Summary Report. Standing Conference on Problems Associated with the Coastline (SCOPAC), 4pp.

High-Point Rendel Ltd., (2000). Lyme Regis Environmental Improvements Preliminary Studies: Phase IV - East Cliff: Landslide Recession Scenarios Volume 1. Report No. R/H439/2/1.

High-Point Rendel Ltd., (2009). Spittles Landslide and Former Landfill Site, Lyme Regis. HPR Report on Site Inspection 9th June 2009, HPR Capital Project Consultants, 7pp.

Hulme, M., Jenkins, G. J., Lu, X., Turnpenny, J. R., Mitchell T. D., Jones, R. G., Lowe, J., Murphy, J. M., Hassell, D., Boorman, P., McDonald, R. and Hill, S., (2002). Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK (2002) 120 pp.

Lowe, J.A., Howard, T., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S., Bradley S., (2009). UK Climate Projections Science Report: Marine and Coastal Projections. Met Office Hadley Centre, Exeter, UK (2009).

Nicholls, R.J., Townend, I.H., Bradbury, A.P., Ramsbottom, D, and Day, S.A., (2013). Planning for long-term coastal change: Experiences from England and Wales. Ocean Engineering, 71:3-16.

Pope, N.D., O'Hara, S.C.M., Imamura M., Hutchinson, T.H. and Langston, W.J., (2011). Influence of a collapsed coastal landfill on metal levels in sediments and biota – a portent for the future? *Journal of Environmental Monitoring*, 13:1961–1974.

University of Southampton (2018a). Coastal Landfill and Shoreline Management: Implications for Coastal Adaptation Infrastructure. Case Study: Wicor Cams near Fareham, Hampshire

University of Southampton (2018b). Coastal Landfill and Shoreline Management: Implications for Coastal Adaptation Infrastructure Case Study: Pennington near Lymington, Hampshire

Walkden, M. and Dickson, M., (2006). The response of soft rock shore profiles to increased sea-level rise. Tyndall Centre for Climate Change Research, Working Paper 105.

WDDC (2005) *Lyme Regis Environmental Improvements – Phase IV*. Project Appraisal Report – Preliminary Design Stage. Technical Services Division, West Dorset District Council (WDDC), 14pp.

WDDC (2014) *Lyme Regis Phase IV, Environmental Improvements*. Lyme Regis coastal protection works, Newsletter June 2014, West Dorset District Council (WDDC). https://www.dorsetforyou.gov.uk/article/340944/

WPA Consultants Ltd (2010). Site specific Human Health Risk Assessment. Rounds 1 to 4 of Soil sampling from soil and waste materials deposited on the beach at Lyme Regis by continued land-slippage from the former Spittles Lane landfill site, Lyme Regis. Report for West Dorset District Council

WPA Consultants Ltd (2013). Human Health Risk Assessment: 2013 soil sampling from soil and waste materials Lyme Regis Bay/former Spittles Lane landfill site, Lyme Regis. Report for West Dorset District Council