PHASE 2 REPORT

Options Assessment Report

Prepared for

Network Rail

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Exeter to Newton Abbot Geo-Environmental Resilience Study

Phase 2: Options Assessment Report

September 2016

Notice

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Document History

Version	Date	Description	Created by	Verified by	Approved by
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Acronyms and abbreviations

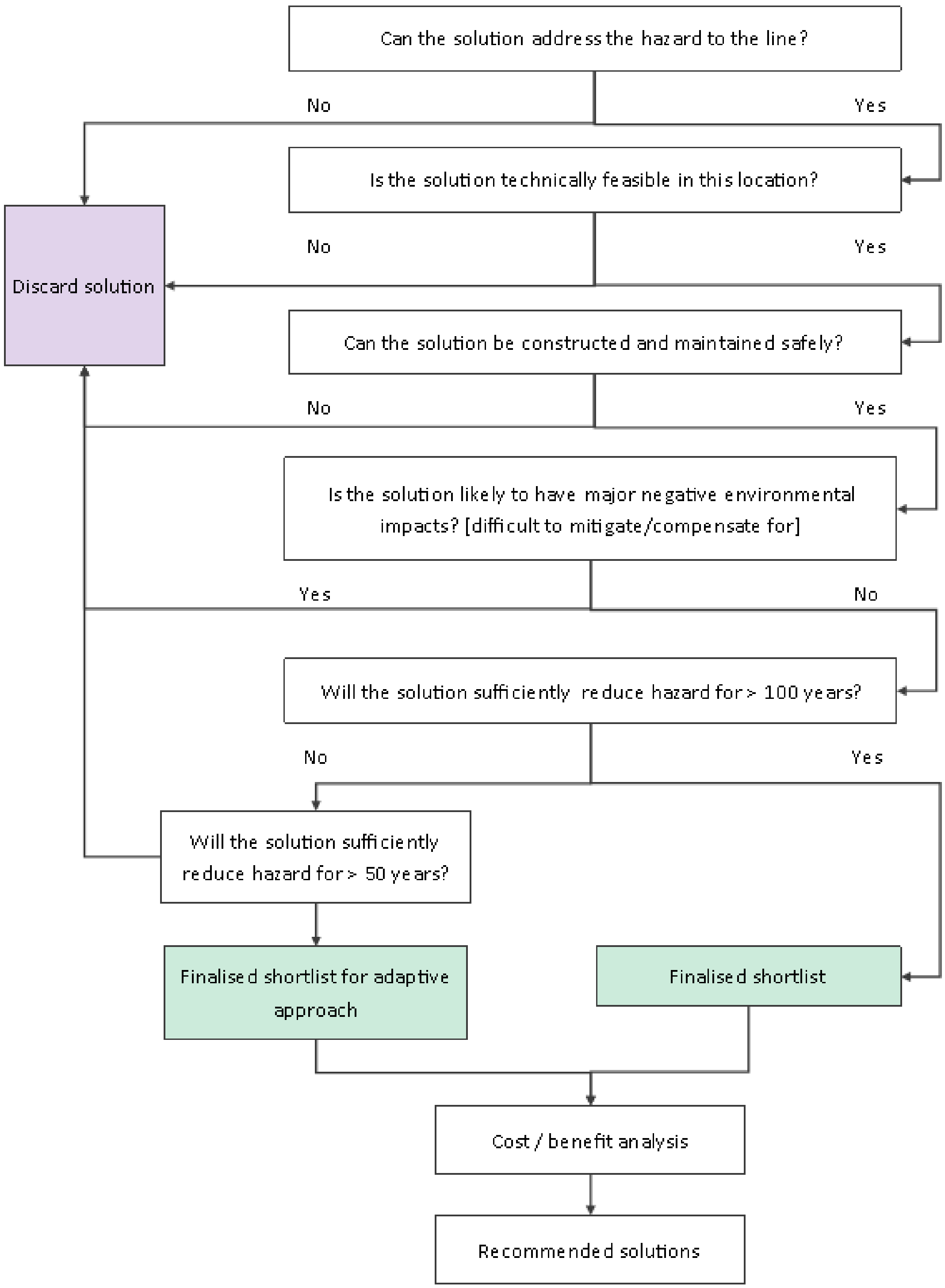
BAU	Business as Usual
BS	British Standard
CBU	Cliff Behaviour Unit
CP	Corrosion protection
CRD	Contract Requirements Document
CWR	Continuously Welded Rail
E&P	Electric and Power
EN	European Standard
ETCS	European Train Control System
FRP	Fibre-reinforced plastic
GDPO	General Permitted Development Order
GIS	Geographical Information System
GRP	Glass Reinforced Polymer
GSM-R	Global System for Mobile Communications – Railway
IP	International Protection
LiDAR	Light Radar
NR	Network Rail
RCM	Remote Condition Monitoring
RSPB	Royal Society for the Protection of Birds
S&C	Switches and Crossings
SAC	Special Area of Conservation
SEA	Strategic Environmental Assessment
SOP	Standard of Protection
SPA	Special Protected Area
SSSI	Site of Special Scientific Interest
TBC	To be confirmed
TOC	Train Operating Companies
UTX	Under-track crossing
WFD	Water Framework Directive

Non-technical summary

As well as providing a frontispiece summary to the full Options Assessment Report, this non-technical summary sets out to fulfil any wider need that may be required for the dissemination of shortlisted options amongst stakeholders and other interested parties.

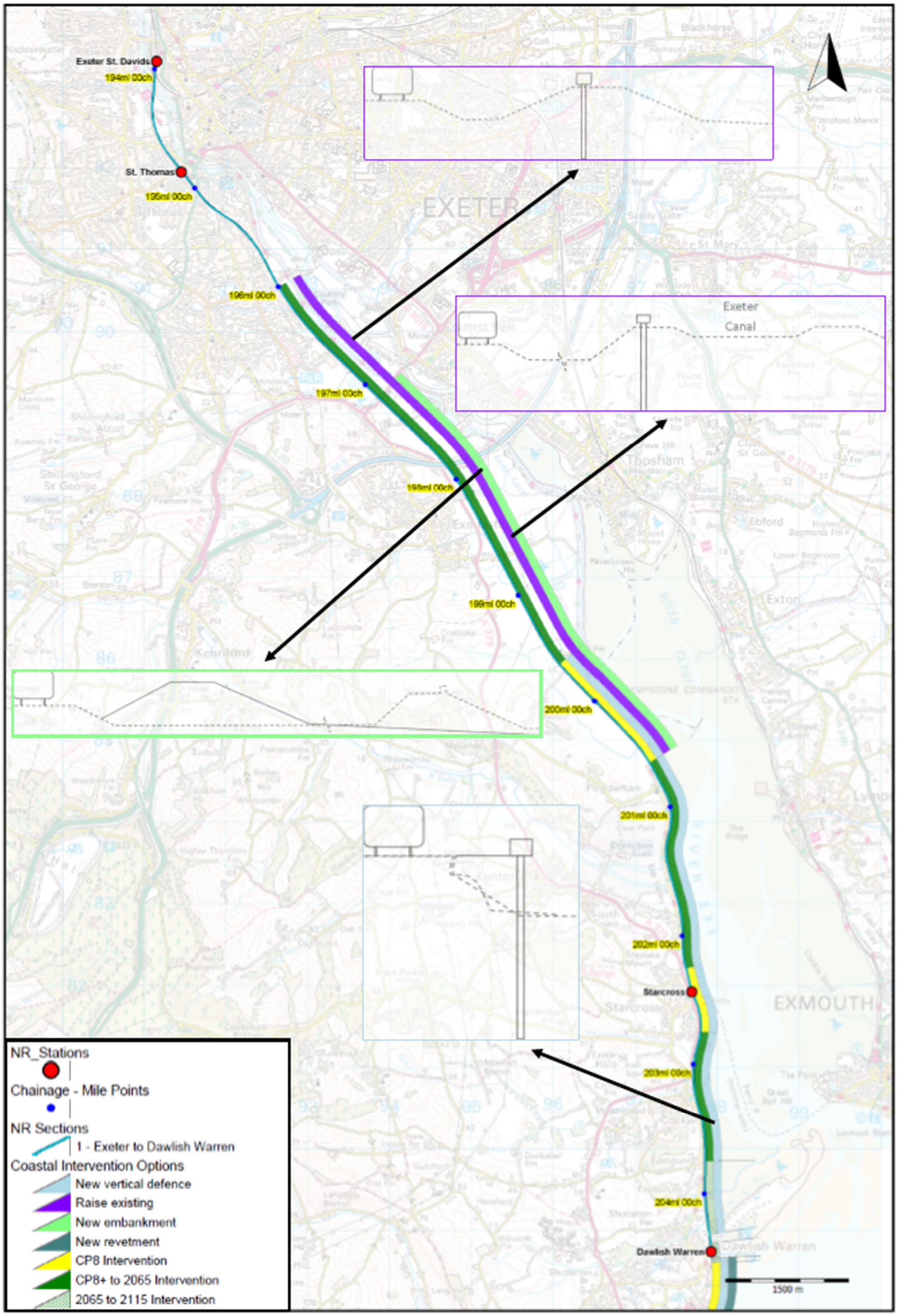
The process

The following figure illustrates the process of longlisting and shortlisting that has been adopted.



The shortlisted options

Section 1 – Exeter to Dawlish Warren



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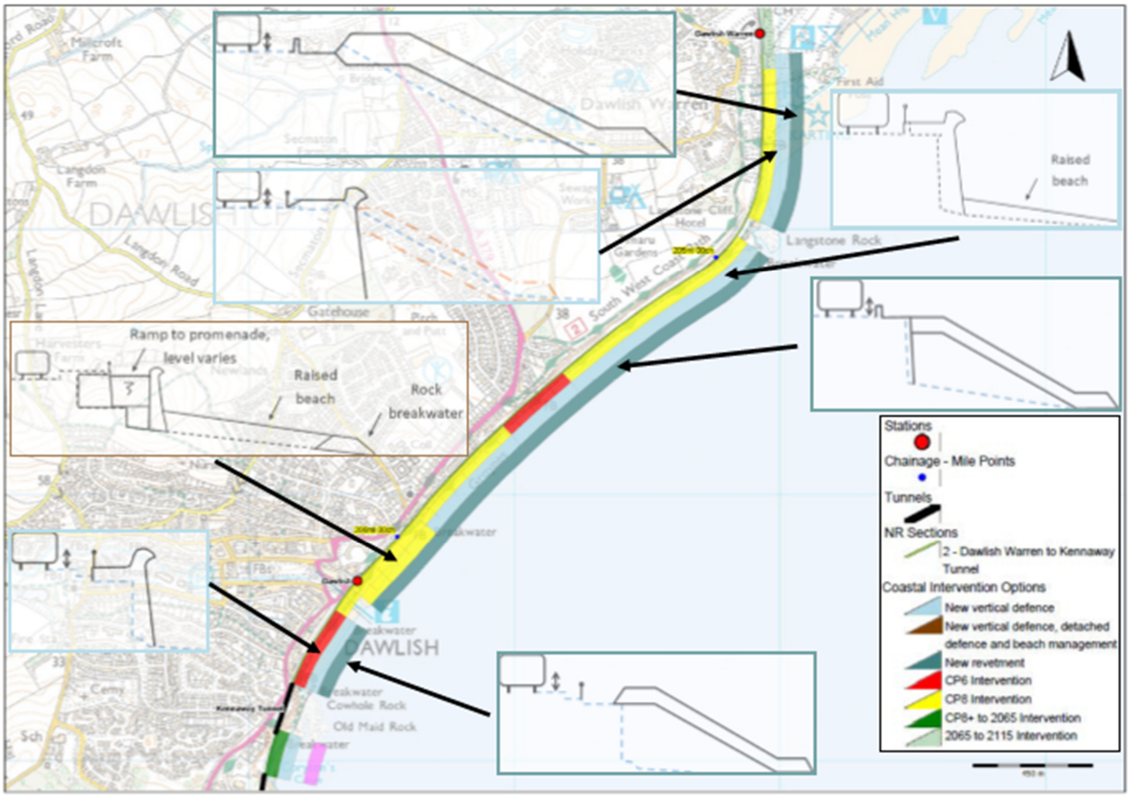
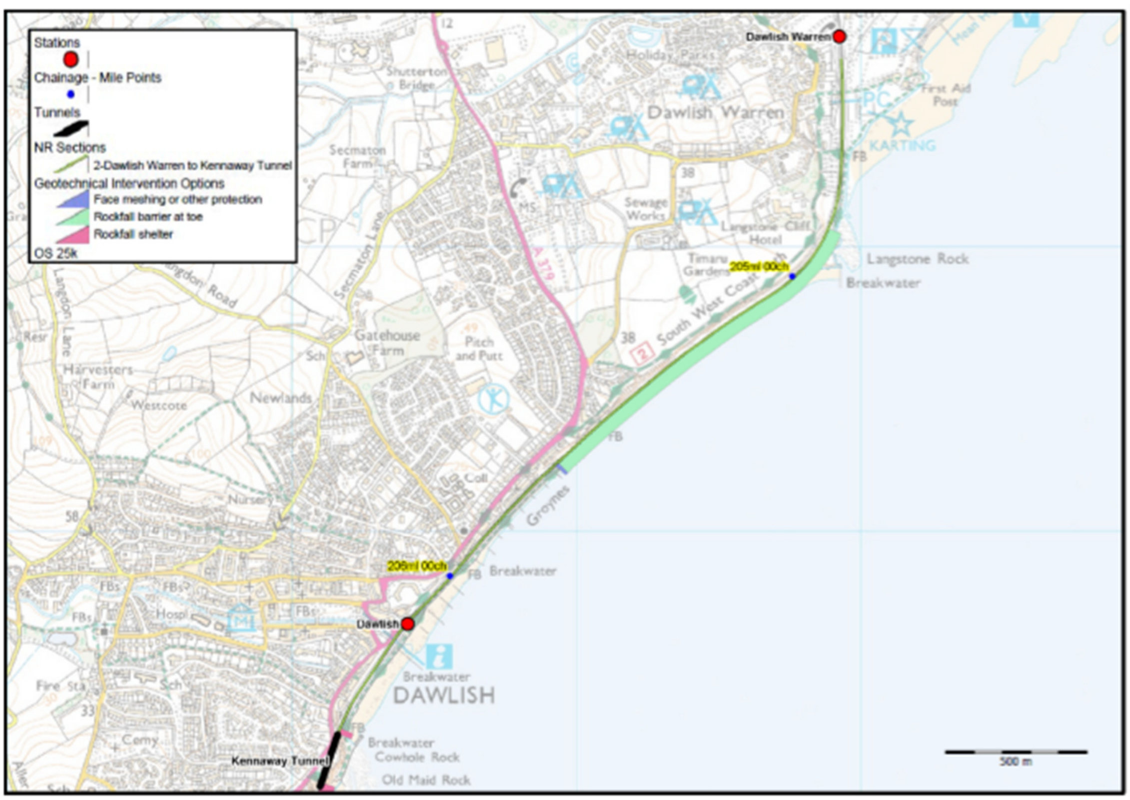
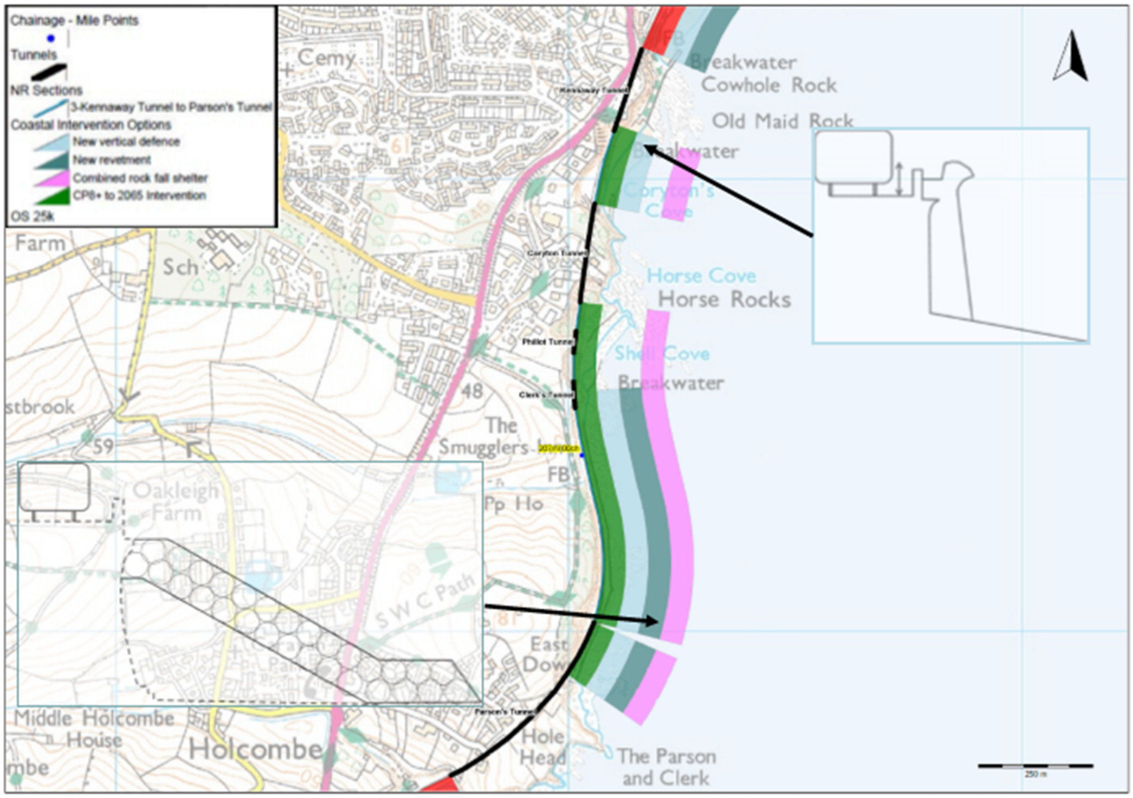
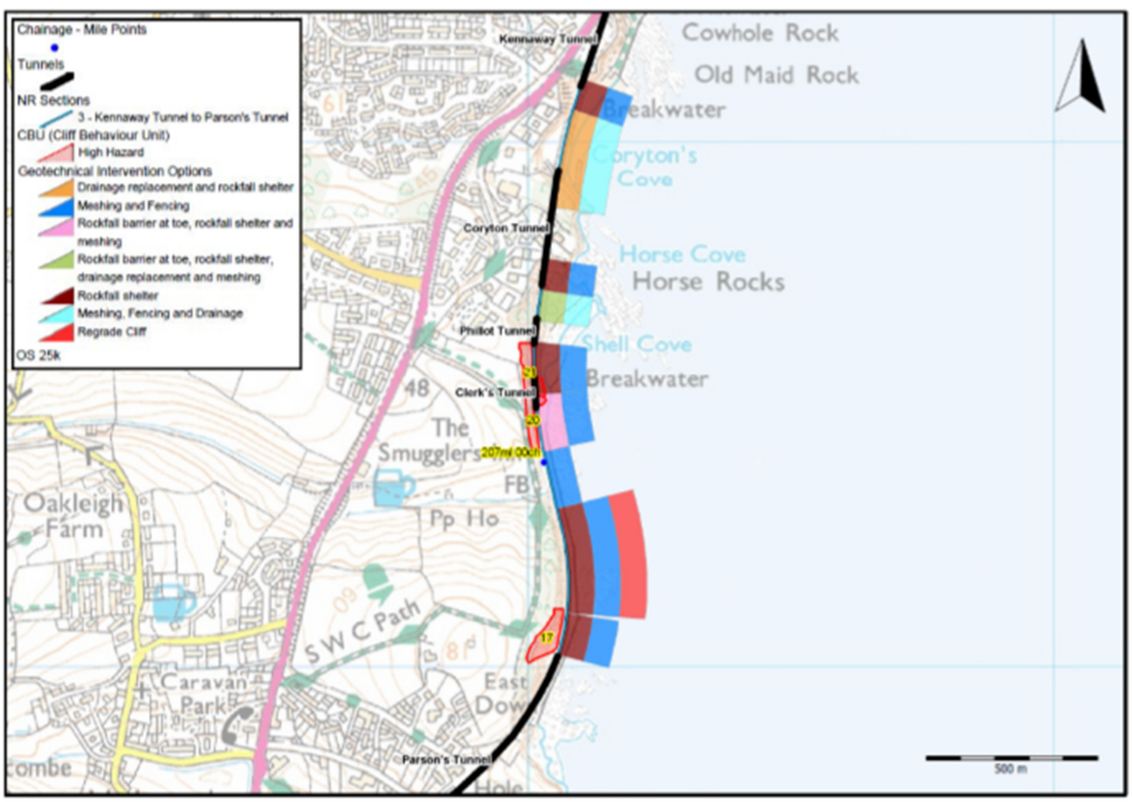
Section 2 – Dawlish Warren to Kennaway Tunnel



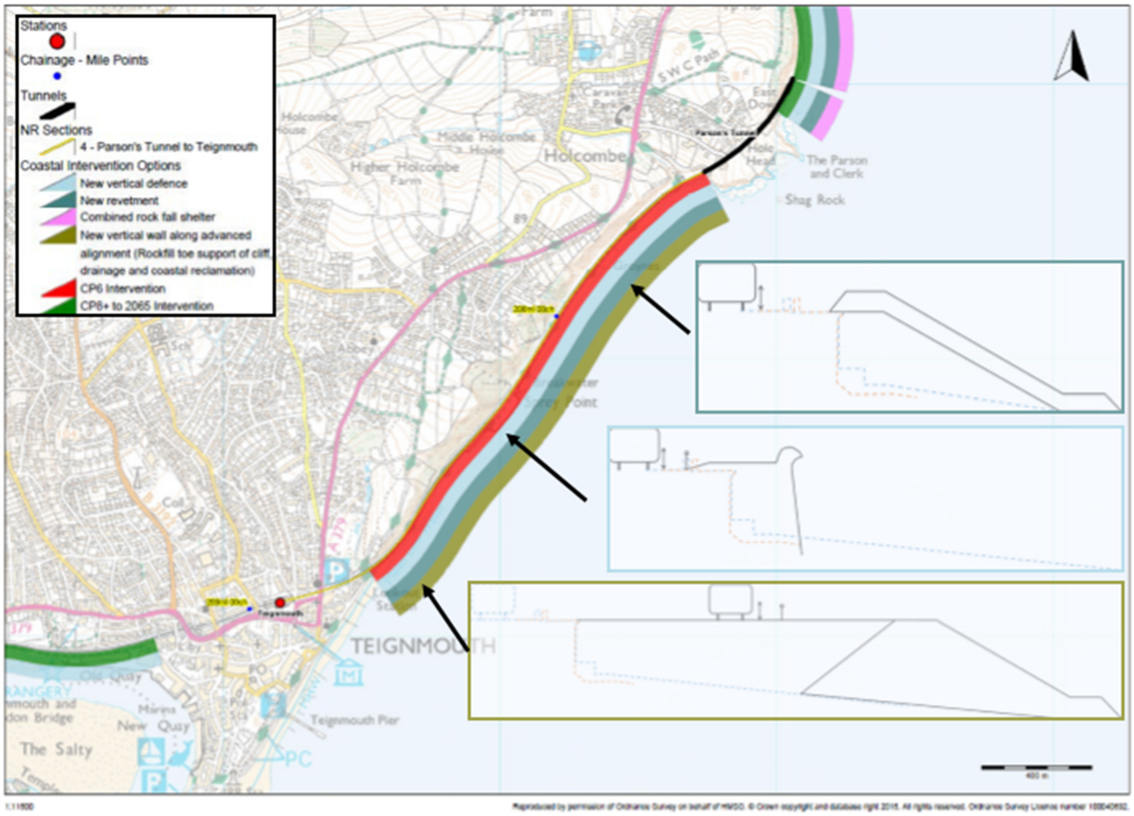


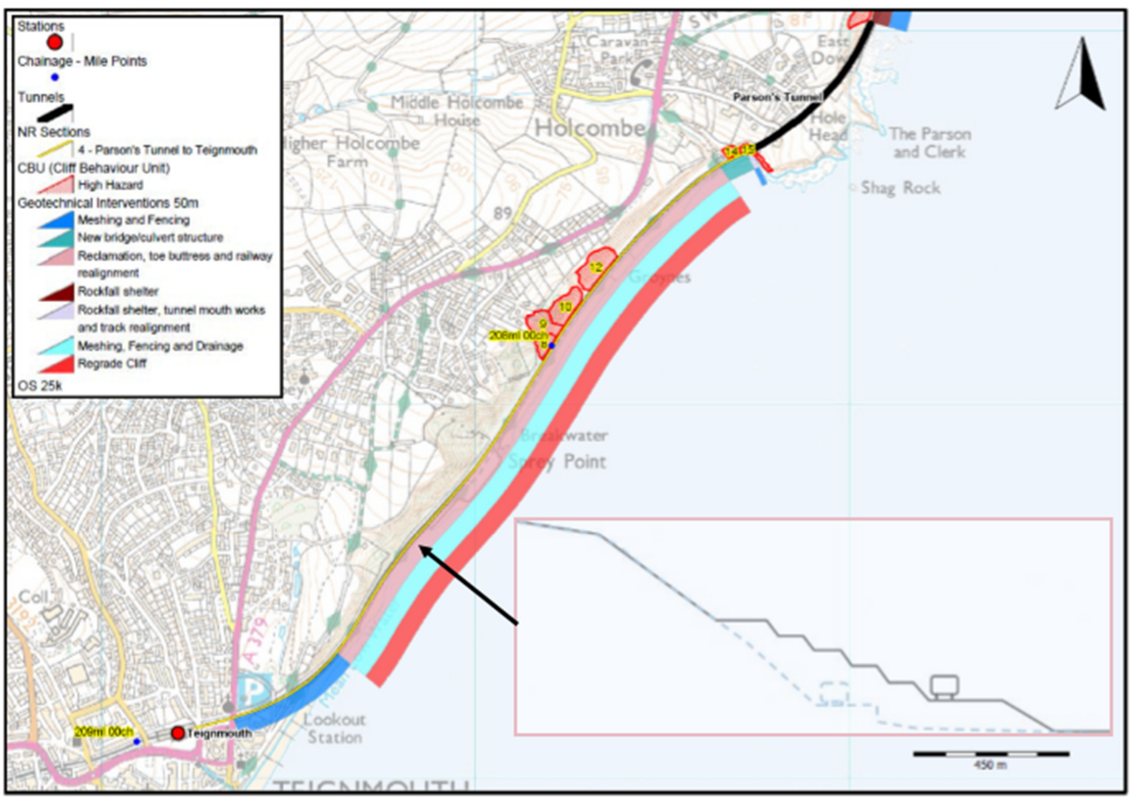
Section 3 – Kennaway Tunnel to Parson's Tunnel



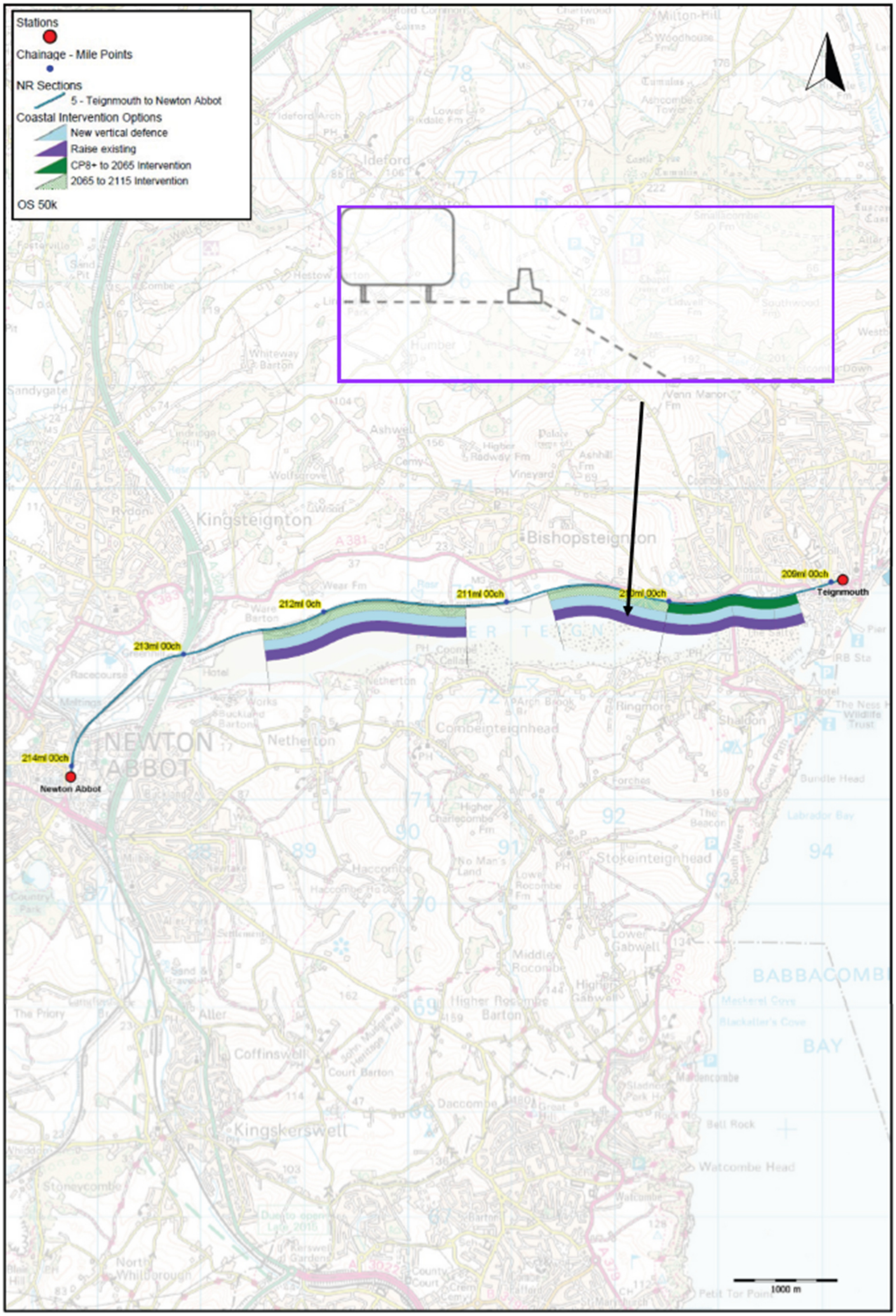


Section 4 – Parson's Tunnel to Teignmouth





Section 5 – Teignmouth



Introduction

1.1 Background

This resilience study focuses upon the 32 kilometres of the Western Route extending between the train stations of Exeter St Davids and Newton Abbot (Figure 1-1). This iconic stretch of railway follows that of Brunel's coastal route established in 1846 and includes both the Exe and Teign estuaries as well as the exposed coastal section between Dawlish Warren and Teignmouth.

This section of the Western Route carries long-distance train services from stations in Devon and Cornwall to London, Bristol, Wales, the Midlands, Northern England and Scotland. It also accommodates freight services and local services; the key local stations are highlighted on Figure 1-1.

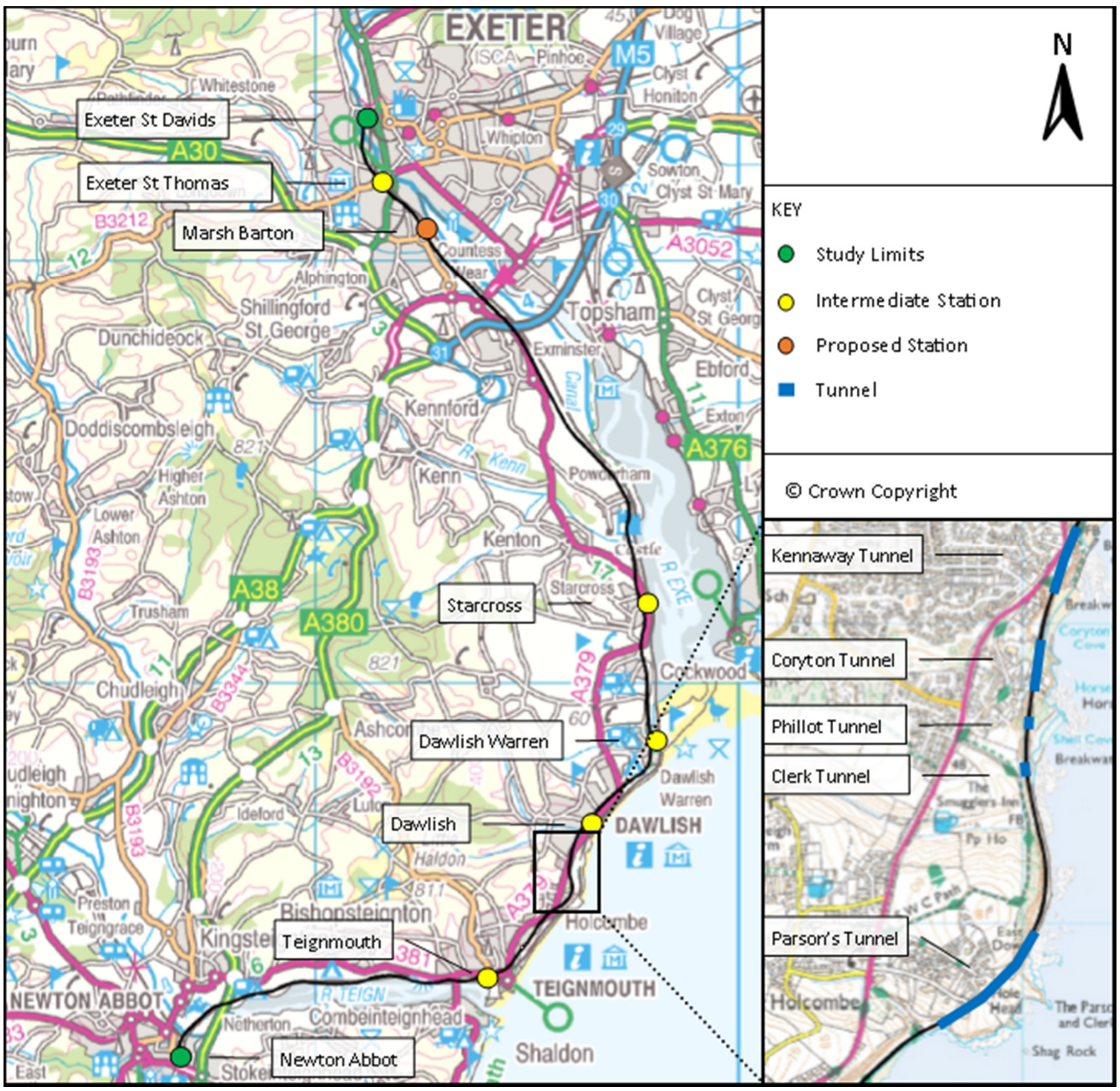


Figure 1-1: Study area with key locations

Despite Network Rail (NR)'s widely acknowledged success in repairing the catastrophic infrastructure damage that occurred in February 2014, and restoring services, the weather resilience of the railway serving Devon and Cornwall remains a significant issue for Government, local stakeholders, for train operating companies and for NR as Britain's rail infrastructure owner.

1.2 Objectives

In December 2014 CH2M was commissioned by NR Infrastructure Limited to undertake the Exeter to Newton Abbot Geo-Environmental Resilience Study. The primary objective of this commission is to develop a Resilience Strategy that identifies a holistic long-term asset management plan for the railway line that:

- gives a minimum 50 year view for engineering solutions;
- gives a Best Whole Life Cost / Social, Economic & Environmental solution;
- is based on a 100 year climate change view;
- gives operational resilience in terms of safety and performance;
- gives mean times between service affecting asset failures;
- gives sufficient capacity to accommodate the long-term strategic requirements;

The study has been split into the following three phases, with key deliverables associated with each:

- Phase 1: Definition of the Baseline
- Phase 2: Option Assessment
- Phase 3: Resilience Strategy

1.3 Report purpose

This report covers Phase 2 only and describes the process involved in producing the intermediate long and short lists and resulting outputs which support the recommendations for preferred options that are presented.

Aligned with requirements set out in the CRD, the document is structured as follows:

Section 1: an introduction which sets out the purpose and context of this Phase 2 report.

Section 2: describes the methodology and assessment criteria that have been applied.

Section 3: describes the generic coastal, geotechnical and rail asset options that have been considered. Appraisals of their respective spatial applicability are presented within referenced appendices – Appendix A containing the Coastal Long Lists; Appendix B the Geotechnical Long Lists; and Appendix C the Rail Asset Long Lists.

Section 4: considers the options that have been shortlisted from the perspectives of effectiveness, constructability and costs/benefits for the section of line between Exeter St Davids Station and Dawlish Warren Station.

Section 5: presents a similar appraisal of options for the section of line between Dawlish Warren Station and Kennaway Tunnel.

Section 6: presents a similar appraisal of options for the section of line between Kennaway Tunnel and Parson's Tunnel.

Section 7: presents a similar appraisal of options for the section of line between Parson's Tunnel and Teignmouth Station.

Section 8: presents a similar appraisal of options for the section of line between Teignmouth Station and Newton Abbot Station.

Section 9: provides a review of the alignment (or not) of the shortlisted options with stakeholder objectives raised in Phase 1

Section 10: sets out recommendations for the preferred options.

Methodology and assessment criteria

2.1 General assessment philosophy and methodology

The options assessment draws heavily upon the information compiled under Phase 1 and presented within the resulting baseline definition report. The long list which details the generic options which could be considered for both maintaining or enhancing the resilience of the different sections and sub-sections of the line have been outlined by each discipline – coastal, geotechnical and rail – largely independently of each other. At this stage some options have been ruled out as being unachievable or not beneficial, while others have been evaluated further to consider their viability as potential solutions worthy of shortlisting.

Workshops with NR were initially used to establish the content of the long lists and then to filter these down to short lists. In this respect Workshop 4 principally focused on the generic options that had been identified; at Workshop 5 (where the Environment Agency and Teignbridge District Council were represented) the location and suitability of the long list options was reviewed along the route and these were further refined at Workshop 5A.

The outcomes of this process for each of the coastal and geotechnical options are presented in Section 3 and Appendices A and B. Those determined to warrant further evaluation have been appraised from a technical standpoint, their potential environmental impacts, any potential health and safety factors, and the relative costs of the solutions.

The rail asset options are assessed against their ability to reduce susceptibility to and resist the effects of climatic influences on rail assets. This also includes better anticipating these effects by improving the flow of relevant information and improving recovery of systems following an event. Each type of asset is considered separately (track, signalling, telecoms, electricity & power, stations, off-track, ancillary structures, tunnels and bridges) by identifying current failure modes and those which are likely to occur more frequently or worsen as a result of climate change.

In terms of presenting a short list of solutions, decisions as to whether or not they should warrant shortlisting are based on the appraisal approaches referred to above.

The shortlisted options have been assessed with regards to their effectiveness at increasing resilience and reducing hazard, issues of constructability and their associated costs. The conflicts or wider benefits of each solution, where appropriate in combination, are also provided. Although this process is primarily focused on the coastal and geotechnical options, options for some specific rail assets are also included. These are discussed in further detail in Section 2.2 below.

2.2 Assessment criteria

The effectiveness of shortlisted coastal and geotechnical options has been assessed using the following criteria:

1. The degree to which the proposed option reduces or eliminates the hazard at a particular location along the route. For the geotechnical assessment this has been done using the judgement-based hazard classification used in and applied across the CBUs outlined in previous reports. For the coastal asset assessment it sets out to reduce disruption and improve the resilience of the coastal defence structure to damage under extreme storm events.
2. The degree of resilience the proposed option adds to the railway at a particular location or CBU. Each shortlisted option should reduce the hazard and increase resilience for maximum effectiveness.
3. The constructability of the option, see Section 2.2.1 below.
4. Indicative costs and anticipated benefits of the solutions.
5. Any alignments or conflicts with identified stakeholder objectives.

2.2.1 Constructability

The constructability assessment considers the health and safety risks and constraints posed by each option during both the construction and maintenance periods. Increasing sea levels over the 100-year appraisal period will have a significant impact on the accessibility of coastal and estuarine defences for the inspection and maintenance regimes of these assets. Tidal working in itself poses significant health and safety risks to operatives during construction and future maintenance.

2.2.2 Environmental Constraints and Opportunities

Due to the environmental sensitivity of the study area and the requirement of the Resilience Study to set the framework for future projects of significant scale that will require development consent, it has been decided that a Strategic Environment Assessment (SEA) should be produced to accompany the Resilience Study. The short list options presented in this report will be subject to an environmental assessment in this SEA and will be appraised against a series of objectives and assessment criteria.

Generic long lists

3.1 Options for reducing coastal hazards

This section presents the potential options considered for the coastal defences which protect the Exeter to Newton Abbot railway line from wave over-topping and coastal erosion. Although the principal focus is to provide resilient options which will enable the railway line to continue to operate over the next 50 to 100 years with minimal disruption from weather-related events, a joined-up approach which embraces the wider impacts and benefits to the local community and to the natural environment is also considered.

The generic coastal options are elaborated upon in the following sub-sections. Such options are to be appraised, both in isolation and in combination, for the different circumstances and phasing options within the study's sub-units. Linked to these generic solutions, Appendix A provides both a summary listing of shortlisted options for each sub-unit and further detailed appraisal.

3.1.1 No active intervention – do nothing

As the name suggests this, generic option does not account for any maintenance or capital works being undertaken in the future. The existing assets would deteriorate more rapidly than if they were maintained and once any coastal defence asset failed no replacement would be installed. This option would result in ultimate failure and closure of the line.

This option needs to be included as a comparative option within the Strategic Environmental Assessment, however, it will be noted in this assessment as a non-viable option.

3.1.2 Hold the line or advance the line

Within this heading a number of options are considered that would result in the coastal defences remaining along the same line as at present or moving the defence line seawards.

3.1.2.1 Asset management – maintain

Maintain consists of keeping the coastal defences at their current height and extending their residual life through maintenance. However with time, the current standard of protection from water levels and wave overtopping reduces due to sea level rise. Continued maintenance will not prevent significant damage or failures such as those sustained during the February 2014 storm events and therefore there would likely still be some requirement for emergency capital investment in the future. Maintenance of the asset can be undertaken in two forms – in a reactive manner or a proactive manner. Some examples of the existing coastal defence assets are given in Figure 3-1.

Reactive maintenance – consists of maintenance works being undertaken following a storm event which has either caused disruption to services and/or damage to the railway or coastal defences.

This is option is not recommended to be taken forward to the short list due to the lack of resilience it provides and increased health and safety concerns.

Proactive maintenance - is undertaken as problems are identified to prevent any further deterioration and or prevent/minimise damage/disruption should a storm event occur. This would also include for a maintenance budget for the continued upkeep of the existing defences.

This is considered to be a "Business as Usual" or "Do Minimum" option as referred to in the CRD and therefore, is recommended to be carried forward to the short list.

Figure 3-1: Views of current defences along the Exe Estuary and open coast

3.1.2.2 Sustain

Sustain refers to improvements to the coastal defences over time to keep their current standard of protection in line with climate change and consequential predicted sea level rise. Sub-options within 'sustain' are as follows:

Local raising of existing coastal defences – to provide the required level of resilience, however, this relies on the existing defences' structure and foundation being sufficient to allow additional height and width. It may only be possible for part of the scheme life to be able to do this, and then new structures would need to be constructed.

This option is recommended to be taken forward to the short list for the estuary sections. The comparatively short residual life on the open coast would limit the opportunity for delivering a high level of resilience.

New or improved channel – is only considered for areas within the upper Exe estuary where the main river channel is located in areas of open land. This option may entail the existing river channel being widened or a secondary channel constructed thereby allowing additional volumes of water to pass without flooding onto adjacent land.

This option is not recommended to be taken forward to the short list as it provides limited benefit to the railway.

Raising of existing railway – albeit not necessarily a 'coastal defence' option, the raising of the railway line may result in the line being higher and/or above wave and water levels thereby reducing and/or preventing damage to NR assets from waves and water. Depending upon the location of the line in relation to the coast the raised line may form a barrier to coastal elements and hence provide additional protection benefits to land and properties located on the landward side of the track. Such an option is potentially constrained by existing clearances at tunnel portals, under existing footbridges, and by other rail asset considerations, notably at stations and therefore would mainly be applicable in the estuary areas.

Due to the high level of disruption, the increased height of railway embankment required, and the consequential very high costs, this option is not recommended to be taken forward to the short list.

3.1.2.3 New coastal defences (Improve)

Improve options involve the construction of new coastal defences which would be designed to cater for increases in waves and sea level rise due to climate change over the design life of the structures. Designed to current standards the residual life of a new defence structure could be 60 to 100 years depending on the form of the structure and its location.

Vertical (or near-vertical) structures – consist of forms of construction such as a wall which could be constructed in a number of materials i.e. concrete, brick, steel sheet piles etc. and potentially involving a recurve wall (to reduce overtopping) near its crest. The form and type of materials would be considered at the 'short list' stage to ensure that the appearance of the structure is in keeping with the area where it is located and that the materials are sufficient to withstand the forces applied to them in that location.

This option is recommended to be taken forward to the short list for all sections.

Sloping structures – commonly this will consist of some form of revetment placed on the seaward face of a structure to help reduce/avoid the impacts of waves from a storm event. Such structures typically are formed in concrete blockwork, rock and stone.

This option is recommended to be taken forward to the short list for the open coast sections. Along the estuaries, environmental designations significantly limit the suitability of this option.

Earth embankments – are generally limited to areas where wave action is minimal and hence only water levels are an issue. Therefore, they are commonly used in estuary locations and where appropriate it is recommended this option is taken forward to the short list.

Figure 3-2: Examples of vertical wall (left) and stepped concrete and rock revetments (centre and right)

3.1.2.4 Integrated rockfall shelter and coastal defence

This option consists of constructing additional rock fall shelters to protect the railway from cliff falls and landslides above the line and wave overtopping from the seaward side. This option only applies to the open coast section. The structure would take the form of a fully enclosed rockfall shelter (similar to the shelter at Parson's Tunnel north portal) with the vertical walls being designed to withstand horizontal wave loading as necessary.

This option is recommended to be carried forward to the short list for the Kennaway to Parson's Tunnel section due to the dual hazard of rock fall and overtopping that is present.

Figure 3-3: Full rockfall shelter which could provide protection from wave overtopping

3.1.2.5 Detached defences

Nearshore detached breakwaters involve the construction of structures parallel to the shore to reduce wave energy along the established defence line. These structures are normally formed from rock and/or concrete blocks. Breakwaters are only of use in reducing wave impacts and hence have limited use in areas where limited wave action occurs such as within sheltered estuaries. At Bradwell-on-Sea on the Essex coast, old lighter barges were sunk to create a series of detached breakwaters. However, this was carried out over 25 years ago and such a solution would be likely to have significant environmental impacts.

This option is recommended to be considered in the short list as a combined option for the Dawlish Station section.

Figure 3-4: Detached defence

3.1.2.6 Beach management techniques

Beach control structures, such as groynes, help to contain beach sediment and increase the volume of beach material in front of the seawall. This option would comprise of a combination of capital and maintenance works: timber or rock groynes would be constructed on the foreshore and beach nourishment would be required initially. Beach recycling could then be carried out as required to ensure beach material remains within the immediate area and is not lost offshore.

The increased beach level can help to reduce wave impacts on coastal defence structures behind them. Creation/retention of beach material can also be of benefit in areas of high public use such as beaches. However, depending on the wave regime and sediment movement along the coastline, additional beach material may have to be regularly imported to maintain a sufficient beach level.

This option is recommended to be considered in the short list for Sections 2 and 4. It is not an appropriate solution within the estuaries and due to the nature of Section 3 (small pocket beaches bounded by headlands) the effectiveness would be extremely limited. Due to the condition of the existing groyne structures along the frontage, beach recycling on its own would not be effective and therefore new structures would be required.

Figure 3-5: Images of beach management and control structures

3.1.2.7 Sand engine

This option consists of importing a large volume of sand and placing the material close to shore. It relies upon wave and tide effects to 'feed' the foreshore with material to create a beach which will help to provide additional protection to the main defences similar in manner to beach management techniques. However, as noted in the option above, additional beach material may have to be regularly imported to maintain the viability of this option. This is essentially a beach nourishment scheme, but with little or no further intervention or management after the initial placing of material.

There is a high level of uncertainty with this option as only one example in the Netherlands (see Figure 3-6) has been developed to date. The form of the foreshore (dune system) and the coastal processes are very different from the study area and therefore this example is not directly comparable. Further studies to ensure suitability and monitoring to prove viability would be required. Therefore, this option is not recommended to be taken forward to the short list given high levels of uncertainty over its suitability and likely effectiveness.

Figure 3-6: Sand engine in development in the Netherlands

3.1.3 Retreat the defence line

Retreat the line refers to moving the main coastal defence line landward. Many of the options discussed in Section 3.1.2 can be undertaken in this manner. By retreating the defence line, the existing foreshore and/or habitat between the existing and new defence line will help to create an additional defence/barrier to waves and may help reduce wave heights. If sufficiently large, the additional 'flood' area can also contribute to reducing overall water levels.

Managed realignment which establishes flood storage reservoirs provides controlled or 'managed' flooding to areas often well inland from existing defences. The extent and depth of flooding is controlled and is bounded on the landward side by either high ground or a secondary set of defences.

This option is not applicable on the open coast due to the high wave energy and the high ground levels behind the defence line which are both unsuitable for the successful development of intertidal habitats. It is however to be considered within the Exe estuary, notably to the North of Powderham, should the existing EA defence line be abandoned and the principal defence line fall back to the railway embankment.

3.2 Options for reducing geotechnical hazards

The geotechnical hazards that threaten the operation of the Exeter to Newton Abbot railway line have been identified in the Phase 1 Baseline Report (CH2M, 2015a). This section presents the approach and options to mitigate geotechnical hazards. The main focus is to identify options to mitigate geotechnical hazard that will result in improved resilience over the next 50-100 years to cliff instability and slope failure events that could otherwise lead to significant impacts, damage and lengthy line closures. However the approach also embraces the wider impacts and benefits of options to the local community and to the natural environment in order to provide a holistic view of the preferred options to build up the resilience of the line to slope instability and coastal defence failure events in the future.

The generic options to mitigate geotechnical hazards are elaborated upon for the coastal route in the following sub-sections. Within the Exe and Teign estuaries, the railway is routed mostly on low embankments or at grade, although there are several low cuttings as the railway heads west from Teignmouth. Assessment of these earthworks indicates they have not posed a significant geotechnical hazard or risk to the operation of the railway in the past over and above what would be considered as 'routine levels' for railway earthworks. Therefore, the Exeter to Dawlish Warren (Langstone Rock) and Teignmouth to Newton Abbot sections are not identified for special consideration in the same way as the three open coast sections.

Linked to these generic options, Appendix B includes a summary long list of geotechnical options considered to be available for potential shortlisting for each sub-unit (in this case identified for each Cliff Behaviour Unit (CBU)) along the line between Langstone Rock and Teignmouth Station, and concludes with sub-unit appraisals in support of the summary listing.

Recognising that some of the options can be expected to improve resilience in the shorter-term, up to 50 years, and others for up to 100 years, this further generic option subdivision is recognised in the sub-sections which follow.

3.2.1 No Active Intervention – Do Nothing

This option does not account for any maintenance or capital works being undertaken in the future, and would represent a less active regime than is currently in operation.

For existing earthworks and natural cliffs that do not benefit from any engineering measures to prevent or arrest cliff instability this would remain the case in the future under this option. That factor, together with ongoing natural processes affecting the slopes (e.g. rock weathering and erosion) would tend to result in increased impacts on the railway from slope failures. It is also possible, if not likely, that changing environmental conditions (e.g. climate change, groundwater levels, and rates of rock weathering) in the future could further lead to a decline in the stability of earthworks and natural cliffs unless intervention occurred.

Furthermore, the existing engineered systems will deteriorate over time as they reach the ends of their design lives. The existing engineering measures installed to mitigate cliff instability are of a range of ages and standards. For the purposes of this assessment, it may be reasonably assumed that they may have a residual life of between 5 and 20 years from the present; they are likely to deteriorate if they are not maintained, and under this option, no replacements would be installed. The outcome would be eventual failure of the engineering measures, which would be expected to result in increased impacts on the railway from slope failures.

It cannot therefore be assumed that apparent stability and historical levels of performance of the earthworks assets can be reasonably projected forward under this option. Taking into account the deterioration of both natural and engineered slopes, geotechnical failures and hazard events would become more frequent and potentially of greater magnitude in the future.

This option is included as a comparative option for the Strategic Environmental Assessment, however, it will be noted as a non-viable option.

It would not be appropriate to take this option forward as it will lead to an increase in the frequency and magnitude of geotechnical hazards and risk to the safe operation of the railway.

3.2.2 Maintain Current Measures

3.2.2.1 Rock face protection – passive rockfall meshing

A number of CBUs have passive rockfall meshing installed to prevent 'uncontrolled' free fall of rock and debris onto the line (Figure 3-7). Dependent on the engineering geological environment, the hazard level and the level of protection required, it is a commonly used and generally effective method for containing rockfalls over areas of exposed rock face. It should be noted, however, that this option does not treat the fundamental causes and mechanisms of cliff falls.

In its passive form, which is the commonly applied type evident on this section of the route, rockfall meshing is designed to 'contain' the detachment of rockfall and cliff debris, which will tend to accumulate behind the mesh and/or disaggregate at the slope toe. The design of the mesh aperture and spacing of pinning to the rock face will depend on the geology and anticipated size of rockfall blocks, which requires investigation and modelling. Large rockfalls and cliff failures may not be contained (or prevented) by this option and regular maintenance is normally required to clear accumulated debris from behind the mesh to prevent bulging and over-straining of the mesh and other structural elements.

This option provides effective mitigation against rockfall hazard for exposed areas of cliff face. Dependent on the design standards and materials adopted, meshing can provide short-term resilience of between 5 and 20 years, and longer, c.50 years, provided regular maintenance, repairs and replacement is carried out.

Figure 3-7: Meshing near Parson's Tunnel

3.2.2.2 Slope reinforcement and protection – soil nailing

Superficial deposits and/or highly weathered rock forms the upper parts of the cliff slopes in a number of areas along the coastal section of the route. Reinforcement of such slopes by soil nailing is a potential technique that has been used in some locations in response to past cliff instability, notably at Windjammer (CBU11) (Figure 3-8) and Woodlands (CBU10). If used together with a structural mesh and face erosion protection, the technique can be effective for treating slope instability in suitable strata e.g. at Lyme Regis (Figure 3-8).

Figure3-8: Left – Soil nailing and meshing at Windjammer (CBU11) and at East Cliff, Lyme Regis

3.2.2.3 Toe protection – renewal of toe barrier

A number of CBUs have some form of barrier (fences and/or solid barriers) installed along the up cess, protecting the railway from cliff instability hazards above (Figure 3-9). Rockfall catch fences up to some 3m in height have been designed and installed in several locations (e.g. Woodlands) where past cliff instability and rockfalls have occurred. Elsewhere, lower lineside fences have been installed. In some areas, the open fences are supplemented by solid (timber sleeper) barriers which provide additional protection against debris run-out. Some barriers are relatively recent, some are believed to be 10 to 20 years old. The fences have been installed either reactively or as ad hoc protective measures, and one result of that is that the up line has differing levels of cliff fall run-out protection along the coastal section.

The installation of a barrier and rockfall catch fence can provide effective protection and mitigation of cliff instability hazard and run-out events from impacting the line. It is a pragmatic and cost-effective solution where the magnitude of cliff fall and debris run-out can be restrained and where there is sufficient space to install the barrier or catch fence system. As such, this option can provide mitigation of small to medium size rockfall and landslide run-out.

A properly designed barrier and rockfall catch fence can provide resilience for c.20 years or longer, up to 50 years, provided regular maintenance and repairs are carried out. Dependent on the location and the size of any failure relative to the barrier, it may not be appropriate that rockfall and landslide debris (talus) is removed from behind the barrier fence where the accumulated debris provides support to the cliffs/slope above. Conversely, an effective barrier height should be maintained to protect against rocks bouncing over the fence onto the railway.

Figure 3-9: Cliff fall barrier at Woodlands (CBU10)

3.2.2.4 Drainage

Sub-horizontal bored drains have been constructed in a number of areas of the slopes between Parson's Tunnel and Teignmouth. CBU11, Windjammer, is one notable example of the use of that technique for facilitating water egress from the cliffs and allowing its conveyance down to the toe. Bored drains such as these tend to be installed on a prescriptive basis rather than being designed to bring about a quantifiable increase in stability. In addition, they are recognised as having a limited design life as silting up is likely to lead to reduced efficacy over time, unless the drains are periodically flushed.

Records indicate that cess drains are installed along some lengths of the up cess (Figure 3-10). It is understood that these are designed to drain surface water from the track ballast but they also serve to collect surface water draining from the cliffs. During extreme weather they have potential to be overwhelmed by the volume of surface water run-off, they are also vulnerable to siltation from materials washed down from the cliffs, reducing flow, silting up and blocking the drains. Therefore, it is important that the cess drains are regularly maintained and cleared of silt to ensure full function and capacity.

Figure 3-10: Upgrading track cess drainage

A number of under-track cross (UTX) drains discharge surface water from the up line cess drains. They are generally pipes of less than 300mm diameter, but there are some larger culverts, such as the one at Shell Cove (Figure 3-11). If they become blocked, or possibly under extreme tidal conditions, water may back up and potentially cause flooding of the cess and ultimately the line. The outlets of the UTX drain pipes on the sea wall are generally fitted with flaps to prevent sea water, beach gravel/debris ingress during tide-locked periods. In locations where these flaps have broken or have been removed, the UTX outlets are vulnerable to blockage from shingle and other debris. Therefore, it is important that the UTX drains are regularly maintained and cleared of debris to ensure full function and capacity.

The existing cess and UTX drainage system, if properly functioning, will assist in providing short-term resilience provided regular maintenance is carried out. In respect of future resilience and the likely impacts of climate change, the medium and longer-term capacity of the cess and UTX drains should be reviewed and improvements made under maintenance to increase capacity and resilience in the short-term.

Figure 3-11: Drainage culvert beneath track at Shell Cove

3.2.2.5 Vegetation

The cliffs and slope crests adjacent to the up line and above the tunnel portals between Kennaway and Parson's Tunnels are in places densely vegetated with mature trees. In the past vegetation clearance was carried out to reduce fire hazard. In general, dense vegetation of low to medium height is likely to be beneficial to the stability of the cliffs due to the binding action of roots and evapotranspiration of surface-groundwater through tree root-leaf systems. Therefore, in most cases it is recommended that general clearance of vegetation and trees is not carried out, except for local and temporary clearance of vegetation for access.

However, there are some exceptions to this general rule. Mature trees located on the cliffs and rock ledges, and within 5-10m of the cliff top and above the tunnel portals, can act to de-stabilise the cliff or rockface due to root wedging, loading and tree-throw action during windy conditions (Figure 3-12). In this situation, coppicing or removal of mature trees would be prudent to prevent rock and tree fall onto the line. It cannot be assumed, therefore, that apparent stability and historical levels of performance of the earthworks assets can be reasonably projected forward under this option. This form of appropriate vegetation management on the open coast section between Dawlish and Teignmouth should provide short-term resilience against tree fall and the effects of root wedging causing cliff falls.

Figure 3-12: Mature trees above Shell Cove

3.2.3 Increase Resilience Options (up to 50 years)

Over a 50 year timescale, design improvements and extension of existing solutions to adjacent areas along with appropriate maintenance to mitigate geotechnical hazard and risk can be considered to build resilience for the future. In respect of rock face protection and cliff toe barrier systems, it is recognised that some current materials and systems may offer theoretical design lives in excess of 50 years. However, in the context of the exposed marine environment of the coastal section of the route, it is considered prudent to put a 50 year upper limit on such systems, beyond which major repair or replacement is likely to be needed.

The options are covered in the sub-sections below.

3.2.3.1 Rock face protection – rockfall ‘passive’ meshing systems

As evident from a number of locations on the coastal section of the route, wire mesh draped on the face of a rock slope can be an effective method of containing rock falls close to the face and preventing them from free fall or bouncing onto the line below. If space permits, rock trap ditches can be excavated at the toe of steep cliffs to collect debris that extends beyond the mesh. If there is no ditch or fence, the lower end of the mesh should be at or very close to the slope toe (typically no more than 0.6m above the toe) to prevent run-out of rock debris.

The main features of a mesh installation are as follows. Anchors are installed on the slope above the rockfall source and support cables consisting of an upper perimeter cable and vertical reinforcement cables are attached to the anchors. The mesh is secured to the cables with lacing wire, 'hog rings', or other types of fasteners. Key to the longevity of any system is the gauge of the metallic elements and the corrosion protection provided. The mesh is not anchored at the bottom or intermediate points on the cliff to allow rock to fall to the cliff toe in a controlled manner. Accumulation and weight of rock debris behind the mesh can cause it to fail and should be removed through regular maintenance.

3.2.3.2 Rock face protection – rockfall 'active' stabilisation and meshing systems

Active cliff stabilisation systems combine various methods of soil and rock protection against erosion and shallow instability including scaling and trimming, rock dentition, rock bolts, dowels and meshing. Several CBUs have active meshing systems installed but the majority are of passive mesh type described above. For areas of relatively competent strata, rock bolts and dowels can be used; meshing is then installed, tensioned and secured onto the nail or bolt heads. In some cases it may be appropriate to carry out minor scaling and trimming of the cliffs to permit a good profile to be achieved.

If soil or highly weathered rock faces are exposed, particularly in upper faces, then a composite solution of soil nailing and bolting/meshing may be appropriate, as installed in Shell Cove as part of the Dawlish Phase 4 works. Although the cliffs between Dawlish Warren and Teignmouth are generally formed of sandstone and breccia, they are often highly weathered close to the surface, particularly in their upper parts, and the material can therefore behave more as a soil than a rock. It follows that where new or replacement meshing is to be installed that active cliff stabilisation and meshing should be considered to increase resilience.

3.2.3.3 Cliff toe protection – upgrading of toe barrier

A variety of barrier fences and rock fall catch fences can be installed to increase resilience over a nominal 50 year period. The required type of barrier and its dimensions will depend on the extent of the line side cliff hazard and the potential energy of rockfalls and or debris run-out. Options include gabions and concrete blocks or geofabric and soil barriers where space permits. Where space is tight, as is the case for much of the line between Dawlish and Teignmouth, use of structural barriers and rockfall catch fences (Figure 3-9 and Figure 3-13) are likely to be preferred.

Figure 3-13: Tethered rockfall catch fence

Along the cliff section north of Dawlish, installation of an appropriately designed barrier system is likely to be the most effective prevention of rockfall and shallow slides onto the track or lineside due to space limitations and the SSSI interest, which is likely to limit, or possibly preclude works on the cliffs. The prevention of surface water run-off and washout of fines from the cliffs and talus slopes, should be considered as part of the design, which might include a composite barrier system comprising a lower solid barrier and upper wire catch fence; choice of materials such as timber sleepers versus concrete, and coated wire versus galvanised wire. Drainage might also be installed on the upside of the barrier system where needed to convey surface water run-off away from the barrier and railway.

A continuous barrier catch fence system designed to current standards would provide an improvement and standardisation of mitigation compared to the current arrangement, and thus improve resilience against geohazard in the short to medium term. Catch fences tend to absorb rockfall energy by deformation and localised damage to components. In the design of such systems placed close to the track, likely deformation limits should therefore be taken into consideration in the selection and siting of systems. Periodic maintenance and/or repair will also be necessary, particularly after a significant rockfall event.

3.2.3.4 Drainage – trackside and slope drainage, UTX drains, culverts

Control of surface water and groundwater is key to the stabilisation and prevention of landslides and cliff instability. Above the slopes, on accessible slopes, and at cliff toes, a priority should be to intercept and convey surface water run-off and groundwater flows away from cliffs and unstable areas, and thereby control one of the fundamental causes off cliff instability and landslides.

The steep nature of most of the cliffs prevents much drainage installation actually on the slopes, although sub horizontal bored drains are present in some areas. The extension of that technique to other areas, whilst recognised good practice in pragmatic terms, could not be relied on to bring about measurable improvements in slope stability (and hence route resilience). One possible area where the slopes are accessible, and hence amenable to drainage improvement might be at the toes of the talus slopes between Langstone Rock and Dawlish.

A variety of methods are available from surface pipework and trench drains (Figure 3-14) to more sophisticated sub-surface drainage systems such as vertical pumping wells or siphon drains, and sub-horizontal drains installed from the base of slopes and cliffs along critical horizons. The hydrogeology study (CH2M, 2015b) of the section between Parson's Tunnel and Teignmouth provides further information and assessment of the sources of surface water run-off and groundwater that contribute to cliff instability and flooding of the up line cess. This report along with the geohazards briefing report (CH2M, 2015c) provides the current state of knowledge and understanding that should inform a review of the layout, optimisation and design of cliff and line side drainage.

Figure 3-14: Deep cut-off trench drain under construction

Along the Teignmouth cliff section, a number of CBUs have been shaped by the influence of surface water and groundwater drainage, many with perennial stream flow, from natural sources, albeit nowadays also influenced by drainage from cliff top development and land use. During extreme conditions, significant surface water run-off, debris and sediment can be washed down the slope onto the lineside. Attenuation of extreme flows could be achieved by installing weirs and sediment traps at key locations along stream channels on the cliffs, subject to space and gradient permitting.

The existing cess and UTX drainage along the coastal section of the railway could be improved to increase capacity and resilience against blockage. Also, the installation of replacement or new UTX large diameter drains or culverts (Figures 3-15) aligned to the main stream outlets from the cliffs will greatly improve surface water run-off and conveyance beneath the track, compared to the current arrangement. Improvements will mitigate flooding hazard during extreme rainfall conditions, whereby surface water runoff from the cliffs overwhelms the current layout of the cess and UTX drains. Examples of UTX drains becoming blocked by shingle and debris potentially causing flooding at Coryton and Shell Coves are key sites to look at.

Figure 3-15: UTX drain (left) and box culvert (right)

3.2.4 Increase Resilience Options (up to 100 years)

Major capital projects including local re-routing, cliff stabilisation and rockfall protection, and combined cliff stabilisation and coastal defence, provide options to build resilience in the longer-term, say over a 100 year period. These are covered in the sub-sections below.

3.2.4.1 Local re-route – Tunnel

Avoidance of cliff instability and landslides is generally the most cost effective mitigation to the problem in the long-term. This applies to all forms of new and re-development, above, upon and below the cliffs. The legacy of the railway and development at Dawlish and Teignmouth means that avoidance is realistically not an option, at least for services infrastructure and property. The planning and building control function of the local authority considers land instability as a material consideration of any future planning proposals, while building control will evaluate building design and serve notice on dangerous structures.

In the context of an avoidance strategy, an option that might be considered by NR is to re-route the railway to avoid the entire coastal section, or parts thereof, in new tunnel(s) and thereby mitigate cliff instability hazard and risk in the future. For the railway to continue to serve the existing Dawlish station, that would probably limit a tunnel to the route length between a point near to the existing north portal of Kennaway tunnel and a point to the north east of Teignmouth station where it would need to tie in with the existing route. That might avoid some of the coastal and slope hazards along that length, but the railway would still be exposed to coastal hazards north of Kennaway tunnel. Furthermore, should a length of the line be moved inland into a tunnel, it appears likely that NR's existing obligations to maintain the coastal slopes (where within its ownership) would remain, thus reducing some apparent benefits. Wider consideration of this inland option is however beyond the scope of this study so the option is not taken forward to the shortlist

3.2.4.2 Rockfall shelters

Rockfall between Kennaway and Parson's Tunnels has been a significant and ongoing hazard since construction of the railway. The hazard is particularly acute above the tunnel portals and along the up line where near-vertical high cliffs abut the lineside over many lengths. In the past, ad hoc works have been carried out to scale the cliffs and install rockfall meshing where events have taken place or where a significant hazard has been identified (following a reactive mitigation approach). This includes the construction of the rockfall shelter at Parson's Tunnel in the 1920s (Figure 3-16, left panel) following a large rockfall at this location.

Figure 3-16: Construction of rockfall shelter at Parson's Tunnel (1921) and near Stromeferry, Scotland

The tunnel portals are particularly exposed to rockfall or debris fall above the portal where debris is more likely to reach the track than for slopes adjacent to the line. Although the likelihood of a significant rockfall event may be low, the consequences of a train being struck by falling debris or colliding with debris on the track could be severe. Effective mitigation of this scenario could be achieved through construction of rockfall shelters (covers) above the portals, thereby building resilience in the long-term, as at Parson's Tunnel north portal. Rockfall shelters have also been used elsewhere on the UK rail network (Figure 3-16, right panel).

The extent and form of the rockfall shelters would be subject to design and the nature of the rockfall hazard in each case. It is understood that a limiting design capacity of a 1.5Mj loading event has generally been adopted elsewhere, which is equivalent to a 5 tonne block falling from 30m. Should analysis indicate a significant risk of a higher impact loading event, then additional measures such as slope meshing may be needed to supplement the protection offered by a rockfall shelter. As an alternative to rigid structures, flexible rockfall barriers might be adopted in some locations, e.g. above tunnel portals. There is an example of such a system on the UK rail network at Bradway Tunnel, south of Sheffield. As noted in 3.2.3.3, the deflection of any such flexible systems should be taken into consideration during design, and also the potential for small debris to pass through mesh apertures.

In some situations, it may be appropriate to install rockfall shelters between adjacent tunnel portals thereby eliminating the cliff instability hazard and risk altogether and providing long-term resilience. As discussed in Section 3.1.2.4, the vertical seaward wall of a fully enclosed rockfall shelter could be designed to withstand wave loading and therefore provide protection against wave overtopping as well.

3.2.4.3 Slope engineering – cliff regrade

Altering the geometry of cliffs (or slopes in general) is an effective method for increasing the stability or factor of safety against failure. As part of the original construction and subsequent remedial and improvement works, regrading of the natural cliffs along the up line has been carried out in a number of locations between Teignmouth and Langstone Rock (CH2M 2015a). A good example of a recent regrade of an unstable slope affecting a railway is Chipping Campden, Gloucestershire (Figure 3-17). Slope engineering may involve cliff regrade, re-profiling and toe-weighting or buttressing. The choice of method is heavily influenced by land-use, land-take and access. All of these are significant issues at Dawlish and particularly the section between Parson's Tunnel and Teignmouth, where steep cliffs separate the railway and cliff top development above.

Figure 3-17: Slope regrade at Chipping Campden, 2014

A significant deep landslide hazard and risk has been identified along parts of the Parson's Tunnel to Teignmouth section. A cliff regrade option (Figure 3-18) for all or part of this section could be effective at mitigation of deep landslide hazard and building resilience for the future. However, such a scheme is likely to have a major impact on the local topography such that cliff top property, and possibly the coastal road, may be impacted and thus need to be the subject of compulsory purchase and realignment respectively. A further length of route where slope regrade may be appropriate is to the north of Parson's Tunnel where the rockfall hazard may also be mitigated by a slope regrade.

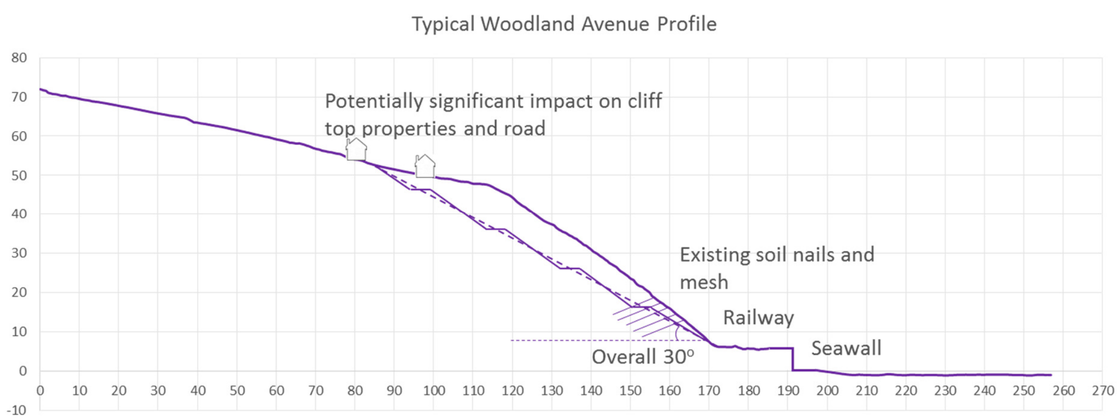


Figure 3-18: Schematic of regraded cliff at Woodlands (subject to ground investigation, analysis and design)

It is recognised that a cliff regrade scheme would be difficult to build given the requirement to continue safe operation of the line beneath the construction site. The scheme would have to be built top down and among the issues the scheme would have to address is the disposal of a large volume of fill. It may be possible for some/all of this material to be re-used locally or disposed of at sea (subject to receiving a licence from the Marine Management Organisation); disposal of landslide debris onto the beach was permitted as part of the Woodlands emergency works in Mar-Apr 2014. However, it is also possible that removal by road may be required.

3.2.4.4 Slope engineering – cliff buttress

An alternative to the cliff regrade option would be to provide support at the base of the cliffs in the form of a toe-fill buttress (Figure 3-19). The buttress would be designed to prevent deep failure of the cliffs. An example of an existing toe-fill buttress is Folkestone Warren (Figure 3-20).

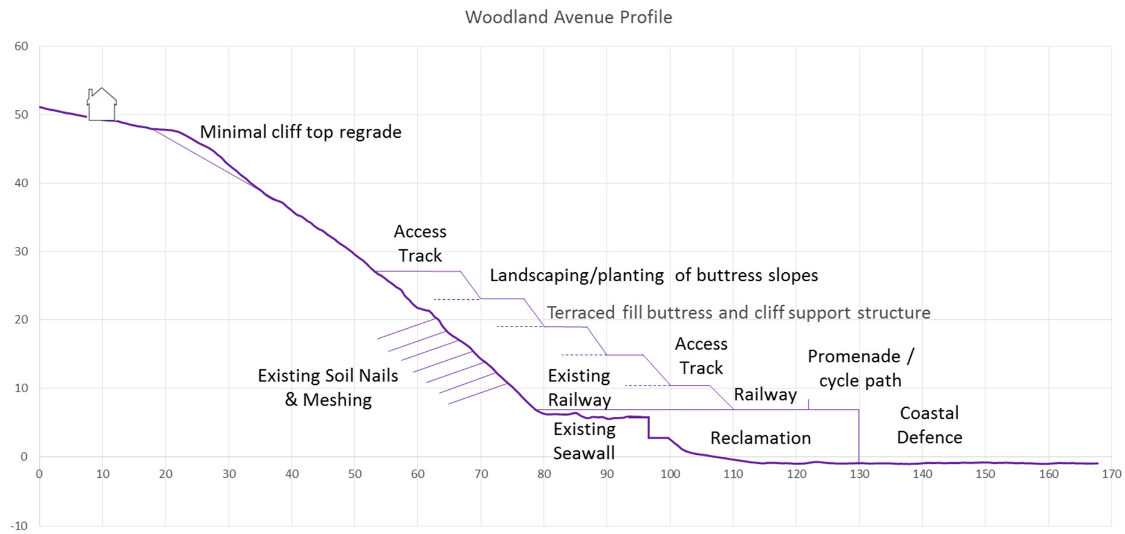


Figure 3-19: Schematic of buttress and coastal reclamation (subject to ground investigation, analysis and design)

Figure 3-20: Use of toe buttress at Folkestone Warren, Kent

3.3 Options for reducing rail asset susceptibility

The rail assets that have been attributed to delays recorded over the last 10 years by NR and the TOCs for the Exeter to Newton Abbot railway line have been analysed. The analysis seems to suggest that some 75% of those delays can be associated with signalling and points, but the varied content of some records (and in thereby identifying any contributory climate factors), limits the conclusions which can be reached. In the absence of this detail, and the lack of access to the work of national research programmes, the team has been forced to rely on anecdotal observations, published research and professional judgement to identify the types of rail asset solution which warrant further consideration as part of the shortlisting process.

The generic options that have been identified to mitigate against potential general delay factors, and to counter any more location specific geotechnical and coastal hazards are elaborated upon for each asset along the study route.

Linked to these generic options, Appendix C provides sub-unit appraisals of the asset options to be considered for shortlisting.

As part of this process, it is important to recognise that rail system assets have an on-going renewal cycle (BAU), in some cases <20 years (telecoms and station systems). Thus there will be opportunities, within the next 50 years to renew and / or upgrade the specification of assets that are at risk.

Anecdotal evidence indicates that assets degrade faster than the respective asset policies define and it is recommended that asset managers collect an evidence base on this to help to support a future business case for additional funding to cover climate-related degradation.

The following sections describe each asset group and sub-group in turn.

3.3.1 Track and drainage

This appraisal is generally based upon the premise that the long-term objective is to improve the design of the coastal defences to a point that would avoid or significantly reduce the wave overtopping that occurs during storms at present. However, it is recognised that these programmes are long aspirations and may take some years to achieve. In the meantime there is a need for temporary measures to provide short-term protection and medium term changes to specifications to ensure that the future iteration of each asset group is more resilient than that for current equipment. This may mean applying for derogations from NR standards to suit local conditions.

3.3.1.1 Track

A number of climate related issues have been raised and relevant potential solutions are detailed below.

Wave damage to ballast

The best short-term solution is to glue the ballast in vulnerable locations. This is already being trialled in some places and has been found to provide some protection but requires regular attention – costing needs to be reviewed.

The most suitable longer-term solutions are (1) the installation of slab track; and (2) containment of the ballast in a pre-cast trough. Option 1 can cost up to 2.5 times the cost of ballasted track systems. Whilst it would avoid some of the problems with shifting ballast, it is unlikely to provide long-term stable support without deep foundations and therefore does not provide “value for money”. Containing the ballast within a pre-cast concrete trough (Option 2) would limit the movement of ballast significantly. This would be similar to some bridge arrangements with drainage in between each pre-cast section. This solution would be an expensive option with major disruption implications and limited value for money.

Accelerated degradation in marine environment

To resist the accelerated asset degradation in the marine environment, coated rails and the use of more corrosion-resistant clips/fittings should be considered as part of any future maintenance works. To reduce the future maintenance regime in this environment, it is recommended that Corrosion Protection finish (CP) clips are specified (ref Figure 3-21). With regards to wooden sleepers, as any remaining such assets reach the end of their life, they should be replaced with concrete elements.

Figure 3-21: Typical Pandrol clips, standard and Corrosion Protection finish

Rail buckling in higher temperatures

Continuously welded rail (CWR) is susceptible to buckling at high temperatures. As part of installation the rail is pre-stressed to set temperature - under extreme conditions this may be reviewed. Solutions to increase resilience to operating under higher temperatures are:

- Increasing the use of Lateral Resistance End Plates (currently used on CWR curves with radius less than 400m);
- Increasing the weight of the track by reducing sleeper spacing and installing a heavier rail section (such as CEN60);
- Increasing the resistance of the ballast to lateral forces by gluing the ballast shoulder or the use of Twin Block Sleepers (which have two faces for lateral resistance instead of one on a mono-block sleeper); and
- Raising the stress free temperature (this would be an exceptional measure and only be recommended where CEN60 rail is used)

The current mitigation is remote monitoring of the rail temperature, primarily inland sections. The team understands that new monitoring equipment is currently under trial. However it is less likely to occur on the coastal section, due the cooling effect of the sea.

The estimated current impact of a rail buckling event is approximately £50k to £60k per event, potentially with a 12-hour speed restriction. This includes the initial work to restore train operations (at reduced speed), approximately 4 hours work to slew the track back into alignment and make good (which may involve cutting the rail to release the compression and fitting emergency clamp plates) and a night shift to restress the track and tamp.

Landslide / fines (talus)

Any debris, whether from waves or from washout from the cliffs, will deposit fines and contaminate the ballast. This will ultimately reduce the effectiveness of the ballast, resulting in a poor ride and sub-specification track geometry. Whilst this can be corrected (through more frequent ballast cleaning), physical barriers should be considered at the foot of slopes and drainage ditches installed to direct run-off away from the track. Installation of new or upgraded UTX drains would also assist in efficient removal of excess water. Further consideration of barriers and drainage are discussed in the geotechnical analysis (refer to Sections 3.2.2.3 and 3.2.3.3).

3.3.1.2 Drainage

The purpose of track drainage is primarily to ensure that the ballast and track bed provide a stable and dynamic support to the track. Excess water in the ballast (referred to as “wet bed”) will decrease the effectiveness of the ballast and thus, ultimately impact on the track geometry and quality of ride. Any flooding of the surrounding ground will also have an impact on track bed stability.

Drainage around the track therefore has two distinct objectives:

- To keep the track bed dry
- To direct surface water run-off away from the track, particularly at the toe of the cliffs alongside/inland of the track bed.

Thus in order to mitigate the impact of a predicted increase in rainfall and run-off, the drainage design must have the capacity to deal with rain falling on the track and protect the track from excessive surface water run-off entering the up cess from the cliffs and adjacent land. The geotechnical work undertaken by the project team has identified the key CBUs where natural gullies concentrate surface and groundwater run-off. Drainage of the cliffs is discussed in more detail in Sections 3.2.2.4 and 3.2.3.4.

Earlier this year NR commissioned a detailed survey of the drainage along this section. Each feature was recorded with GIS data points, and this data has now been compared spatially with the location of CBUs and cliff drainage features. This has helped identify the ideal positions for additional cliff drainage, lineside drainage and UTX. These will need to be checked against specific local constraints to assess constructability and spatial issues. The provision of additional UTX drains would help in the removal of excess water and fines from the up cess as currently experienced in many locations.

One of the observations made is that long sections of track do not currently have any drainage installed, the assumption being that water percolates through into the sub-surface, effectively running under the track into the beach. Once this survey data has been uploaded to Ellipse by NR, more information on the current condition and functionality of the drainage system is expected to be available. However, without detailed capacity modelling, this study has assumed that the current capacity will not be sufficient in the longer-term and will need to be increased alongside other proposed resilience improvement measures, however, with the exception of the works associated with reducing the Geotechnical Hazard, this will be dealt with on an as-needed basis over time as part of Business as usual approach.

3.3.2 Rail systems

The following sub-sections identify the solutions to increase resilience of the various rail systems including signalling and telecoms.

3.3.2.1 Signals

The Phase 1 Baseline Report (CH2M, 2015a) identified four major climate impacts on signals: (1) flooding of track circuits; (2) impact of wave overtopping on axle counters; (3) loss of power caused due to flooding; and (4) accelerated corrosion of ground level location boxes.

The current age profile for signalling equipment is not defined but assumption have been made that it will need to be in operation until the introduction of ETCS (2026) by which time the equipment will be circa 35-40 years old based on the premise that it was installed c1986. The power supply (650v) for the signalling is currently being renewed (see Section 3.3.2.6) but recent surveys have highlighted the poor state of the existing equipment cabinets, so early renewal of these may be required.

With regards to train detection equipment, the view from within NR is that the lower the technology used (i.e. axle counters), the less susceptible these assets will be to impacts from weather and salting from wave overtopping. It is assumed that such events will increase in frequency in the future and that the existing system is not resilient. A general statement was made by NR that life expectancy of rail assets is 40% lower in coastal locations but this is anecdotal and has not been supported by evidence.

Although there are still some track circuits in operation, these are due to be phased out. Until then, they present a risk of failure under moderate track flooding, so decisions over continuing to replace them, at least until such time as the new flood defences around Exeter St Davids Station are in place, need to be considered.

3.3.2.2 Location boxes

A new specification for Location Boxes in line with BS EN 50125-3 (see Figure 3-22), which specifies the standard for enclosure for electronic systems, is an example of the need to upgrade NR specifications to reflect changes in technology as well as to respond to climate change. The current location box standard does not currently meet this standard.

Whilst the aim of the coastal and geotechnical options is to reduce disruptions from wave overtopping and geohazards, these solutions may not be installed immediately. Therefore, there may be a need for specific locations boxes to be relocated to a more protected position or for provision of additional protection against these hazards.

Figure 3-22: Example of upgraded location box

3.3.2.3 Signal room

Exeter Signal Room, located adjacent to Exeter St Davids Station was initially identified to be at risk. However, as this area will be protected against a 1 in 100 year return period flood event by the Environment Agency-funded Exeter Flood Defence Scheme (1% chance of occurring annually), it has been agreed that this is to be considered as lying outside the study area.

3.3.2.4 European train control system (ETCS)

The Western Route Study (Network Rail, 2015) specifies that the requirement along this section for the ETCS is seven trains per hour and installation in the Exeter area is anticipated from 2026. NR has stated that the introduction of ETCS will bring about significant savings in maintenance costs, due to the reduction in lineside equipment but it will also bring challenges as there will be a higher dependence on sensitive micro-electronics and radio masts (GSM-R). A new specification for enclosures for "sensitive" equipment will need to be developed based on the requirements defined in BS EN 50125-3.

3.3.2.5 Telecoms

The Telecoms Equipment Building and GSM-R mast at Smugglers Lane (207 m 42ch) are set back from the cliffs adjacent to the authorised access point. Whilst the risk from cliff fall and wave overtopping is low, relocation to a less exposed and more elevated position could be considered. The GSM-R mast at Dawlish Station (206m 00ch) is exposed to potential run-out from cliff fall and wave overtopping. The risk is similarly low and relocation to a less exposed site could likewise be considered.

Figure 3-23: Equipment building and mast at Smugglers Lane (left panel) and mast within Dawlish Station compound (right panel)

Concerns have been raised in regard to potential flooding of the cable troughs from cliff run-off and overtopping impacts; this is mainly concerned with the silting up of the cable troughs at the cliff side by fine material washed down the cliffs. A potential solution would be to consider the use of cable racks. However, this may expose the cables to additional damage from other sources.

There is opportunity to review the specification of the enclosure and associated air conditioning unit before the facility is subject to any significant major climate impacts i.e. temperature increase. Although the actions relate to lineside buildings, the environmental specification required for modern electronics and heat generated by units needs to be considered. Where NR specifications for enclosures i.e. equipment cabinets do not meet the required IP 67 rating, these are to be improved in line with BS EN 50125-3 Railway applications.

3.3.2.6 Electric and power (E&P)

The E&P equipment along this section is primarily signal power (650v) and is currently subject to a substantial renewal programme (contract placed March 2015). This is primarily replacing the cabling and some transformers. One of the work streams of this project is to provide new power connection boxes (termed power annex) to each cabinet – this is to meet requirements of a national improvement notice (SIN 119).

This achieves Class II insulation (by removing the need for an earth strap) and also provides a more resilient enclosure, with higher IP rating. To facilitate the retrofitting of these connection boxes, all the existing location cases have been surveyed and a number have been found to be badly corroded. The Class II connection box would look similar to the location box shown in Figure 3-22.

The proposed mitigation to address this corrosion (put from the supplier) is to re-clad the location boxes with GRP panels, "in situ" which would provide a stable structure for the power annex (see above) and improve the resilience of the box but without disturbing the contents. At present this option is being considered but the project may not have sufficient funding within the current capital budget.

In addition to accelerated corrosion, these location cases are subject to physical damage by waves. Whilst the long-term solution will be to reduce or eliminate the wave over-topping, in the short-term (next 5-10 years) some additional physical protection should be considered, in terms of a protective wall or GRP shroud.

3.3.2.7 Remote condition monitoring

An early-warning system to detect cliff movements is in place along sections of the cliff between Parson's and Phillot tunnels, and also at Woodlands. This system is linked to the signalling assets along the route, allowing services to be halted in the event of any slope movement endangering the track.

The system is formed of a series of instrumented mesh/barriers in and beneath vulnerable sections of the cliff. It is understood that NR intends to install further instrumentation between Teignmouth and Dawlish as part of its drive to enhance Remote Condition Monitoring (RCM) along that length of the route. The proposed instrumentation essentially comprises accelerometers, tiltmeters and CCTV cameras networked to dataloggers and gateways to allow real time transmission of the data to a remote monitoring location. It is also intended that piezometers in the proposed Preliminary Phase 1 ground investigation be linked into this system, and specifications have allowed for that forward compatibility where possible. Further comment on the resilience of the proposed systems is beyond the scope of this report, other than to note that provision of positive mitigation of some of the slope hazards (ref Sections 6.2.2 and 7.2.2) would likely lead to redundancy for some or all of the RCM network over time.

3.3.3 Stations and lineside buildings

The Western Route Study (Network Rail, 2015) makes reference to a new station planned at Marsh Barton which already has planning permission. Although in a less exposed location, it may need special measures to limit any flood risk.

Some of the existing station buildings have listed status which constrains the choice of materials and limits changes in design. For example, when the 1937 footbridge at Dawlish station had deteriorated beyond repair, an innovative GRP footbridge solution (Figure 3-24) was deemed by English Heritage to satisfy their requirements. The station was originally designed by Isambard Kingdom Brunel in 1830 and is Grade II listed. The replacement is a lightweight structure weighing approximately one third of the original bridge. It mainly utilises standard FRP structural profiles, produced by a process known as pultrusion, combined with parapet sandwich panels moulded by film infusion. The stairs at each end of the bridge are also moulded FRP units.

Figure 3-24: Old steel v new grp footbridge at Dawlish Station

There is a need to address the buildings' specification to ensure local conditions are addressed.

It is likely that a re-design of the wooden downside platform structure at Dawlish Station will be required as this is currently susceptible to lifting under storm events. This will be an integral consideration within the design of the upgraded seawall.

At Starcross, the station is likely to need rebuilding and protection in the longer-term. Stations at Exeter St Thomas and the planned new station at Marsh Barton are at lesser risk from flooding and associated impacts and these are not considered further in this analysis.

3.3.4 Off track

The main climate impacts are considered to be: (1) wind impact i.e. physical damage to trees; and (2) cliff falls, landslides or talus impact on boundary fences and walls. Structures may become dangerous and at risk of collapse where they are undermined by cliff instability and ground movement. Although the particular feature is not a NR asset, an example is a boundary wall located at the crest of the cliff at Shell Cove House which has had to be removed under controlled demolition.

CH2M has not received any information on age / condition of these assets or of any planned renewals programme for boundary fencing and walls. Ideally any upgrades should be coordinated with the need for protective walls around equipment boxes or other works. In the coastal environment these would need to be made of corrosion-resistant materials. From the HD video it appears that long lengths of boundary fencing appear to be missing.

As noted under 3.2, mature trees located on or at the crest of cliffs and above tunnel portals pose a potential hazard to the safe operation of the line. Those may be within the NR boundary, although many may be on private land, as for example at Shell Cove House, where a number of trees have been recommended for felling. Where identified, such trees should either be coppiced or removed. Records indicate a limited number of "high risk" trees in this section of route. A national level LiDAR survey is now being used to monitor growth. No options are considered for vegetation assets although it is acknowledged that the frequency of periodic inspections may need to be increased in the future.

3.3.5 Ancillary structures

The main climate impacts on ancillary structures are: (1) high winds; (2) accelerated corrosion; (3) major cliff falls or landslides; and (4) lattice towers subject to loosening, corrosion and fatigue of bolts and antenna joints.

An example of this are the GSM-R Masts and Signal Gantries (ref Figure 3-23). These structures are approximately five years old with an approximate design life of 20 years. Existing masts are rated at 125mph wind speeds – but lattice towers suffer from bolts loosening/corrosion/fatigue; also loosening antennas. A key constraint is being able to access and inspect these assets as part of maintenance regime. This requires an outage on the GSM-R radio system, thus has an impact on train operations which must be negotiated with the TOC. Investment in increased coverage (200%) would allow increased redundancy in the system and enable better access for maintenance of individual masts.

Consideration should be given to utilising a more robust solution for any future replacements as this will help to address the impacts from local conditions, in the short-term this is likely to involve higher specification steel structures, but looking further into the future GRP structures may be feasible. Where vulnerable, masts have been identified and suggested interventions listed in Sections 4 to 8 of this report.

3.3.6 Tunnels

The main climate impacts on tunnel structures are: (1) rock fall or landslide exposes tunnel structure and/or lining; (2) drainage adits present running above tunnels could present a significant hazard where degradation occurs and; (3) coastal erosion underneath tunnels, extending the cave systems on the headlands through which Coryton and Parson's Tunnels run. The latter could lead to potential rock stack failures, undermining the stability of the tunnel structure. Potential solutions include bricking up any side tunnels and passages and providing additional coastal protection (e.g. rock armour) in vulnerable locations.

3.3.7 Bridges

The main climate impacts are scour-related, the risks of which can be expected to increase as sea levels rise and rainfall intensity increases. As is the current requirement, any bridges spanning watercourses should be inspected routinely and after any significant flooding related event and locally protected as required, all as part of the BAU approach.

Exeter St Davids to Dawlish Warren

4.1 Shortlisted options

The main geo-environmental hazard and source of risk in Section 1 is flooding from the Exe Estuary. This risk varies substantially along the route from Exeter St Davids to Dawlish Warren. For much of the upper estuary the existing estuary defences can be expected to protect the line from flooding until the end of this century although increasing maintenance and eventual replacement will have to be considered. There are however several low points in the defences which will need to be addressed in the first 50 years of this strategy. The most critical areas are Powderham Banks (199m 50ch to 200m 50ch) and at Starcross (202m 20ch to 202m 60ch); these will require work in the next 15 to 25 years.

The standard of protection along the first two miles from Exeter St Davids is very high with negligible risk from flooding occurring over the next 50 years. The area from 196m to 197m 10ch, is currently well protected, with a projected reduction in standard of protection to approximately a 1 in 75 year return period by 2065 (this equates to a 1.33% chance of flooding in a given year). For this section of the route, the proposed shortlisted coastal options are costed to provide a 1 in 200 return period standard (0.5% annual chance of being exceeded) in 2115. Due to mobilisation and initial capital costs, a lesser standard of protection is unlikely to cost significantly less.

With regards to geotechnical assets, the railway within the Exe Estuary is routed on low embankment or at grade, with some local shallow cuttings. Assessment of these earthworks indicates they have not posed a significant geotechnical issue or hazard to the operation of the railway.

It is possible that changing environmental conditions (e.g. climate change, groundwater) in the future could lead to a decline in the stability of earthworks without any intervention, which should be reviewed. However, large scale intervention to increase resilience is unlikely to be required in response to geohazards. The effects of the coastal options on the groundwater regime have not been considered at this stage and should be given due consideration in subsequent design stages.

Table 4-1 presents a summary of the shortlisted options for Section 1.

Table 4-1: Summary of short list options in Section 1
For the coastal options, the likely year for implementation of the options at different locations along the study are presented.

<table>
<tr><th></th><th></th><th colspan="4">Coastal Short List</th><th>Geotechnical Short List</th><th>Rail Assets Requiring Specific Attention</th></tr>
<tr><th>Mile</th><th>Chain</th><th>Year</th><th>Option</th><th>Option</th><th>Option</th><th>Option</th><th>Asset</th></tr>
<tr><td>194
196</td><td>00
00</td><td colspan="4">Negligible flood risk to railway due to height of embankment and Exeter Flood Defence Scheme</td><td rowspan="9">Negligible risk from geotechnical hazards</td><td>Negligible risk to rail assets - consider replacement of track circuits to axle counters</td></tr>
<tr><td>196
197</td><td>00
10</td><td>2065</td><td>Raise existing</td><td>New embankment</td><td>No other options suitable</td><td>Critical Rail Assets in Section 196 00 – 197 10
No: Type
5 Location Case - raise to above flood height > 1:200
5 Signal Cabling - consider cable support</td></tr>
<tr><td>197
199</td><td>10
50</td><td>2065</td><td rowspan="6">New vertical wall</td><td rowspan="2">Raise existing</td><td rowspan="2">New embankment</td><td rowspan="7">Critical Rail Assets in Section 197 10 – 204 29
No: Type

49 Location Case - raise to above flood height > 1:200
18 Switch Cabinet - raise to above flood height > 1:200
6 Track Circuit (DC Med Volt) - priority to replace with axle counter
33 Signal Cabling - consider cable support
1 Relay Room- raise to above flood height > 1:200</td></tr>
<tr><td>199
200</td><td>50
50</td><td>2030</td></tr>
<tr><td>200
202</td><td>50
20</td><td>2050</td><td colspan="2" rowspan="4">No other options suitable</td></tr>
<tr><td>202
202</td><td>20
60</td><td>2030</td></tr>
<tr><td>202
203</td><td>60
60</td><td>2065</td></tr>
<tr><td>203
204</td><td>60
20</td><td>2080</td></tr>
<tr><td>204
204</td><td>20
29</td><td colspan="4">Not directly affected by coastal flooding</td></tr>
</table>

4.2 Assessment of effectiveness of options

The effectiveness of the shortlisted options is assessed by considering how much each option reduces the current hazard and increases the resilience at each location. The hazards posed to the railway line from overtopping are considered on a three-point scale: low, medium and high. The residual life of the coastal assets are then considered in years. These have been used to determine the likely year of implementation of interventions: where the future hazard is high, interventions are recommended sooner than the existing defences' residual life would suggest.

The residual life following mitigation is given as "60+" years from implementation to reflect the typical design life of a new structure in the coastal environment and this is dependent on the form and location of the defence. However, it is likely that new structures will be effective for longer than 60 years (as the existing structures have already done) but this cannot be guaranteed.

Table 4-2: Assessment of effectiveness of coastal options in Section 1

Location	Option	Hazard			Residual / Design Life (years)	
		Current	Future	Post-mitigation	Current	Post-mitigation
196m 00ch to 197m 10ch	Raise existing	Low	Medium	Low	80	80 +
	New vertical wall	Low	Medium	Low	80	80 +
	New embankment	Low	Medium	Low	80	80 +
197m 10ch to 200m 50ch	Raise existing	Low	High	Low	40+	60 +
	New vertical wall	Low	High	Low	40+	60 +
	New embankment	Low	High	Low	40+	60 +
200m 50ch to 202m 20ch	New vertical wall	Low	Medium	Low	60	60 +
202m 20ch to 203m 10ch	New vertical wall	Low	High	Low	50	60 +
203m 10ch to 204m 20ch	New vertical wall	Low	Medium	Low	50	60 +

Re-cladding the location boxes in a GRP case will reduce their susceptibility to flooding and corrosion impacts and extend their life. Noting that assets in the coastal environment deteriorate more quickly than in inland locations, this will lead to asset renewal cycles being better aligned with the national average.

4.3 Constructability

The general philosophy of and comments on constructability are discussed in Section 2.2.1. Table 4-3 below highlights the construction and maintenance issues that apply for the different coastal options which have been shortlisted in Section 1. Here there are two main situations: (1) where the defence is offline from the railway (up to 200m 50ch); and (2) where the railway embankment forms the defence structure. These different situations present different challenges; where the current/new defences are distant from the railway, access to the structures is safer due to the reduced tidal risk but may be impacted by land ownership. There is also likely to be a much smaller impact on railway operation, compared to where the railway embankment provides the front line defence. In the latter case, some disruption will be inevitable as the distance from the train to the seaward face of the wall is extremely small. It may be therefore be necessary to operate single-line working for a short period of time to reduce the risk to the public.

Table 4-3: Constructability and maintainability of options considered for Section 1

Option	Constructability Issues	Maintenance Issues
Raise existing	Where flood defences are set away from the railway line - access can be gained from the land in the majority of cases. Works may impact upon publicly accessible land, public safety to be addressed. Public safety of station users to be considered at Starcross. Where defences are immediately adjacent to railway line new defences to be built riverward of existing. Works would be undertaken from riverward side requiring floating plant. Form and method of construction to be considered to minimise vibration and stability impact on rail operations.	No/limited impact upon the railway operation as defences located some distance from railway line. Public safety to be considered during maintenance works. Where defence located adjacent to the railway line, maintenance plant and operations will need to access defences from river, possibly requiring floating plant.
New vertical wall	Where flood defences are set away from the railway line - access can be gained from the land in the majority of cases. Works may impact upon publicly accessible land, public safety to be addressed. Public safety of station users to be considered at Starcross. Where defences are immediately adjacent to railway line new defences to be built riverward of existing. Works would be undertaken from riverward side requiring floating plant. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Access for materials would be limited especially concrete works which if required may need some access from/over the railway line.	Where defences are located immediately adjacent to railway line (200m 50ch to 204m 20ch), maintenance plant and operations would need to access defences via floating plant requiring work from river. Public safety to be considered during maintenance works. Inspection and maintenance of wall could only be undertaken from the river requiring floating plant. Similar considerations required as for 'constructability issues' for delivery of any materials.
New embankment	Flood defences are set away from the railway line - access can be gained from the land in the majority of cases. Works may impact upon publicly accessible land, public safety to be addressed.	No/limited impact upon the railway operation as defences located some distance from railway line. Public safety to be considered during maintenance works. Dimensions and slopes of embankment to be designed to allow suitable/safe maintenance/grass cutting - discussions with maintenance operator required.

4.4 Environmental constraints and opportunities

This section outlines high level environmental constraints, opportunities and relevant SEA assessment criteria for Section 1 (193m 70ch to 204m 20ch).

4.4.1 Environmental Constraints

1. Continued coastal squeeze of intertidal habitat within Exe Estuary SPA/Ramsar with associated impacts on feeding/roosting resource for SPA birds.

2. Natural processes will be constrained and existing hydromorphological pressure on Exe transitional water body will continue or increase.
3. Reduction in landscape character and visual amenity from raising defences/new structure and disconnection of recreational features.
4. Potential impacts or exposure of material at two disused landfills, dependent on alignment of new structures.
5. Potential impact on bass nursery areas.
6. Large land take from managed realignment with significant changes in townscape and visual amenity.
7. Potential impact on buried archaeology and listed buildings.

4.4.2 Environmental Opportunities

1. Continued protection of railway and other environmental assets including two disused landfill sites.
2. Protection of railway, terrestrial habitats in Country Wildlife Site, coastal grazing marsh at the RSPB reserve

4.4.3 Relevant SEA Assessment Criteria

1. Are the adaptation options likely to affect any designated nature conservation sites?
2. Are there any opportunities for habitat improvement or creation?
3. Are the adaptation options likely to affect Habitats of Principal Importance and/or associated species?
4. Will the adaptation options cause severance of wildlife corridors?
5. Will the adaptation options affect fish within the study area?
6. Do the adaptation options support biodiversity improvements?
7. Will the adaptation options detrimentally affect water quality resulting in effects on flora and fauna? Are the adaptation options likely to affect surface and/or ground water quality?
8. Are the adaptation options likely to affect WFD protected areas including designated bathing waters and shellfish waters?
9. Do the adaptation options conflict with or contribute to meeting WFD objectives for good ecological status/potential?
10. Do the adaptation options allow natural geomorphological processes?
11. Are the adaptation options in keeping with the existing landscape character and visual amenity?
12. Does the siting of the adaptation options affect distinct landscape components?
13. Is there a pollution risk from known contaminated land or landfill sites as a result of implementing the adaptation options?
14. Will the adaptation option impact on tourism or recreational pursuits (e.g. footpaths, cycleways) and associated local economy?
15. Will the adaptation option maintain the formal and informal recreational and amenity facilities along the estuaries and coastal fringes?
16. Will the adaptation options significantly affect the character of any historical, cultural and archaeological designated sites, and their setting?
17. Will the adaptation options significantly affect any historic landscapes?

18. Is there potential for loss of access to heritage resources?

4.5 Identification of costs and benefits

Within the bodies of the coastal and geotechnical long list tables reproduced in Appendices A and B, an indication of the relative costs of the different options is provided. In Table 4-4 below, for those options that have been shortlisted, an indicative current day cost for each option has been derived. The rates used for these budget estimates, their source, and any assumptions made are all included in Appendix D.

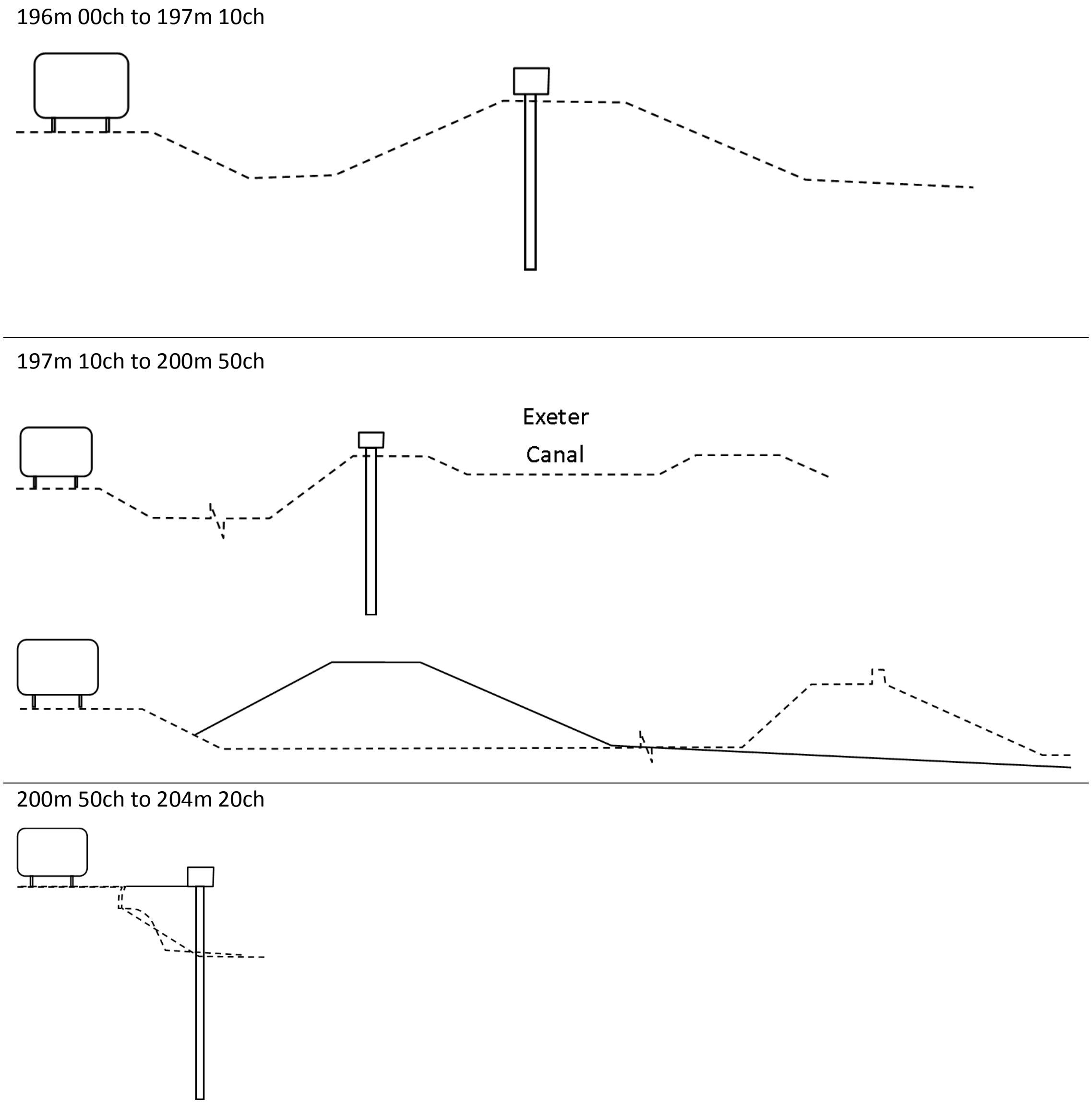


Figure 4-1: Schematics of coastal options

Table 4-4: Indicative costs of options shortlisted in Section 1

Chainage	Length (m)/Qty	Option/Measures	Indicative cost estimate (£)	Notes
193m 70ch to 196m 00ch	No option considered			
196m 00ch to 197m 10ch	3018	Raise existing	12,080k	
		New embankment	17,540k	

Table 4-4: Indicative costs of options shortlisted in Section 1

Chainage	Length (m)/Qty	Option/Measures	Indicative cost estimate (£)	Notes
193m 70ch to 196m 00ch	No option considered			
197m 10ch to 200m 50ch	4426	Raise existing	17,715k	
		New vertical wall	24,410k	
		New embankment	26,425k	
200m 50ch to 202m 20ch	2414	New vertical wall	21,775k	
202m 20ch to 203m 10ch	1609	New vertical wall	14,125k	
203m 10ch to 204m 20ch	1871	New vertical wall	16,410k	
193m 70ch to 204m 20ch	52 No.	Re-clad/protect location boxes	276k	
	13 No.	Re-clad/protect switch cabinets	69k	
	3 No.	Protect axle counters	6k	
	12 No.	Protect signal heads	23k	
	17 No.	Replace track circuits with axle counters	1275k	

Dawlish Warren to Kennaway Tunnel

5.1 Shortlisted options

For this section of the line, options which enhance the protection afforded by adjacent coastal defences and measures which limit the exposure of the line to rockfall and talus have been identified. The scale of the rockfall and talus hazard that generally exists and the designation of the area covered by CBUs 34 to 26 as a SSSI, rules out generic regrading of the Dawlish Cliffs as a potential option. Nevertheless for CBUs 26 and 27, an option which provides a rockfall shelter at the Kennaway Tunnel portal and works to the existing engineered slopes along Riviera Terrace are taken forward to the short list.

There are a few locations where a barrier catch fence may not be suitable due to space constraints. In these locations it may be necessary to consider alternative local cliff face engineering measures to mitigate the cliff instability hazard in consultation with Natural England and other stakeholders.

The shortlisted coastal options are described in more detail in Appendix A and further supporting analysis of these finalised options is presented in Appendix E. The standard of protection against structural damage from wave overtopping along this section varies considerably: ranging from greater than a 1 in 200 year return period storm (0.05% annual exceedance) north of Langstone Rock to damage being sustained on an approximately annual basis near Kennaway Tunnel. With regards to railway operations, the areas of most concern are Pinewood Close to Dawlish Station and at Kennaway Tunnel where disruption to train services is currently anticipated more frequently than once a year. Langstone Breakwater plays an important role in the continued protection of Langstone Rock which in turn provides some defence to the railway. The continued maintenance of this structure is highlighted as advisable and it is therefore included within this analysis.

One particular area of concern is the outflow from Dawlish Water where historically there has been a problem with the flow being restricted at high tide. As discussed at project workshops, these effects are likely to be exacerbated by climate change and the railway is not the only influence on this. It is acknowledged that none of the solutions listed below will remove or reduce the tide-locking effect currently present. A full solution to this problem is beyond the scope of this study and will be better addressed in subsequent design stages. Measures which help to reduce the speed at which rainfall waters within the catchment get into the main watercourse are likely to be a significant component of any solution.

The phasing of interventions suggested in Table 5-1 takes into account the remaining life and the current and future standard of protection provided by the existing defences. Defences have been costed to limit temporary disruption to the railway in 2065 to similar levels as the present day but to reduce damage under extreme storm events. A summary of the rail assets at risk and the recommended solutions to mitigate these risks are also presented.

Table 5-1: Summary of short list options in Section 2

For the coastal options, the likely year for implementation of the options at different locations along the study are presented.

Mile	Chain	Coastal Short List Year	 Option	 Option	Geotechnical Short List Option	Other Assets Requiring Specific Attention Asset
204	30	DAWLISH WARREN STATION (negligible coastal hazard)			Negligible risk from geotechnical hazards	Dawlish Warren Station Shelter – consider GRP alternative
204	30	2070	New vertical defence with supporting revetment	New revetment		204 30 to 204 70 11 Location Case – local protection against wave 1 Switch Cabinet– local protection against wave 5 Signal Head– local protection against wave 9 Track Circuit – replace with axle counter
204	42					
204	43	2030				
204	56					
204	56	2030				
204	70					
204	70	LANGSTONE ROCK			CBU 34 to 27(part) Toe Protection (Cliff toe barrier and catch fence system) plus counterfort drainage of the talus slopes	204 70 to 205 75 3 Location Case } local protection against wave & rock fall 4 Switch Cabinet } local protection against wave & rock fall
204	75					
204	75	2065	New vertical defence + Beach management	New revetment		
204	79					
205	00	2030				
205	36					
205	36	2015				
205	51					
205	51	2030				
205	53					
205	75					
205	75	2030	New vertical defence + Detached defence + Beach management		Negligible risk from geotechnical hazards	205m 75ch to 206m 34ch Dawlish Station – Rail Assets: 3 Location Case – local protection to wave 3 Switch Cabinet – local protection to wave 2 Signal head – local protection to wave 2 Axle counter – local protection to wave
206	16					
206	16	2030	New vertical defence + Beach management			
206	18					
206	19	2015				
206	34					
206	34	KENNAWAY TUNNEL			CBU 26 Rockfall canopy/shelter for north portal (206m 33ch to 206m 34ch)	

5.2 Assessment of effectiveness of options

The effectiveness of the shortlisted options is assessed by considering how much each option reduces the current hazard and increases the resilience at each location. The hazards posed to the railway line from cliff instability and wave overtopping are considered on a three-point scale: low, medium and high. The residual life of the cliff and coastal assets are then considered in years.

With regards to the critical rail assets, re-cladding the location boxes in a GRP case will reduce their susceptibility to flooding and corrosion impacts and extend their life. Noting that assets in the coastal environment deteriorate more quickly than in inland locations, this will lead to asset renewal cycles being more similar to the national average.

In a similar way, considering corrosion resistant materials, such as GRP, for footbridges, gantries and support platforms would provide a long-term benefit in this aggressive marine environment.

The residual life of the coastal shortlisted options following mitigation is given as "60 +" years to reflect the typical design life of a new structure in the coastal environment depending on form and location. However, it is likely that new structures will be effective for longer than 60 years (as the existing structures have already done) but this cannot be guaranteed.

Table 5-2: Assessment of effectiveness of coastal options in Section 2

Section	Option	Hazard			Likely design life (years)	
		Current	Future	Post-mitigation	Current	Post-mitigation
204m 30ch to 204m 56ch	New Vertical Wall	Low	Medium	Low	15	60 +
	New Revetment	Low	Medium	Low	15	60 +
204m 56ch to 204m 70ch	New Vertical Wall	Low	Medium	Low	15	60 +
	New Revetment	Low	Medium	Low	15	60 +
204m 75ch to 205m 75ch	New vertical defence + Beach management	Medium	High	Low	5	60 +
	New Revetment	Medium	High	Low	5	60 +
205m 75ch to 206m 16ch	New vertical defence + Detached defences + Beach management	Low	Medium	Low	15	60 +
	New Revetment	Low	Medium	Low	15	60 +
206m 16ch to 206m 34ch	New vertical defence + Beach management	High	High	Low	0	60 +
	New Revetment	High	High	Low	0	60 +

The solutions considered in Table 5-2 are those coastal options which can reduce the long-term hazard to low. Interventions which have less effective outcomes such as beach management and/or the installation of detached defences will extend the residual life of the existing structures, but will not reduce the overtopping hazard to the same degree as constructing a new and higher wall and therefore these are not included as standalone options in the finalised shortlist.

The first length (204m 30ch to 204m 56ch) consists of EA-owned defences which do not directly affect the railway and are unlikely to require intervention in the next 50 years. Therefore, no preferred option is recommended to be taken forward for this section.

For the second length, and for other sections within Dawlish Bay (204m 75ch to 206m 34ch) both rock revetments and new raised vertical defences are considered. Rock revetment structures are highly effective at reducing the hazard from wave overtopping and therefore the height of the structure required will be much lower than a new vertical or recurve wall. However, the footprint of a revetment structure would be large (typically 15 to 20 m) and within Dawlish Bay may be less acceptable to the public due to the loss of beach amenity. A revetment has however been retained as a short-list option as it will significantly improve the resilience of the railway line.

A vertical wall with wave return will also be highly effective at reducing the disruption from wave overtopping. However, to achieve a suitable level of resilience the height of a structure at Dawlish would need to be significantly higher than the existing structure. Depending on the level of residual risk that is acceptable to NR, the finished height of this structure may have an impact on the sea view currently enjoyed by the railway. A new defence designed to modern standards would be less susceptible to wave damage and therefore failures similar to those sustained during the 2014 storms would be unlikely to occur.

Table 5-3 below shows the hazard reduction and resilience (expressed as likely design life in years) achieved for the shortlisted option by CBU. A more detailed version of this table is included in Appendix B including all shortlisted options. The 'current' and 'future' hazard and resilience levels have been coloured using a traffic-light system to indicate the relative benefit of each shortlisted option.

Table 5-3: Assessment of effectiveness of shortlisted geotechnical options

Location	CBU	Option	Hazard		Likely design life	
			Current	Post-mitigation	Current(1)	Post-mitigation
204m 69ch	34	Rockfall barrier / Catch fence	Low	Low	20	50
	33		Low	Low	20	50
	32		Low	Low	20	50
to	31		Low	Low	20	50
	30		Medium	Low	20	50
	29		Medium	Low	20	50
	28		Medium	Low	20	50
205m 53ch	27(part)		Low	Low	20	50
206m 33ch to 206m 34ch	26	Rockfall shelter	Medium	Low	20	100

Notes

(1) Where measures do not currently exist at a location, this is the estimated period within which intervention might become necessary. Where there are existing measures, this is the estimated remaining design life.

Rockfall barrier systems, if properly designed in relation to the hazard, can be highly effective at protecting an asset from rockfall impact. The required parameters for effectiveness include knowledge of: cliff height and gradient; geological conditions and materials; and likely form and size of rockfall. Some of those factors are known and some remain to be confirmed by further investigations.

The effectiveness of a catch fence in this location will be determined by the character of the Dawlish Sandstone and overlying Quaternary deposits which form the cliffs in this area. The cliff material often breaks up into a silty sand and gravel on impact with the ground, as evidenced by the debris fans and talus slopes which mantle the lower parts of substantial lengths of the cliffs. It would therefore be necessary to supplement a catch fence by solid (e.g. sleeper and king post) barriers over the lower portion to ensure the debris does not pass through the barrier and contaminate the ballast or the cess drainage. It is considered that such provision is likely to be needed as and when any new barriers are provided, although slabbing the track over this length may mitigate some ballast contamination issues. Such slab provision would need to be considered under the heading of rail assets, refer to Section 3.3.

A new rockfall fence system designed to modern standards would provide a significant improvement from the current arrangement and thus improve resilience against geohazard in the short to medium term. High specification fencing systems would be expected to have a design life of around 20 to 50 years. Within that period, maintenance would be required, including clearing out of fallen debris where appropriate (where effective barrier height became compromised for example), and planning for a cycle of replacement. The latter could be on a chainage basis as budget permitted, with any damaged lengths being renewed as a priority. It is recognised that this level of resilience is not necessarily as high as may be provided under some other capital works options. However in the context of relatively low hazard levels this technique remains a favoured option for much of the route between Langstone Rock and Kennaway Tunnel.

Talus slopes mantle significant lengths of the lower cliff slopes between Langstone Rock and Dawlish. Those slopes comprise eroded material from the cliffs above, and are therefore likely to be a mixture of sand, fine gravel and silt. The talus slopes are relatively steep (up to some 40 degrees), and whilst there are no recorded substantial failures, it would be prudent to include some counterfort drainage in the management strategy for the slopes over this length in order to manage pore pressures within the talus. A suitable allowance has therefore been made in the costings in Table 5-5.

The north portal of Kennaway Tunnel (206m 34ch) is formed in a steep bluff of Dawlish Sandstone. Public footpaths criss-cross the hillside and it is understood that NR does not own the land over the tunnel portal. There is some evidence of weathering and erosion of the sandstone. Any substantial fall of material at the portal could have significant consequences owing to limited visibility for trains travelling in the up direction. For reasons therefore of land access constraints and a hazard level assessed as 'medium', long-term resilience could reasonably be provided by construction of a relatively short (say 15m long) rockfall canopy/shelter abutting the current portal. Restricting the shelter to that length would obviate the need to translocate the public footbridge at approximate chainage 206m 33ch. Design development may result in a skewed structure given the topography, but for this assessment (and costing in Section 7), it has simply been assumed as rectangular on plan.

5.3 Constructability

General comments relating to constructability and the assessment philosophy are discussed in Section 2.2.1. Further comments relating to the construction and maintenance issues that apply to the coastal and geotechnical options shortlisted for Section 2 of the study area are presented in Table 5-4 below.

The coastal options considered could all be constructed immediately seaward of the existing structure to minimise disruption to the railway. It would however be necessary to close sections of the promenade and beach to address public safety and enable a suitable tie-in with the existing structure to be achieved. The implementation of the beach management and detached defences options would pose no risk to the operation of the railway as these would be fully on the foreshore.

A practical issue regarding rockfall protection is that fences work by deformation on impact, and hence require a certain minimum space for them to be constructed and operate. That space depends on a number of factors including barrier type and height. It is understood that a minimum working space of 3m (measured from the nearest running rail) has been the criterion adopted for fences constructed to date on this section of the route. That 3m clear working space does not exist along the full length between Langstone Rock and Kennaway Tunnel. For that reason, the use of fencing is precluded from a number of (relatively short) sections, and a rigid barrier may have to be constructed as an alternative. The actual selection would be carried out during design development and for costing purposes (see Section 5.4), the lengths have all be grouped together at this stage.

With regards to the proposed portal protection at Kennaway Tunnel, the construction and form of the structure may be limited by the presence of a public promenade and nearby footbridge. For the safety of the public, it would be preferable to temporarily restrict access to these.

Table 5-4: Assessment of constructability and maintainability of options applied in Section 2

Option	Constructability Issues	Maintenance Issues
New vertical wall	New vertical wall would need to be built from the seaward side and would be tidally affected and require floating plant. Access for materials would be limited especially concrete works which if required may need some access from/over the railway line. Depths of water and underwater hazards such as outcrops from Langstone Rock to be considered. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Public safety to be considered as works may affect public beach, coastal footpath and access structures such as slipways and steps.	Inspection and maintenance of wall could only be undertaken from the coastal path and seaward side from the coast requiring floating plant. Depths of water and underwater hazards such as outcrops from Langstone Rock to be considered. Similar considerations required as for 'constructability issues' for delivery of any materials. Public safety of those using the coastal path to be considered.
New revetment	Revetment would need to be built from the seaward side and would be tidally affected and may require floating plant. Limited access (tidally affected) may be provided along the existing beach. No access for materials exists without access over/across the railway line, otherwise all materials would need to be shipped in. Rock deliveries to be by sea. Depths of water and underwater hazards to be considered such as existing timber groynes, outfall structures and rock outcrops around Langstone Rock. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Public safety to be considered as works may affect public beach, coastal footpath and access structures such as slipways and steps.	Maintenance of rock revetment likely to be limited to approx. 20 year intervals to reposition rocks to suit. Access for maintenance will be from seaward side - works will require tidal working. Limited access to beach is available from landward side (will be tidally affected). Works may impact upon public beach - public safety to be considered including those using the adjacent station
Beach management	Beach nourishment works and deliveries of sand will be undertaken from the sea. Land based activities will be tidally restricted and safe storage/compound location will be required. Limited access is available from landward side to foreshore from slipway. Groyne structures, associated materials and installation plant will need access to the beach; working will be tidally restricted. Public safety to be considered as works will affect public beach, coastal footpath and access structures such as slipways and steps.	Regular monitoring to be undertaken of beach including after any storm event to ensure sufficient beach material exists. Windblown sand to be monitored as may impact on rail operations. Re-nourishment likely to be required on regular basis (approx. every 5 years) to maintain beach levels - requiring similar works to construction. Potential for public injury on groyne structures.
Detached defences	Defences would need to be built from the sea and would be tidally affected and require floating plant. Rock deliveries to be via sea - delivery locations on beach to consider public. Depths of water and underwater hazards to be considered such as existing timber groynes. Public safety to be considered as works may affect public beach, coastal footpath and access structures such as slipways and steps.	Maintenance of defence likely to be limited to approx. 20 year intervals to reposition rocks to suit. All access for maintenance and inspections will be via floating plant.
Toe barrier	Lineside construction project, requires detailed SHEQ management. Form and method of construction to be considered to minimise vibration and temporary stability impact on rail operations.	Inspection and maintenance of fence may need to be undertaken from railway line.
Rockfall shelter (at N end of Kennaway Tunnel)	Construction of a rockfall canopy/shelter would impact upon railway operations. Works will potentially impact upon publically accessible areas i.e. footpaths and beaches - public safety to be taken into consideration.	Maintenance and inspection likely to be minimal and from lineside and from slopes above. Works may impact upon publically accessible areas - public safety to be taken into consideration.

5.4 Environmental constraints and opportunities

This section outlines the high level environmental constraints, opportunities and relevant SEA assessment criteria for Section 2 (204m 30ch to 206m 34ch).

5.4.1 Environmental Constraints

1. Continued coastal squeeze of intertidal habitat and direct impacts on Exe Estuary SPA/Ramsar & Dawlish Warren SAC (and associated impacts on feeding/roosting resource for SPA birds).
2. Constrains natural coastal processes & potential to impact on Dawlish Cliffs SSSI
3. Potential impacts on Dawlish Warren and Dawlish Town bathing waters.
4. Increases hydromorphological pressure on Lyme Bay coastal waterbody
5. Permanent changes/reduction in landscape character and visual amenity/ Potential deterioration in views for property occupants/ Loss of sea/cliff views from railway.
6. Increased footprint on foreshore for sloping structure.

5.4.2 Environmental Opportunities

1. Improved flood protection to railway and terrestrial environmental assets including Dawlish Warren & its recreational/heritage assets.

5.4.3 Relevant SEA Assessment Criteria

1. Are the adaptation options likely to affect any designated nature conservation sites?
2. Is there potential for contribution to achieving 'favourable' conservation status of the SSSIs?
3. Are there any opportunities for habitat improvement or creation?
4. Are the adaptation options likely to affect Habitats of Principal Importance and/or associated species?
5. Will the adaptation options cause severance of wildlife corridors?
6. Will the adaptation options affect fish within the study area?
7. Do the adaptation options support biodiversity improvements?
8. Will the adaptation options detrimentally affect water quality resulting in effects on flora and fauna?
9. Are the adaptation options likely to have a detrimental effect on national and local geological sites?
10. Do the adaptation options allow natural geomorphological processes?
11. Are the adaptation options likely to affect surface and/or ground water quality?
12. Are the adaptation options likely to affect WFD protected areas including designated bathing waters and shellfish waters?
13. Do the adaptation options conflict with or contribute to meeting WFD objectives for good ecological status/potential?
14. Are the adaptation options in keeping with the existing landscape character and visual amenity?
15. Does the siting of the adaptation options affect distinct landscape components?

5.5 Identification of costs and benefits

Within the bodies of the coastal and geotechnical long list tables reproduced in Appendices A and B, an indication of the relative costs of the different options was provided. In Table 5-5 below, for those options that have been shortlisted, an indicative current day cost for each has been derived. The rates used for these budget estimates, their source, and any assumptions made are all included in Appendix D.

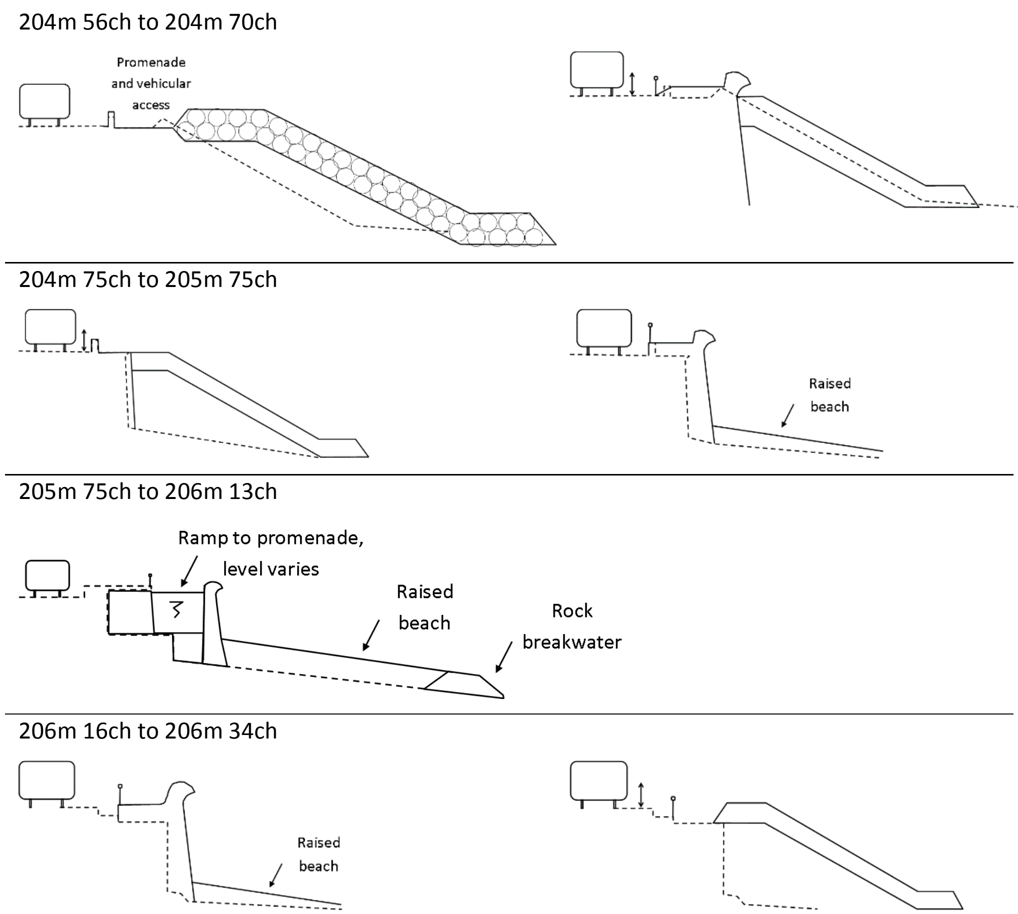


Figure 5-1: Schematics of coastal options

Table 5-5: Indicative costs of options shortlisted in Section 2

Underlined red Items are for information only and are not intended to be included in the Strategy

Location (miles and chains)	Length (m)/Qty	Option/Measures	Indicative cost estimate (£)	Notes
204m 30ch to 204m 56ch	543	New vertical wall	1,410k	
		New sloping revetment	47,470k	
204m 56ch to 204m 70ch	272	New vertical wall with small revetment	6,225k	
		New sloping revetment	8,590k	
204m 75ch	70	Langstone Breakwater	4,360k	Assumes encasing with rock armour
204m 70ch to 205m 52.5ch	1270	Rockfall barrier at toe, with counterfort drains in talus slopes	6,011k	CBU numbers 34, 33, 32, 31, 30, 29, 28
205m 52.5ch to 205m 53ch	10	Face meshing or other protection (dentition) Rockfall barrier at toe	75k	CBU number 27 (part only)
204m 75ch to 205m 75ch	1710	New vertical wall + beach management	23,260k	
		New sloping revetment	38,475k	
205m 75ch to 206m 13ch	322	New vertical wall + detached defences + beach management	10,670k	
		New sloping revetment	9,320k	
206m 16ch to 206m 34ch	523	New vertical wall + beach management	7,775k	
		New sloping revetment	16,765k	
206m 33ch to 206m 34ch	20	Rockfall canopy/ shelter	1,095k	CBU number 26 (portal only)
204m 30ch to 206m 34ch	17 No.	Re-clad/protect location boxes	90k	Critical Rail Assets
	8 No.	Re-clad/protect switch cabinets	42k	
	4 No.	Protect axle counters	8k	
	7 No.	Protect signal heads	13k	
	9 No.	Replace track circuits with axle counters	675k	

Kennaway Tunnel to Parson's Tunnel

6.1 Shortlisted options

For this section of the line, options which enhance the protection afforded by adjacent coastal defences and measures which limit the exposure of the line to rockfall and landslides have been identified. The scale of the rockfall hazard that generally exists and the designation of the area covered by CBUs 24 and 25 as an SSSI limits generic regrading of these slopes as a potential option. Construction of rockfall canopy / shelters at tunnel portals alongside cliff face meshing, catch fencing and drainage/washout control measures are taken forward to the short list. An alternative slope regrade option is presented for part of CBU 18, to the north of the existing extension to Parson's Tunnel.

Although rockfall meshing has been installed over a portion of this section, it is unlikely that this alone would be able to provide the degree of resilience required by NR. The mesh has a typical design life of less than 30-50 years and would require an active programme of maintenance and replacement if protection standards are to be kept at acceptable levels. In addition, ongoing natural processes, predominantly weathering of the cliffs, are likely to result in increased levels of hazard in the future as described above (ref Section 3.2.1), with the consequence that existing measures may become inadequate or superseded in some areas.

In addition to the geohazards on the landward side of the railway, there is also evidence of small openings and natural caves on the seaward side of Coryton Tunnel, as observed by NR staff in September 2015. The extent of those features is not well known or documented, and therefore it is not possible to recommend remedial measures, if any. Nonetheless, a survey of all voids and tunnels in the cliff headlands would be a prudent measure as a first step in establishing the degree of hazard they might pose to the adjacent railway tunnels.

The shortlisted coastal options are described in more detail in Appendix A and further supporting analysis of these finalised options is presented in Appendix E. The present standard of protection against structural damage from wave overtopping along Section 3 is very good, providing sufficient protection to railway operations under extreme storms up to and including a return period of 1 in 200 (0.5% chance of happening in a given year). Disruption will become more frequent in the future, with potential delays occurring annually. The defence at Shell Cove (between Coryton and Clerk's Tunnels) is currently protected by a very large beach and therefore no works are proposed beyond maintenance and reinstatement of the rock protection adjacent to Clerk's Tunnel following any damage.

The phasing of interventions suggested in Table 6-1 takes into account the remaining life and the current and future standard of protection provided by the existing defences. Defences have been costed to limit temporary disruption to the railway in 2065 to similar levels as the present day but to reduce damage under extreme storm events. A summary of the rail assets at risk and the recommended solutions to mitigate these risks are also presented.

Table 6-1: Summary of short list options in Section 3

For the coastal options, the likely year for implementation of the options at different locations along the study area frontage is indicated.

Mile	Chain	Coastal Short List			Geotechnical Short List		Rail Assets Requiring Specific Attention	
		Year	Option	Option	Option	Option	Chainage	Asset
206	42	KENNAWAY TUNNEL					No critical rail assets	
206	42	2050	New vertical defence	Combined rock fall shelter	CBUs 25 and 24 Rockfall Shelters	No other options to provide >50 years resilience suitable		
206	52							
206	53	CORYTON TUNNEL			CORYTON TUNNEL			
206	62							
206	63	2050	No formal defence proposed	Combined rock fall shelter	CBUs 23 and 22 Rockfall Shelters, meshing and drainage	No other options to provide >50 years resilience suitable	Rail Assets: 1 Location Case – local protection to wave 1 Switch Cabinet – local protection to wave 1 Axle counter – local protection to wave	
206	65							
206	65	PHILLOT TUNNEL			PHILLOT TUNNEL		No critical rail assets	
206	68							
206	68	2050	No formal defence proposed	Combined rock fall shelter	CBU 22 and 21 Rockfall Shelter	No other options to provide >50 years resilience suitable		
206	71							
206	73	CLERK'S TUNNEL			CLERK'S TUNNEL			
206	74							
206	74	2050	New vertical defence	New revetment	CBU 20 (part), 18 and 17 Rockfall Shelter	CBU 20 Rockfall meshing and catch fence	1 Signal Head – local protection to wave and rockfall UM206 Signal Gantry – move asset	
206	79							
207	00					No other options to provide >50 years resilience suitable		
207	04							
207	05					CBU 18 Regrade slope (alternative to shelter)	1 Location Case – local protection to wave and rock fall 1 Switch Cabinet – local protection to wave and rock fall	
207	14							
207	15					No other options to provide >50 years resilience suitable	No critical rail assets	
207	18							
207	18				CBU 16 Possible upgrade of existing rockfall shelter			
207	25							
		PARSON'S TUNNEL			PARSON'S TUNNEL			

6.2 Assessment of effectiveness of options

The effectiveness of the shortlisted options is assessed by considering how much each option reduces the current hazard and increases the resilience at each location. The hazards posed to the railway line from cliff instability and wave overtopping are considered on a three-point scale: low, medium and high. The resilience of the cliff and coastal assets are then considered in years.

With regards to the critical rail assets, re-cladding the location boxes in a GRP case will reduce their susceptibility to flooding and corrosion impacts and extend their life. Noting that assets in the coastal environment deteriorate more quickly than in inland locations, this will lead to asset renewal cycles being more similar to the national average.

In a similar way, considering corrosion resistant materials, such as GRP, for footbridges, gantries and support platforms would provide a long-term benefit in this aggressive marine environment.

The resilience following mitigation is given as "60+" years to reflect the fact that the typical design life of a new structure in the coastal environment. However, it is likely that new structures will endure for longer than 60 years (as the existing structures have already done) but this cannot be guaranteed.

Table 6-2: Assessment of effectiveness of coastal options in Section 3.

Section	Option	Hazard			Likely design life (years)	
		Current	Future	Post-mitigation	Current	Post-mitigation
206m 42ch to 206m 52ch	New Vertical Wall	Low	High	Low	35	60 +
206m 63ch to 206m 66ch	None proposed	Low	Low to Medium	Low	35 +	60 +
206m 74ch to 207m 25ch	New Vertical Wall	Low	Medium	Low	35	60 +
	New Revetment	Low	Medium	Low	35	60 +

In Table 6-2 it can be seen that for all of the existing defences in Section 3 the disruption generated by wave overtopping is low and therefore they perform to a high standard. However, in spite of the current defences being highly effective, due to the age of the existing structures it is likely that these will need to be replaced in the medium term to provide sufficient resilience against storm damage.

For Coryton and Shell Cove, there is only one option shortlisted due to the presence of a relatively high but self-contained beach. For the section from 206m 74ch to 207m 25ch (including the rockfall shelter at Parson's north portal) it would also be possible to construct a rock revetment in front of the existing wall. This would significantly prolong the life of the existing wall and reduce wave loading on the existing structure. The shortlisted options for Section 3 would all prove effective at reducing wave overtopping in the long-term.

Table 6-3 below shows the hazard reduction and resilience (expressed as likely design life in years) achieved for the shortlisted options by CBU. A detailed version of this table is included in Appendix B including all shortlisted options. The 'current' and 'future' hazard and resilience levels have been coloured using a traffic-light system to indicate the relative benefit of each shortlisted option.

The shortlisted options to provide long-term (50 to 100 years) resilience against the geohazards along the route are described in Section 3.2 and are shown in Table 6-1. A commentary on their potential effectiveness at providing increased resilience is set out below.

Table 6-3: Assessment of effectiveness of geotechnical options in Section 3

Chainage	CBU	Option	Hazard		Likely design life	
			Current	Post-mitigation	Current(1)	Post-mitigation
206m 42ch to 206m 52ch	25	Rockfall shelter	High	Low	5	100
	24	Rockfall shelter	Medium	Low	20	100
206m 63ch to 206m 65ch	23	Rockfall shelter	Medium	Low	20	100
206m 68ch to 206m 72ch	22	Rockfall shelter, cliff face meshing and toe drainage	Medium	Low	20	50/100
	21		High	Low	5-20	100
206m 74ch to 207m 18ch	20	Rockfall shelter or cliff face meshing and rockfall catch fence	High	Low	5	50/100
	19	*None proposed*	Low	Low	100	100
	18	Rockfall shelter/Partial regrade	Medium	Low	20	100
	17	Rockfall shelter	High	Low	5-20	100
207m 18ch to 207m 25ch	16	Rockfall shelter upgrade	Low	Low	20-50	100

Notes

(1) Where measures do not currently exist at a location, this is the estimated period within which intervention might become necessary. Where there are existing measures, this is the estimated remaining design life.

The topography of this length of route is markedly different to the other two open coast sections; the coastline is a series of headlands and bays, and from the southern portal of Kennaway Tunnel the railway passes through three short tunnels before reaching the northern portal of Parson's Tunnel. These features heavily influence the geohazard location, type and level and hence the favoured options to provide long-term resilience.

The eight tunnel portals in this section (Kennaway South, Coryton North and South, Phillot North and South, Clerk's North and South and Parson's North) have been assessed as being in high to medium hazard zones. Rockfall protection canopies or shelters would provide long-term resilience against rockfall at each of those tunnel portals in the section by effectively extending the structures entrance away from the cliffs above and immediately adjacent to the existing tunnel portals. As shown in the table below, most of the structures would be relatively short, with two exceptions. Given the high rockfall hazard and the difficulty of gaining access to the area, it is considered appropriate to construct a shelter over the full length (some 70m) between Phillot and Clerk's Tunnels. Further south, unless other measures were adopted (see below), the proposed shelter would extend some 250m north from the existing (1920's) rockfall shelter at the north end of Parson's Tunnel owing to the high steep cliffs and the relatively high assessed geohazards. Rockfall shelters would be designed to withstand typical rockfall events without significant damage or deformation, and that would be expected to be sufficient to provide long-term resilience along the majority of this section of the route. Additional protection may be appropriate in parts of CBUs 17 and 18 (where wedge failure is evident north of Parson's Tunnel) and 22 (where shallow slides are considered a hazard in Shell Cove). Such protection would be likely to take the form of active cliff face meshing and rockbolting. The reduced design life of meshing compared to a rockfall shelter would need to be taken into account in the planning of repair and renewal cycles. It should be noted that the presence of a rockfall shelter would remove many of the construction constraints associated with such renewals above an active railway. There would also be an additional benefit in negating the need for the existing early warning rockfall system that is currently in operation in this area (ref Section 3.3.2.7).

Another area where rockfall mesh may have a role in enhancing long-term resilience is at the proposed end point of the proposed rockfall shelter at Clerk's Tunnel (see Table 6-5). Passive mesh, together with suitably designed fencing, would provide an enhanced degree of resilience as a transition zone where a shelter would be difficult to justify on hazard and cost grounds. Similarly, rockfall fencing may be an appropriate measure alongside the up cess in CBU22 (Shell Cove) between the proposed rockfall shelters.

To the south of Clerk's Tunnel the line is relatively straight and passes beneath cliffs of varying heights and steepness, above which is agricultural land. The alignment and topography, together with the lack of properties at the cliff top presents an opportunity to undertake an alternative hazard reduction option, namely re-grading the cliffs to a more stable profile. Based on the topography, that could reasonably be done over a length of some 190m, with a consequent loss in the requirement to construct a rockfall shelter beneath the length in question. Spoil removal would be a significant aspect of any such works, and whether that material would need to be transported off site via the public highway network or whether it could be disposed of in the sea is likely to have significant impact on programme and cost, although there is a relatively short potential haul route to the A379 which would facilitate removal by road. Estimated quantities are of the order of 1.45Mm^3. Depending on programming issues and other future works that might be commissioned by NR in the future, the waste material might be re-used as bulk fill elsewhere subject to earthworks suitability issues.

There are two main areas where existing drainage provision may require enhancement: Shell Cove and much of Coryton Cove. In both areas, there are low-lying areas between the cliffs and the railway which appear poorly drained, and improvements in surface and sub-surface drainage provision are considered advisable to provide long-term resilience against flooding. Efficient drainage systems would also tend to improve slope stability, and appropriate provision should be designed into any regrade option.

6.3 Constructability

General comments regarding constructability are discussed in Section 2.2.1 and the key constructability issues for the geotechnical and coastal options in Section 3 of the study area are considered in Table 6-4.

All of the coastal options would be built from the seaward side of the defences and would likely be built directly in front of the existing. Therefore disruption to railway operation would be fairly limited. The geotechnical options are likely to be more disruptive as many of these consist of lineside construction projects

All works below mean high water springs will require land acquisition from the crown estate. All works above the cliff top will require landowner agreement, temporary and permanent possession and possibly a General Permitted Development Order (GPDO).

Table 6-4: Constructability and maintainability issues for coastal and geotechnical options in Section 3

Option	Constructability Issues	Maintenance Issues
New Vertical Wall	Would need to be built from the coast, would be tidally affected and require floating plant. Limited access to 3-A may be provided along the existing beach via the slipways and prom. Public safety of footpath and beach users to be considered. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Depths of water and underwater hazards to be considered such as existing timber groynes and rock outcrops.	Inspection and maintenance of wall undertaken from the seaward side from the coast which is tidally affected. Maintenance works may require floating plant - depths of water and underwater hazards to be considered such as existing timber groynes and rock outcrops. Limited access (tidally affected) from the slipways may be provided along the existing beach via the prom. Public safety of those using the beach and coastal footpath to be considered (Coryton Cove).
New revetment	Would need to be built from the coast and would be tidally affected and require floating plant. Form and method of construction to be considered to minimise vibration and stability impact on rail operations.	Inspection and maintenance of wall undertaken from the seaward side from the coast which is tidally affected. Maintenance works may require floating plant - depths of water and underwater hazards to be considered such as rock outcrops.

	Depths of water and underwater hazards to be considered such as rock outcrops.	Public safety to be considered albeit limited public access to area.
Cliff face meshing systems	Lineside construction project, requires detailed SHEQ management. Form and method of construction to be considered to minimise vibration and temporary stability impact on rail operations.	Regular inspection and maintenance of fence to be undertaken. Works would be undertaken from railway line. Mesh has a typical design life of less than 30-50 years and would require an active programme of maintenance and replacement.
Rockfall barrier	Lineside construction project, requires detailed SHEQ management. Form and method of construction to be considered to minimise vibration and temporary stability impact on rail operations.	Inspection and maintenance of fence may need to be undertaken from railway line.
Rockfall shelter	Construction of shelter would impact upon railway operations. Works may potentially impact upon publically accessible areas I.e. beaches - public safety to be taken into consideration.	Maintenance and inspection likely to be minimal and from lineside and (dependent on location) externally via roped access. Works may impact upon publically accessible areas - public safety to be taken into consideration. Note: access will be difficult, particularly in CBUs 21, 22 and 23
Regrade the slope	Re-grading works could impact on the operation and safety of the line. However, it is possible that a workaround could be achieved with sufficient planning in subsequent design stages. Potential to also impact other publically accessible areas such as the SW coastal path - impacts on various users/public to be considered. Constrained work area. Disposal of a large volume of fill would be required – either by road or sea depending on licensing.	Inspection of slope may be undertaken on foot, possibly from trackside. Maintenance works (e.g. on drainage features) may require rail restrictions.
Cliff toe drainage	Toe drainage will be undertaken from lineside. Form and method of construction to be considered to minimise vibration and temporary stability impact on rail operations.	Regular inspection and maintenance required to ensure long-term efficacy of solution. Inspection and maintenance would be undertaken from railway line. Note: access will be difficult in CBU 22

6.4 Environmental constraints and opportunities

This section outlines the high level environmental constraints, opportunities and relevant SEA assessment criteria for Section 3 (206m 42ch to 207m 25ch).

6.4.1 Environmental Constraints

1. Constrains natural coastal processes & potential to impact on Dawlish Cliffs SSSI. Likely negative impact on Dawlish Cliffs SSSI (currently in unfavourable condition but recovering) by any new structures obscuring cliff face
2. Increases hydromorphological pressure on Lyme Bay coastal waterbody.
3. Potential deterioration in views for property occupants. Reduction in landscape character and visual amenity associated with new structure, netting, drainage measures and fence
4. Potential to affect Dawlish Coryton's Cove bathing waters.
5. Cortyon's Cove is small and there would be significant loss of beach width if a revetment were built.
6. Significant land-take and landscaping required (Partial re-grade)

6.4.2 Environmental Opportunities

1. Continued protection to railway and areas at flood risk.
2. Vegetation removal would improve exposure of sandstone and breccias helping the SSSI achieve 'favourable' status.

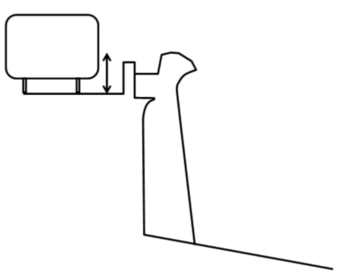
6.4.3 Relevant SEA Assessment Criteria

1. Is there potential for contribution to achieving 'favourable' conservation status of the SSSIs?
2. Are the adaptation options likely to have a detrimental effect on national and local geological sites?
3. Do the adaptation options allow natural geomorphological processes?
4. Are the adaptation options likely to affect surface and/or ground water quality?
5. Are the adaptation options likely to affect WFD protected areas including designated bathing waters and shellfish waters?
6. Do the adaptation options conflict with or contribute to meeting WFD objectives for good ecological status/potential?
7. Are the adaptation options in keeping with the existing landscape character and visual amenity?
8. Does the siting of the adaptation options affect distinct landscape components?

6.5 Identification of costs and benefits

Within the bodies of the coastal and geotechnical long list tables reproduced in Appendices A and B, an indication of the relative costs of the different options was provided. In Table 6-5 below, for those options that have been shortlisted, an indicative current day cost for each has been derived. The rates used for these budget estimates, their source, and any assumptions made are all included in Appendix D.

206m 42ch to 206m 52ch



206m 74ch to 207m 18ch

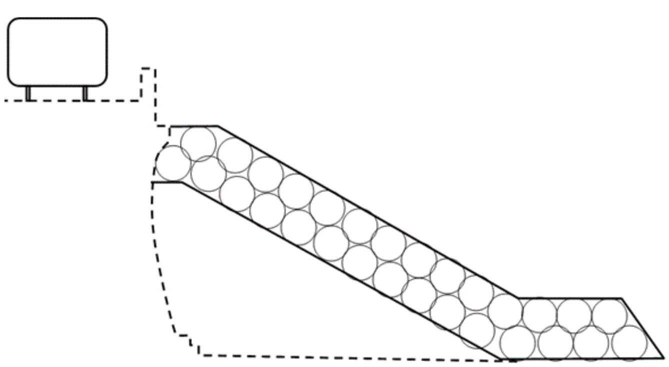


Figure 6-1: Schematics of coastal options

Table 6-5: Indicative costs for coastal and geotechnical options applicable in Section 3.

Location (miles and chains)	Length (m)/Qty	Option/Measures	Indicative cost estimate (£)	Notes
206m 42ch to 206m 52ch	201	New vertical wall	1,875k	
206m 42ch to 206m 46ch	30	Rockfall shelter	1,640k	CBU 25 Option A
	80	Meshing and fencing	1,213k	CBU 25 Option B
206m 46ch to 206m 55.5ch	165	Drainage replacement	60k	CBU 24 Option A
	15	Rockfall shelter	820k	
	190	Meshing, fencing and drainage	1,023k	CBU 24 Option B
206m 60.5ch to 206m 63.5ch	10	Rockfall shelter	545k	CBU 23 Option A
	70	Meshing and fencing	1,780k	CBU 23 Option B
206m 63.5ch to 206m 66.5ch	30	Rockfall barrier at toe	90k	CBU 22 Option A
	50	Drainage replacement	20k	
	20	Rockfall shelter	1,095k	
	30	Meshing	280k	
	60	Meshing, fencing and drainage	1,046k	CBU 22 Option B
206m 68.5ch to 206m 73.5ch	70	Rockfall shelter	3,830k	CBU 21 Option A
	90	Meshing and fencing	1,269k	CBU 21 Option B
206m 74ch to 207m 18ch	483	New revetment	20,115k	
206m 73.5ch to 206m 79ch	50	Rockfall shelter	2,735k	CBU 20 Option A
	40	Meshing Rockfall barrier at toe	250k 120k	
	120	Meshing and fencing	1,106k	CBU 20 Option B
206m 79ch to 207m 4.5ch	110	Meshing and fencing	247k	CBU 19
207m 4.5ch to 207m 14.5ch	170	Rockfall shelter	9,295k	CBU 18 Option A
	190	Regrade cliff	28,700k	CBU 18 Option B
	200	Meshing and fencing	1,930k	CBU18 Option C
207m 14.5ch to 207m 18.5ch	80	Rockfall shelter	4,375k	CBU 17 Option A
	80	Meshing and fencing	1,263k	CBU 17 Option B
206m 40ch to 207m 40ch	2 No.	Re-clad/protect location boxes	11k	Critical Rail Assets
	2 No.	Reclad/protect switch cabinets	11k	
	1 No.	Protect axle counters	2k	
	1 No.	Protect signal heads	2k	

Parson's Tunnel to Teignmouth

7.1 Shortlisted options

For this section of the line, options which enhance the protection afforded by adjacent coastal defences and measures which limit the exposure of the line to washout, rockfall and landslide have been identified. Construction of a rockfall shelter at Parson's Tunnel and large scale regrading and a major cliff buttress solution involving significant reclamation out to sea are amongst the measures taken forward to the short list.

The shortlisted coastal options are described in more detail in Appendix A and further supporting analysis of these finalised options are presented in Appendix E. The standard of protection against structural damage from wave overtopping is generally poor along Section 4 as damage under a 1 in 10 year return period storm is expected in the present day (10% annual occurrence). This decreases to damage being expected to be sustained annually by 2065. Disruption to railway operation is predicted to be greater than once a year currently and therefore it this section will require early intervention.

The phasing of interventions suggested in Table 7-2 takes into account the remaining life and the current and future standard of protection provided by the existing defences. Defences have been costed to limit temporary disruption to the railway in 2065 to similar levels as the present day but to reduce damage under extreme storm events.

This section has various existing remediation measures installed, which include active and passive cliff face meshing, soil nailing, catch fences and barriers, and drainage measures. However, the level of resilience provided by these measures falls short of the longer-term requirements for resilience in their present state. At a section-wide scale, the range of geohazards experienced in this section eliminates the "rockfall shelter" option as a generic option; moreover, it would not provide an appropriate solution to mitigate washout and deep-seated cliff instability. There may, however, be merit in inclusion of a short shelter at the southern portal of Parson's Tunnel.

As noted previously (in relation to Coryton Tunnel), it is understood from discussions with NR staff that there may be voids and caves on the seaward side of the headland through which Parson's tunnel passes. The extent of any such features is not well known, and therefore it is not possible to recommend remedial measures, if any. Nonetheless, a survey of all voids and tunnels in the cliff headland would be a prudent measure as a first step in establishing the degree of hazard those might pose to the adjacent railway tunnels.

As noted earlier (in Sections 3.2.4.3 and 3.2.4.4), there are two major capital scheme options identified that will provide long-term resilience which are taken forward to the short list.

The first option would involve a cliff regrade for all or part of the frontage (see Figure 3-18). This has been suggested at a nominal angle of 30^o, which should be refined after further investigation and as part of design. The scheme would be constructed top-down with the construction site adjacent to the lineside which could allow continued operation of the railway. However, this option would have a major adverse impact on clifftop property which will be a major constraint to planning and construction of the scheme, along with the significant environmental issues to be considered.

The second option would involve reclamation and advance of the coastal defences and railway seaward of their current alignment (see Figure 3-19), allowing for the construction of a cliff support buttress. The scheme provides opportunities for other benefits such as space for construction, amenity and landscape incorporated into the design, and will allow the existing railway to continue to operate during construction. Once the reclamation, new coastal defence and new rail alignment are completed, the existing rail can be used as a siding for construction and import of fill for the cliff buttress.

Table 7-1 presents a summary of the shortlisted options.

Table 7-1: Summary of shortlisted options in Section 4

For the coastal options, the likely year for implementation of the options at different locations along the study are presented.

Mile	Chain	Coastal Short List: Year	Coastal Short List: Option	Coastal Short List: Option	Coastal Short List: Option	Geotechnical Short List: Option	Geotechnical Short List: Phasing	Rail Assets Requiring Specific Attention: Asset
		PARSON'S TUNNEL						
207 / 207	42 / 43	2020	New vertical wall along existing alignment	New revetment structure along existing alignment	New revetment along advanced alignment (Rockfill cliff buttress, drainage and coastal reclamation). This would be in 2020	CBU 15 Rockfill shelter	No credible options to provide >50 years resilience suitable in marine environment	5 Location Case } Local protection 2 Switch Cabinet} against 1 Signal Head } wave & rock 5 Axle Counter } 3 Track Circuit – replace by Axle Counter
207 / 208	45 / 14	2020				CBU 14 to 2 Rockfill cliff buttress, drainage and coastal reclamation	CBU 14 to 2 Major regrade	
208 / 208	14 / 56	2030						
208 / 208	56 / 60	NO COASTAL INFLUENCE						
208 / 208	60 / 66					CBU 1 Cliff face meshing system	No credible options to provide >50 years resilience suitable	
208 / 208	66 / 73					Negligible risk from geotechnical hazards		

7.2 Assessment of effectiveness of options

The effectiveness of the shortlisted options is assessed by considering how much each option reduces the current hazard and increases the resilience at each location. The hazards posed to the railway line from cliff instability and wave overtopping are considered on a three-point scale: low, medium and high. The resilience of the cliff and coastal assets are then considered in years.

With regards to the critical rail assets, re-cladding the location boxes in a GRP case will reduce their susceptibility to flooding and corrosion impacts and extend their life. Noting that assets in the coastal environment deteriorate more quickly than in inland locations, this will lead to asset renewal cycles being more similar to the national average.

In a similar way, considering corrosion resistant materials, such as GRP, for footbridges, gantries and support platforms would provide a long-term benefit in this aggressive marine environment.

The assessment of the effectiveness of the coastal options is considered in Table 7-2. The resilience following mitigation is given as "60+" years to reflect the fact that the typical design life of a new structure in the coastal environment. However, it is likely that new structures will endure for longer than 60 years (as the existing structures have already done) but this cannot be guaranteed.

Table 7-2: Assessment of effectiveness of coastal options in Section 4

Section	Option	Hazard			Resilience (years)	
		Current	Future	Post-mitigation	Current	Post-mitigation
207m 42ch to 208m 55ch	New Vertical Wall	Medium	High	Low	15	60 +
	New Revetment	Medium	High	Low	15	60 +

As can be seen in Table 7-2, a new structural defence (revetment or vertical wall) would be highly effective and deliver a large reduction in the coastal hazard at Section 4. Due to the wave-breaking nature of a rock revetment, this type of structure would be particularly effective and could provide protection to the existing structure. However, this structure would have a significant reduction on the beach amenity available.

The construction of detached defences and implementation of beach management techniques would maintain the existing hazard into the future and would prevent an increase in hazard as the effects of climate change are felt. These options would therefore be less effective and would not sufficiently address the coastal risk.

If the advance the line reclamation option were to be taken forward as the preferred option it is likely that the rock revetment would be perceived to be less favourable as this would extend the footprint of the reclamation an additional 20 to 30 metres seaward of the new alignment of the reclamation. The reclamation option has an additional disadvantage as the deeper water will make construction more difficult and will also increase the wave height at the structure. To achieve the same reduction in overtopping a higher structure will be required in this case.

Table 7-3 below shows the hazard reduction and resilience (expressed as likely design life in years) achieved for the shortlisted option by CBU. A detailed version of this table is included in Appendix B including all shortlisted options. The 'current' and 'future' hazard and resilience levels have been coloured using a traffic-light system to indicate the relative benefit of each shortlisted option.

Table 7-3: Assessment of effectiveness of geotechnical options in Section 4

Location	CBU	Option	Hazard		Resilience (years)	
			Current	Post-mitigation	Current(1)	Post-mitigation
207m 42ch to 207m 42.75ch	15	Rockfall shelter	High	Low	5	100
	14		High	Low	5	100
207m 43ch to 207m 46.5ch	13	Reclamation, coastal defence and rockfill cliff buttress OR Major regrade Rockface systems and fencing	Medium	Low	10	100
207m 46.5ch to 208m 50ch	12		High	Low	5	100
	11		Medium	Low	5	100
	10		High	Low	10	100
	9		High	Low	5	100
	8		High	Low	20	100
	7		Medium	Low	0	100
	6		Medium	Low	20	100
	5		Low	Low	0	100
	4		Medium	Low	20	100
	3		Medium	Low	0	100
	2		Medium	Low	20	100
208m 60ch to 208m 66.5ch	1	Meshing and fencing	Medium	Medium	20	50

Notes

(1) Where measures do not currently exist at a location, this is the estimated period within which intervention might become necessary. Where there are existing measures, this is the estimated remaining design life.

The shortlisted options to provide long-term (50 to 100 years) resilience against the geohazards along the route are described in Section 3.2 above and are shown in Table 7-1. A commentary on their potential effectiveness at providing increased resilience is set out below.

Rockfall barriers and fencing exist along substantial sections of the route, albeit of differing designs and ages. The effectiveness of those systems in preventing rockfall from reaching the line is reasonably well understood, and any future replacement system would be expected to provide a slightly higher level of resilience than at present assuming a uniformity of design approach. However, those systems would not be effective in mitigating hazard from deep seated failure, likely to involve hundreds or thousands of cubic metres of material. In order to provide long- term resilience against deep seated failure, two options have been considered and are described more fully below. Either would be substantial capital projects.

Re-grading the cliff to a stable landform is an option that would, subject to design, meet the technical requirements of providing resilience for much of the route between Smugglers Lane and Teignmouth. This option has already been indicated for a length of route north of Parson's Tunnel (ref Section 6). A regrade option would have a significantly larger environmental and socio-political impact south of the tunnel as there is infrastructure close to the cliff top in this region, including the A479, together with many properties. The 'set back' envelope indicates significant land-take in some areas, and the re-profiling of up to 1600m length of cliff would therefore result in very substantial quantities of spoil material. Whether that material would need to be transported off site via the public highway network or whether conveyed down the slope for re-use or disposal by rail or sea is likely to have significant impact on programme and cost.

An alternative option to re-grading the slopes by removing the crest of the cliffs would be to build a new alignment for the railway further seaward. The new alignment would depart from the existing one at about the southern portal of Parson's Tunnel, at 207m 42ch and re-join the current tracks at about 208m 50ch. The vertical alignment would be essentially as at present. The horizontal alignment needs to be verified, particularly at the Parson's Tunnel end, and it may be that works around the tunnel mouth would be needed in order to enable this option. Moving the railway seawards would provide an effective solution to deep seated instability hazard as described in Section 3.2.4.4, and also provides opportunity to straighten the line along this section.

Under this option, land would need to be reclaimed seaward of the current coastal defence line. The extent of the reclamation would be subject to design but is likely to range from 10 to 35m seaward of the current wall and could comprise all or part of the Parson's Tunnel to Teignmouth frontage (Figure 7-1). The reclamation, coastal defence and new railway alignment would be constructed first, using the existing line for access and supplies. A toe buttress could then be built against the existing cliff slopes where necessary in a series of benched fill slopes to the required height (determined during design). Some minor regrade and cliff protection works are also likely to be required on the upper cliff to prevent shallow failures.

Figure 7-1: Indicative plan showing extents of the 10m and 35m "advance the line" alignments

Increasing the effectiveness of slope drainage in this particular length is also considered to be a key part of the provision of long-term resilience against slope hazard. If either the slope regrade or the toe buttress options are followed, then the design of the earthworks would need to incorporate suitable surface and sub-surface drainage. The effectiveness of the drainage systems would be dependent, in large part, on ensuring adequate capacity and efficient alignment of discharge routes to convey run-off down the slopes, beneath the railway and into the sea (Section 3.2.3.3).

Although rockfall mesh is not considered to provide long-term resilience for the reasons described above, it may have a role in enhancing resilience at the proposed end point of the proposed realignment, near Teignmouth station as major earthworks in that area would be difficult to justify on socio-political and cost grounds.

7.3 Constructability

General comments on constructability are discussed in Section 2.2.1 and Table 7-4 below highlights the construction and maintenance issues that apply for the different coastal and geotechnical options which have been shortlisted in Section 4.

As for Section 2 and 3, the coastal defence works can be built directly in front of the existing wall from the seaward side, creating little disruption to railway operations. In the case of the reclamation option, the initial work would be 10-30 metres offline from the existing wall.

The construction sequence for the combined coastal reclamation and toe buttressing solution is an additional advantage to this option as it allows for the reclamation, coastal defence and new railway alignment to be constructed first, while the existing line remains fully operational. The mainline would then be transferred onto the newly constructed line before commencing work on the cliffs; the decommissioned service line would then be available as a siding for import of supplies for the construction of the cliff buttress. The buttress would be built in a series of benched fill slopes to the required height (determined during design). Some minor regrade and cliff protection works may be required on the upper cliff to prevent shallow failures.

Table 7-4: Constructability and maintainability of coastal and geotechnical options in Section 4

Option	Constructability Issues	Maintenance Issues	Notes
New Vertical Wall	New vertical wall would need to be built from the coast and would be tidally affected and require floating plant. Public safety of beach and coastal footpath users to be considered. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Depths of water and underwater hazards to be considered such as rock outcrops and old groynes.	Inspection and maintenance of wall undertaken from the seaward side from the coast which is tidally affected. Maintenance works may require floating plant - depths of water and underwater hazards to be considered such as rock outcrops and old groynes. Public safety of those using the beach and coastal footpath to be considered.	
New Revetment	Works would require tidal working and use of floating plant. Rock deliveries to be from sea. Depths of water and underwater hazards such as rock outcrops of and old groynes to be considered. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Works may impact upon public beach and coastal footpath - public safety to be considered.	Maintenance of rock revetment likely to be limited to approx. 20 year intervals to reposition rocks to suit. Access for maintenance will be from seaward side - works will require tidal working.	
Beach Management	Beach nourishment works and deliveries of sand will be undertaken from the sea. Land based activities will be tidally restricted and safe storage/compound location will be required. Limited access is available from landward side to foreshore from slipway. Groyne structures, associated materials and installation plant will need access to the beach; working will be tidally restricted. Public safety to be considered as works will affect public beach, coastal footpath and access structures such as slipways and steps.	Regular monitoring to be undertaken of beach including after any storm event to ensure sufficient beach material exists. Windblown sand to be monitored as may impact on rail operations. Re-nourishment likely to be required on regular basis (approx. every 5 years) to maintain beach levels - requiring similar works to construction. Potential for public injury on groyne structures.	
Regrade the slope	Re-grading works likely to impact on railway line in safety terms. Potential to also impact other publically accessible areas such as the SW coastal path - impacts on various users/public to be considered. Constrained work area. Disposal of a large volume of fill would be required – either by road or sea depending on licensing.	Inspection of slope may be undertaken on foot, possibly from trackside. Maintenance works (e.g. on drainage features) may require rail restrictions.	

Rockfill cliff buttress, Drainage and Coastal Defence Reclamation	Reclamation works require tidal working. Depths of water and consideration of underwater hazards such as groynes and rock outcrops to be accounted for. Reclamation materials will be from the sea. Land based activities will be tidally restricted and safe storage/compound location will be required. Public safety to be considered as works will affect public beach and public footpath. Works will impact upon rail operations.	Inspection and maintenance of revetment wall undertaken from the seaward side from the coast which is tidally affected. Maintenance works may require floating plant - depths of water and underwater hazards to be considered. Public access along footpaths/promenade created by the works will have to be restricted during maintenance.

7.4 Environmental constraints and opportunities

This section outlines the high level environmental constraints, opportunities and relevant SEA assessment criteria for Section 4 (207m 41ch to 208m 66ch).

7.4.1 Environmental Constraints

1. Increased footprint on foreshore and potential changes in water quality (works would be within Teignbridge bathing waters).
2. Constrains natural coastal processes, loss of sandy beach, potential changes to downdrift beaches and SW Coastal Path would need rerouting.
3. Increases hydromorphological pressure on Lyme Bay coastal waterbody.
4. Advancing the line would produce a significant impact on marine flora and fauna (including fish) and potential impacts on intertidal archaeology (Church Rocks protected wreck sites)
5. Significant land-take and landscaping required.
6. Change to landscape character & potential deterioration in views.
7. Visual impact of toe barrier. Temporary deterioration in visual amenity from replacement works on cliff and possible vegetation clearance

7.4.2 Environmental Opportunities

1. Opportunities to integrate recreation, amenity and biodiversity benefits.

7.4.3 Relevant SEA Assessment Criteria

1. Are the adaptation options likely to affect Habitats of Principal Importance and/or associated species?
2. Will the adaptation options cause severance of wildlife corridors?
3. Will the adaptation options affect fish within the study area?
4. Do the adaptation options support biodiversity improvements?
5. Will the adaptation options detrimentally affect water quality resulting in effects on flora and fauna?
6. Do the adaptation options allow natural geomorphological processes?
7. Are the adaptation options likely to affect surface and/or ground water quality?
8. Are the adaptation options likely to affect WFD protected areas including designated bathing waters?
9. Do the adaptation options conflict with or contribute to meeting WFD objectives for good ecological status/potential?
10. Are the adaptation options in keeping with the existing landscape character and visual amenity?

11. Does the siting of the adaptation options affect distinct landscape components?

7.5 Identification of costs and benefits

Within the bodies of the coastal and geotechnical long list tables reproduced in Appendices A and B, an indication of the relative costs of the different options was provided. In Table 7-5 below, for those options that have been shortlisted, an indicative current day cost for each has been derived. The rates used for these budget estimates, their source, and any assumptions made are all included in Appendix D.

207m 42.5ch to 208m 55ch

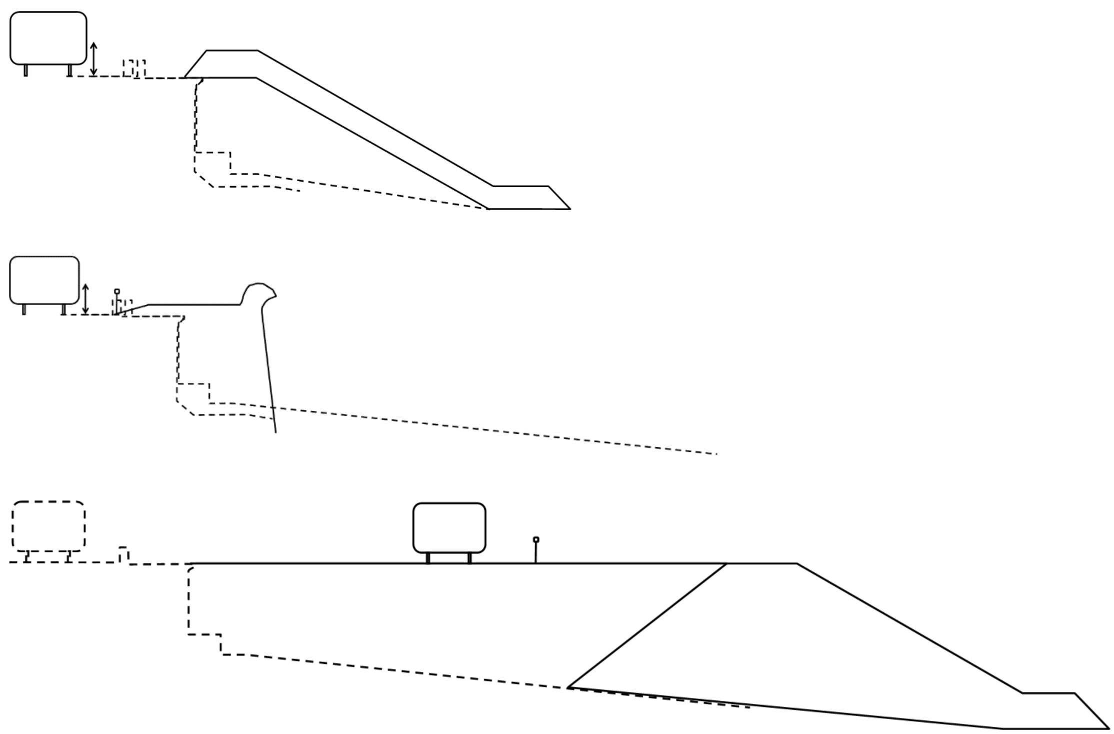


Figure 7-1: Schematics of coastal options

Table 7-5: Indicative costs for coastal and geotechnical options applicable in Section 4

Location (miles and chains)	Length (m)/Qty	Option/Measures	Indicative cost estimate (£)	Notes
207m 42ch to 207m 42.75ch	15	Rockfall shelter and tunnel mouth works	2,420k	CBU 15 Option A
	20	Track realignment	24k	
	15	Meshing and fencing	262k	CBU 15 Option B
207m 42.5ch to 208m 55ch	1861	New vertical wall + beach management	54,650k	
	1861	New sloping revetment	49,820k	
207m 43ch to 207m 46.5ch	70	New bridge/culvert structure	3,200k	CBU 14 Option A
	70	Meshing (partial)	114k	CBU 14 Option B
207m 46.5ch to 208m 50ch	1660	Cliff regrade (Option A)	322,245k	CBU 13 to 2. Option A
		Reclamation, toe buttress and realign railway (Option B)	262,545k	CBU 13 to 2. Option B
	1660	Meshing, fencing and drainage (taking account of existing recent measures)	19,116k	CBU 13 to 2. Option C
208m 60ch to 208m 66.5ch	130	Meshing and fencing	743k	CBU 1
207m 40ch to 208m 66.5ch	5 No.	Re-clad/protect location boxes	27k	Critical Rail Assets
	2 No.	Re-clad/protect switch cabinets	11k	
	5 No.	Protect axle counters	10k	
	1 No.	Protect signal heads	2k	
	3 No.	Replace track circuits with axle counters	225k	

The cliff buttress and reclamation scheme has a number of potential benefits:

- It would mitigate deep failure risk and provide long-term resilience for the future
- It can be built with much reduced impact on the operational line compared with the regrade option
- Subject to confirmation by design, it would have reduced impact on cliff top property compared to the regrade option
- It would include a reclaimed area built to modern standards and incorporating future climate change resilience
- Improved access to the slopes above the railway along this section
- Has the potential to be expanded to include for one or more passing lines
- It would provide opportunity for environmental enhancement and habitat creation

- It would provide additional local community and amenity opportunity benefits such as an improved and safer promenade, cycle paths

Teignmouth to Newton Abbot

8.1 Shortlisted options

For most of the estuary the existing estuary defences can be expected to protect the line from flooding until the end of this century although increasing maintenance and eventual replacement will have to be considered.

The railway is routed within the Teign Estuary substantially at grade, but with locally raised lengths and some sections where the line cuts through sloping sidelong ground. The earthworks assets therefore primarily comprise some limited cliff lengths and cut slopes to the northern side of the line, with some smaller slopes (and retaining structures) to the south side leading down to the estuary. The most significant slope is to the west of the Shaldon (road) bridge, between approximate chainages 209m 55ch and 209m 70ch, where sandstone and breccia cliffs are up to some 8m high and stand at up to some 70 degrees. In 2003, a small surface slip took place on the lower part of the slope at around 209m 61ch, and remediation comprising meshing and nailing/bolting was installed in c2005, termed the ‘Shaldon Quay’ works

Other than the above works, there are no known significant geotechnical issues or geohazards to the operation of the railway relating to this section of the line, and it may therefore reasonably be considered that the level of geohazard is lower than some of the coastal lengths. It is possible that changing environmental conditions (e.g. climate change, groundwater) in the future could lead to a decline in the stability of earthworks without any intervention, which should be reviewed. However, although typical inspections and maintenance of the earthworks assets will need to continue, large scale intervention to increase resilience is unlikely to be required in response to geohazards.

The standard of protection against flooding along Section 5 is generally good with works not widely required until 2065 or later. The exception to this is a short section between Teignmouth station and Shaldon Bridge where the track level is considerably lower than the desired design flood level in 2065.

The phasing of interventions suggested in Table 8-2 takes into account the remaining life and the current and future standard of protection provided by the existing defences. Defences have been costed to limit temporary disruption to the railway in 2065 to similar levels as the present day and to reduce damage under extreme storm events in 2115.

Table 8-1 presents a summary of the shortlisted coastal options considered for Section 5.

Table 8-1: Summary of shortlisted options in Section 5

For the coastal options, the likely year for implementation of the options at different locations along the study are presented.

Mile	Chain	Coastal Short List			Geotechnical Short List	Other Assets Requiring Specific Attention	
		Year	Option	Option	Option	Chainage	Asset
208	73	TEIGNMOUTH STATION			Negligible risk from geotechnical hazards	No rail assets at significant risk	
208	74	NO COASTAL INFLUENCE					
209	20						
209	20	2065	Raise existing	New vertical wall			
209	30						
209	30	2040	Raise existing	New vertical wall			
209	50						
209	50	2065	Raise existing	New vertical wall			
210	00						

210	00	2080	Raise existing	New vertical wall		
210	60					
210	60	Works unlikely to be required				
211	20					
211	20	2080	Raise existing	New vertical wall		
212	20					
212	20	Works unlikely to be required				
213	79					

8.2 Assessment of effectiveness of options

The effectiveness of the shortlisted options is assessed by considering how much each option reduces the current hazard and increases the resilience at each location. The hazards posed to the railway line from overtopping are considered on a three-point scale: low, medium and high. The resilience of the coastal assets are then considered in years.

With regards to the critical rail assets, re-cladding the location boxes in a GRP case will reduce their susceptibility to flooding and corrosion impacts and extend their life. Noting that assets in the coastal environment deteriorate more quickly than in inland locations, this will lead to asset renewal cycles being more similar to the national average.

In a similar way, considering corrosion resistant materials, such as GRP, for footbridges, gantries and support platforms would provide a long-term benefit in this aggressive marine environment.

The resilience following mitigation is given as "80+" years to reflect the fact that the typical design life of a new structure in an estuarine environment. However, it is likely that new structures will endure for longer than 80 years (as the existing structures have already done) but this cannot be guaranteed. The effectiveness is summarised in Table 8-2.

Table 8-2: Assessment of effectiveness of coastal options in Section 5

Location	Option	Hazard			Likely residual life (years)	
		Current	Future	Post-mitigation	Current	Post-mitigation
209m 20ch to 210m 60ch and 211m 20ch to 212m 20ch	Raise Existing	Low	Medium	Low	80	80 +
	New Vertical Wall	Low	Medium	Low	80	80 +

8.3 Constructability

The constructability assessment considers the health and safety risks and constraints posed by each option during both construction and maintenance. Increasing sea levels over the 100-year appraisal will have a significant impact on the accessibility of coastal and estuarine defences for the inspection and maintenance regimes of these assets. Tidal working in itself poses significant health and safety risks to operatives during construction and future maintenance.

The resilience following mitigation is given as "60+" years to reflect the fact that the typical design life of a new structure in the coastal environment. However, it is likely that new structures will endure for longer than 60 years (as the existing structures have already done) but this cannot be guaranteed.

Table 8-3: Constructability and maintainability issued for options in Section 5

Option	Constructability Issues	Maintenance Issues
Raise Existing	Where existing defence is adjacent to railway line, railway operations may need to be suspended/reduced to suit. Works may have to be undertaken from the river. Assessment of existing structure capacity to be undertaken prior to any works being undertaken.	Railway operations may need to be reduced/suspended to suit.
New Vertical Wall	New vertical wall would need to be built from the estuary and would be tidally affected and require floating plant. Form and method of construction to be considered to minimise vibration and stability impact on rail operations. Depths of water and underwater hazards to be considered.	Inspection and maintenance of wall undertaken from the seaward side from the coast which is tidally affected. Maintenance works may require floating plant - depths of water and underwater hazards to be considered.

8.4 Environmental constraints and opportunities

This section outlines the high level environmental constraints, opportunities and relevant SEA assessment criteria for Section 5 (208m 73ch to 213m 79ch).

8.4.1 Environmental Constraints

1. Increased footprint on foreshore potential loss of sandy beaches. Increased hydromorphological pressure on WFD waterbody and potential changes in water quality (works would be within Teignbridge bathing waters).
2. Constrains natural coastal processes/sediment movement.
3. Change to landscape character and potential deterioration in views.

8.4.2 Environmental Opportunities

1. Opportunities to integrate recreation, amenity and biodiversity benefits.

8.4.3 Relevant SEA Assessment Criteria

1. Are the adaptation options likely to affect Habitats of Principal Importance and/or associated species?
2. Do the adaptation options support biodiversity improvements?
3. Will the adaptation options detrimentally affect water quality resulting in effects on flora and fauna?
4. Do the adaptation options allow natural geomorphological processes?
5. Are the adaptation options likely to affect surface and/or ground water quality?
6. Are the adaptation options likely to affect WFD protected areas including designated bathing waters?
7. Do the adaptation options conflict with or contribute to meeting WFD objectives for good ecological status/potential?
8. Are the adaptation options in keeping with the existing landscape character and visual amenity?
9. Does the siting of the adaptation options affect distinct landscape components?

8.5 Identification of costs and benefits

Within the body of the coastal long list tables reproduced in Appendix A, an indication of the relative costs of the different options was provided. In Table 8-4 below, for those options that have been shortlisted, an indicative current day cost for each has been derived. The rates used for these budget estimates, their source, and any assumptions made are all included in Appendix D.

209m 20ch to 210m 60ch and 211m 20ch to 212m 20ch

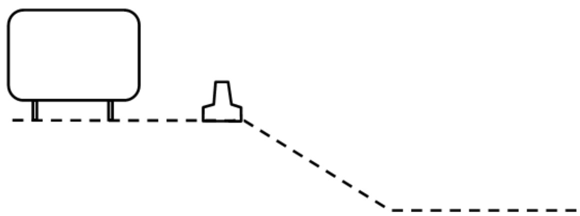


Figure 8-1: Schematic representation of "raise existing" option.

Table 8-4: Indicative costs for options considered in Section 5

Location (miles and chains)	Length (m)/Qty	Option/Measures	Indicative cost estimate (£)	Notes
209m 20ch to 210m 60ch and 211m 20ch to 212m 20ch	4023	Raise existing	23,685k	
		New vertical wall	25,900k	
208m 73ch to 213m 79ch	29 No.	Re-clad/protect location boxes	154k	Critical Rail Assets
	2 No.	Re-clad/protect switch cabinets	11k	
	10 No.	Protect axle counters	19k	
	11 No.	Protect signal heads		

Alignment with stakeholder objectives

As part of the consultation process undertaken during Phase 1 of this study, the “must do”, “should do” and “could do” aspirations of two key stakeholders, the Environment Agency and Teignbridge District Council that might have an influence on the options considered were recorded. How the shortlisted options identified for each section align with these are indicated in Table 10.1 below.

Table 9-1: Summary of options alignment with stakeholder objectives
Key: n/a – not applicable to this section; ✓ - section options support objective; o - section options have no impact on objective; x – section options in conflict with objective

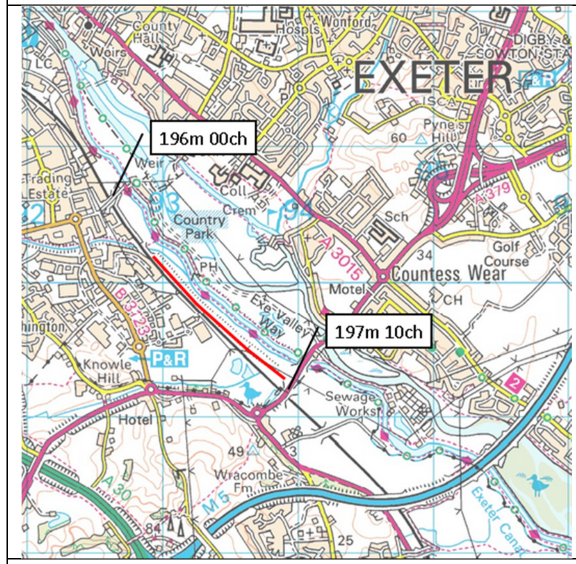
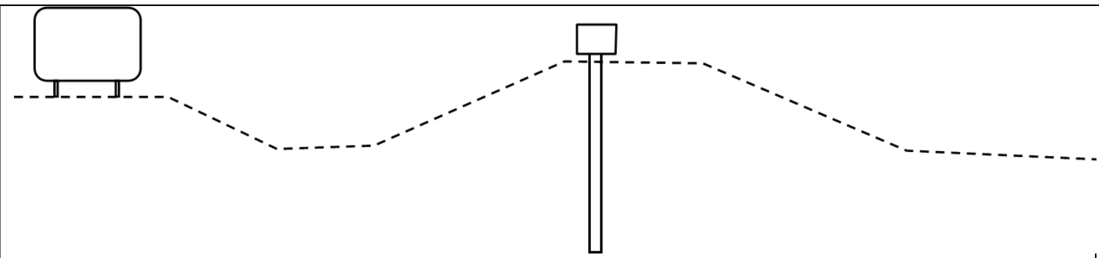
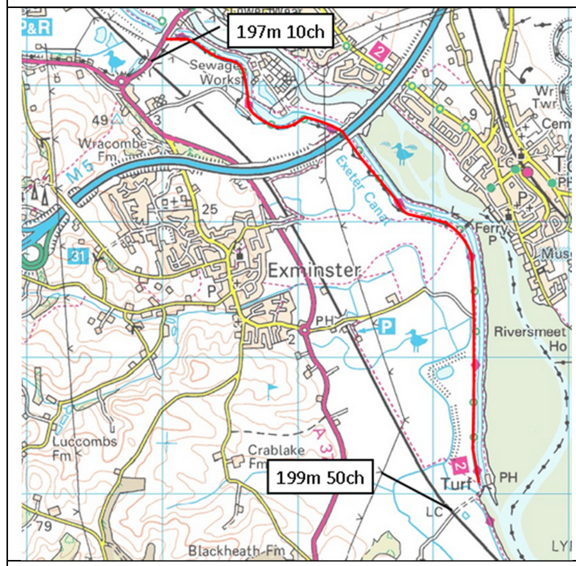
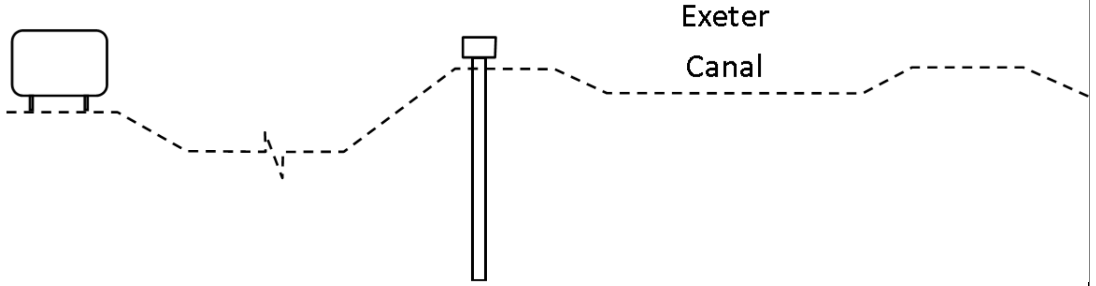
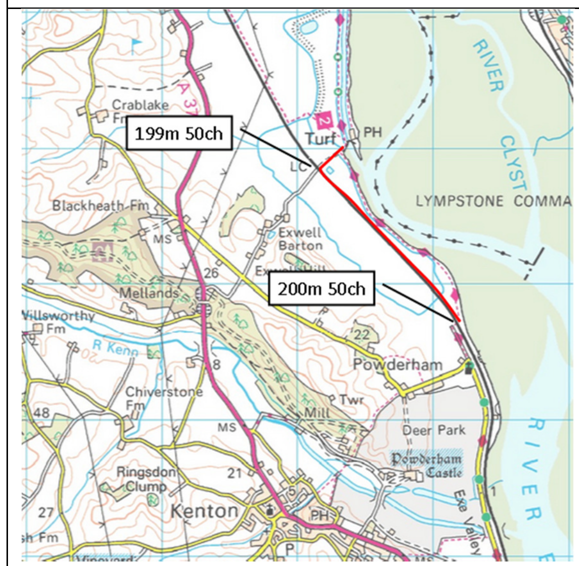
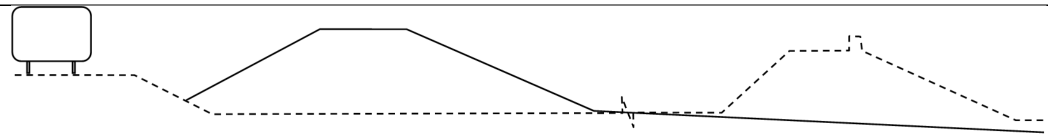
Stakeholder Objectives	Section Length				
	1	2	3	4	5
MUST DO					
Reduce risk of flooding & erosion to people, property, infrastructure, commercial assets and activities	✓	✓	✓	✓	✓
Comply with Habitats Regulation, WFD, Bathing Water Regulations etc and other environmental assessments	✓	✓	✓	✓	✓
Identify long-term sustainable management of Powderham Banks	✓	n/a	n/a	n/a	n/a
Maintain watercourse function through structures for WFD and Eel regulations	✓	✓	✓	✓	✓
Develop Beach Management Plan for FCERM, environmental and amenity purposes along coastal frontage to CIRIA manual standard/requirements between Red Rock, Dawlish Warren to Teignmouth Pier	n/a	O	n/a	o	n/a
SHOULD DO					
Reduce risk of flooding & erosion to key community, recreational and amenity facilities	✓	✓	n/a	✓	✓
Improve NR structures that currently blight community along Dawlish town Beach	n/a	✓	n/a	n/a	n/a
Not compromise longer-term opportunity for intertidal habitat creation behind Powderham Banks	o	n/a	n/a	n/a	n/a
Enhance public & stakeholder communication of impacts of climate/coastal change with respect to railway infrastructure, FCERM etc	o	O	o	o	o
Support development (through financial and information support) of proposed new Teignbridge DC visitor/education centre at Dawlish Warren and visitor centre at Dawlish Town	o	O	o	o	o
Improve information and data exchange between Partner organisations	o	O	o	o	o
Encourage academic links/research	o	O	o	o	o
Implement BIM methodology	o	O	o	o	o

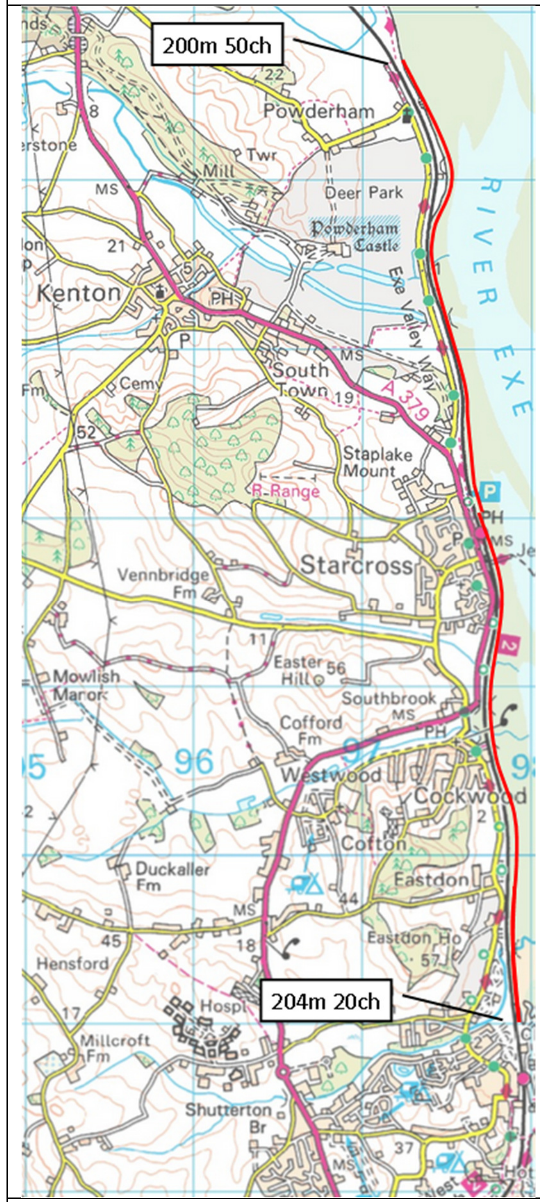
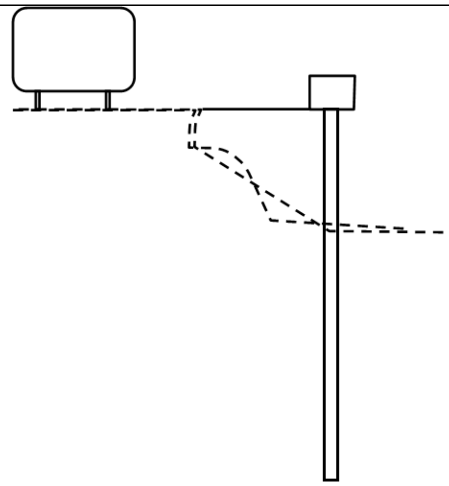
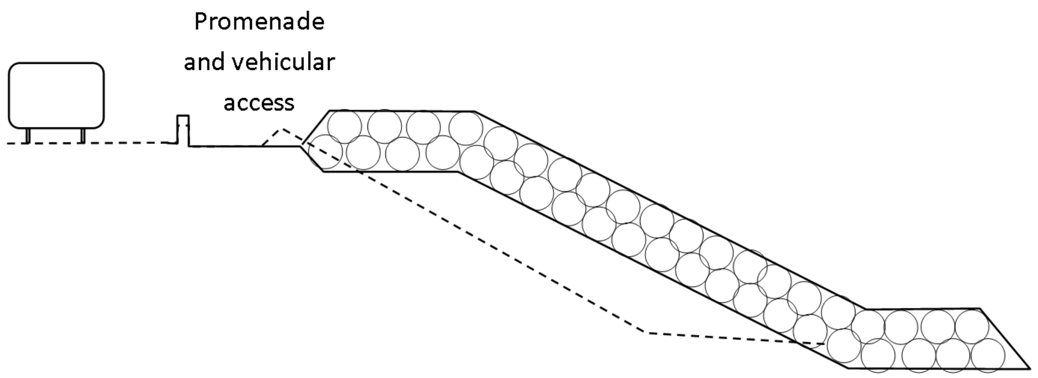
Minimise impacts on landward & marine operations and activities	✓	✓	✓	✓	✓
Maintain public access and amenity	✓	✓	n/a	✓	✓
In Kenn valley, obtain in-perpetuity agreement to allow water through railway embankment to estuary and ensure preferred options do not interfere with this	o	n/a	n/a	n/a	n/a
In Exminster Marshes, maintain/improve relevant NR toe drains to maintain important network for water level management as part of objectives for Exminster Marshes Water Level management Plan	o	n/a	n/a	n/a	n/a
Review flood warning areas and criteria along estuary and coastal frontage to improve warning service for flooding and disruption to communities and railway infrastructure	o	O	o	o	o
COULD DO					
Enhance key community, recreational and amenity facilities, including beaches	o	✓	n/a	✓	n/a
Enhance local economy	o	✓	n/a	✓	n/a
Investigate function of Langstone Rock Long Groyne to identify if options available to improve sediment transport to Dawlish Warren	n/a	O	n/a	n/a	n/a
OTHER OBJECTIVES SUBSEQUENTLY RAISED					
Provides opportunity for extension of SUSTRANS cycle route	n/a	n/a	n/a	✓	o

Recommendations for preferred options

The following solutions are proposed as the options which should be subject to further consideration under Phase 3 of this study.

The cost ranges reported against each option in these summary tables provide an indication of the relative magnitude of each option and are subject to ground investigation, analysis and further design. All costs presented below are in 2015 values and include for preliminaries and an optimism bias of 66 % as a proxy for risk and contingency.

196m 00ch to 197m 10ch			
		£4.5m - £6.0m	This option is recommended because: • Reduced impact on Alphington flood relief channel compared with embankment raising. • Most economical solution Key residual risks: • Alphington embankment is not strong enough to take additional load resulting in longer steel sheet piles (increased cost). • Visual impact • Vibration from piling (close to railway line) • Embankment ownership
197m 10ch to 199m 50ch			
		£12.1m - £16.3m	This option is recommended because: • Most economical solution • Works would have no impact on railway operations • Opportunity should be taken by ECC to also raise embankment along East side of canal Key residual risks: • If the integrity of the existing EA embankments proves insufficient, the pile length may need to be increased. • Embankment ownership may affect ease of access/adaptation
199m 50ch to 200m 50ch			
		£13.0m - £17.5m	This option is recommended because: • Allows compensatory habitat to be created by realignment of Powderham Banks section • Cycle path can be maintained by diversion onto the new embankment along the railway at Powderham Banks before re-joining the Exeter Canal at Turf Locks Key residual risks: • Visual impact • Where material will be sourced from • Need to consider through flow of water from existing culverts • Change in habitat from freshwater to intertidal – additional compensatory habitat may be required to achieve this

200m 50ch to 204m 20ch			
		£38.8m - £52.5m	This option is recommended because: • Limits impact on the intertidal habitats (compared to other defence options) • Limits impact on railway operations during construction. • Provision of wider working platform for rail operatives Key residual risks: • Need for compensatory habitat • Potentially limited windows for sheet pile installation due to noise and vibration impacts environmental designations (e.g. eels, breeding and overwintering birds) • Need to ensure no impact on through flow of water from existing culverts and outfalls • Interface with existing riverside structures to be considered (fishing piers etc.) maybe use flood glass and gates where appropriate) • Need for local accommodation of replacement for existing Curlew high tidal roost at 204m (e.g. by placing some rock above high water
204m 56.5ch to 204m 70ch			
		£7.2m - £9.8m	This option is recommended because: • This is most similar to the existing defence's footprint and will not significantly reduce passenger views. • Limited effect on railway operations during construction. • Allows pedestrian and maintenance vehicle access along this section to be maintained. • A suitable ramp / slipway could be installed to provide future maintenance access to the foreshore Key residual risks: • Loss of intertidal habitat

<table>
<tr><td colspan="4">204m 75ch to 205m 75ch</td></tr>
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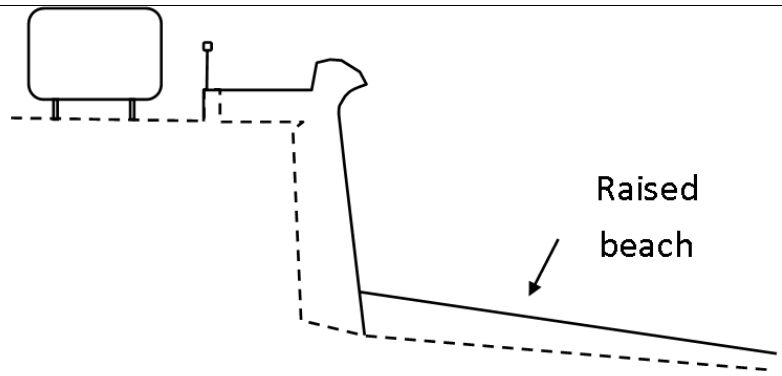
<td>
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<td>£28.8m - £39.0m</td>
<td>This option is recommended because:
• The small footprint of the new vertical wall with recurve allows continued public access to the beach in the short to mid-term (up to 2065).
• The defence is easily adaptable for climate change over the long term by addition of a rock revetment.
• Maintenance access improved – accessible to larger vehicles/plant
Key residual risks:
• Performance against overtopping can be reduced if the beach level is not maintained at a sufficiently high level.</td>
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<tr><td colspan="4">205m 75ch to 206m 13ch</td></tr>
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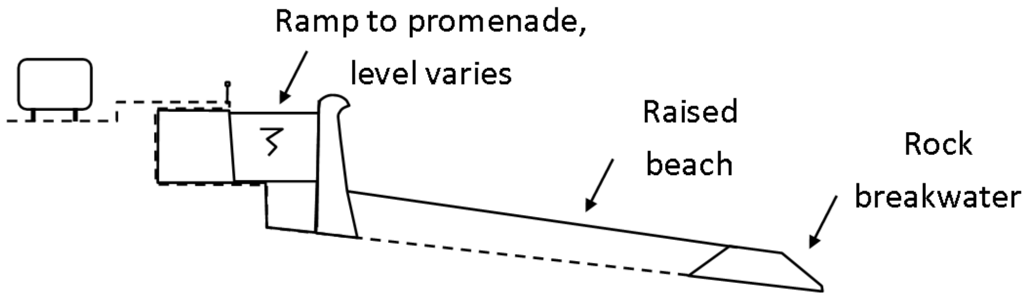
<td>
</td>
<td>£12.0m - £16.3m</td>
<td>This option is recommended because:
• The small footprint of the new vertical wall with recurve allows continued public access to the beach in the short to mid-term.
• The defence is easily adaptable for climate change over the long term by addition of a rock revetment
Key residual risks:
• Interface with station buildings (e.g. drainage)
• Final route of wall dependent on the structural capacity of the existing lower walkway.
• Interface with EA/others regarding flood protection to Dawlish town at underbridge to be considered separately.</td>
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<tr><td colspan="4">206m 16ch to 206m 34ch</td></tr>
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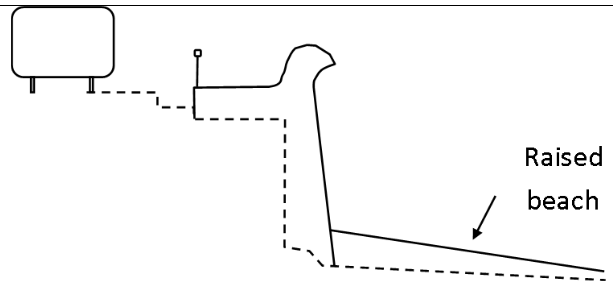
<td>
</td>
<td>£5.6m - £7.6m</td>
<td>This option is recommended because:
• It does not constrain access to Boat Cove.
• The small footprint of the new vertical wall with recurve allows continued public access to the beach in the short to mid-term.
Key residual risks:
• Performance against overtopping can be reduced if the beach level is not maintained at a sufficiently high level.
• Tie in with existing ramp up from/to promenade and link with footbridge
• Solution needs to tie into cliff face or portal protection if implemented</td>
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<tr><td colspan="4">206m 42ch to 206m 52ch</td></tr>
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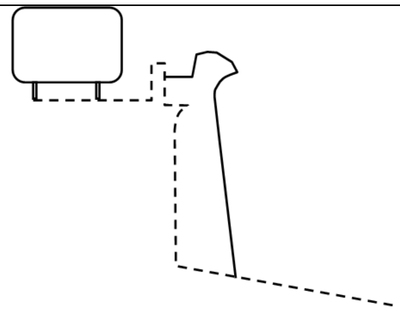
<td></td>
<td>£2.5m - £3.4m</td>
<td>This option is recommended because:

The small footprint of the new vertical wall with recurve allows continued public access to the beach in the short to mid-term.
The defence is easily adaptable for climate change over the long term by addition of a rock revetment.

Key residual risks:

Performance against overtopping can be reduced if the beach level is not maintained at a sufficiently high level.
Access to Coryton Cove is very limited and could increase cost to transport materials to site.
Difficulty in storing materials on/near to site.
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<tr><td colspan="4">206m 74ch to 207m 25ch</td></tr>
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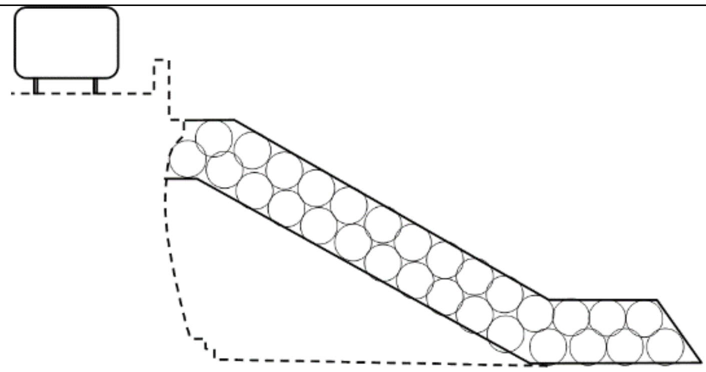
<td></td>
<td>£31.5m - £42.6m</td>
<td>This option is recommended because:

Due to the deeper water at the toe of the existing structure, a revetment is the simplest solution to construct.
Limited disruption to railway operations as work can be done seaward of the railway.
The full extent of the wall is considered (to 207m 25ch) to protect the structure from damage which could lead to undermining of Parson's Tunnel shelter.

Key residual risks:

The consenting process (through the Marine Management Organisation) could be complicated by the seaward extension of the defence.
Access is very limited (only accessible by sea); this could increase cost to transport materials to site.
Difficulty in storing materials on/near to site (likely to need a jack-up barge).
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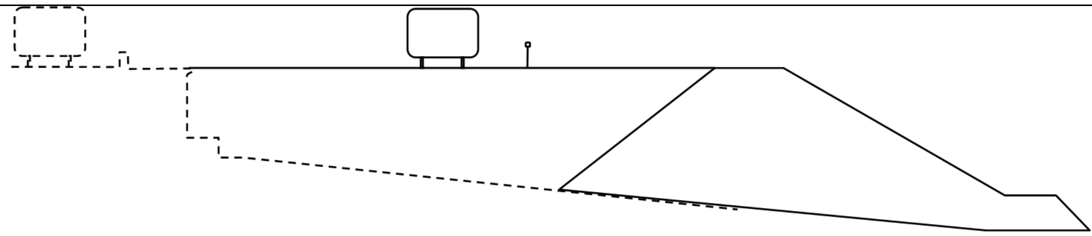
<td></td>
<td>Included in geotech solution, approximate cost for the coastal element:

£13.8m - £59.2m</td>
<td>This option is recommended because:
It presents significant cost efficiencies due to combined coastal and geotechnical solution.
The revetment solution presents the simplest and safest construction methodology for the reclamation.
Limited disruption to railway operations as initial work can be done seaward of the railway
Key residual risks:
The consenting process (through the Marine Management Organisation) could be complicated and lengthy due to the large area of reclamation.
Environmental impacts (on benthic habitats)
Potential to meet considerable resistance due to the scale of the suggested works.</td>
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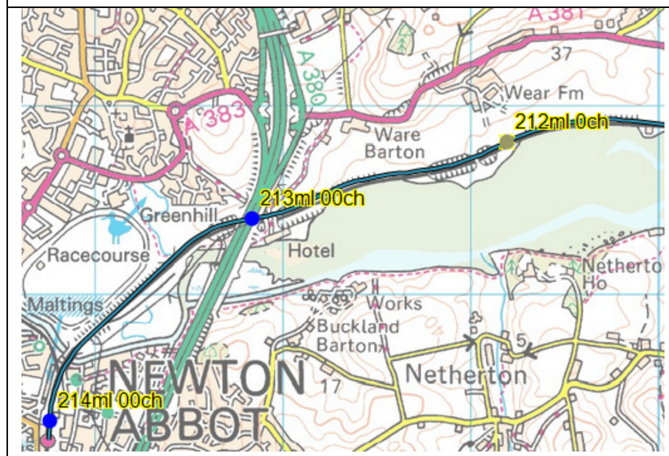
<tr><td colspan="4">209m 20ch to 210m 60ch and 211m 20ch to 212m 20ch</td></tr>
<tr>
<td>
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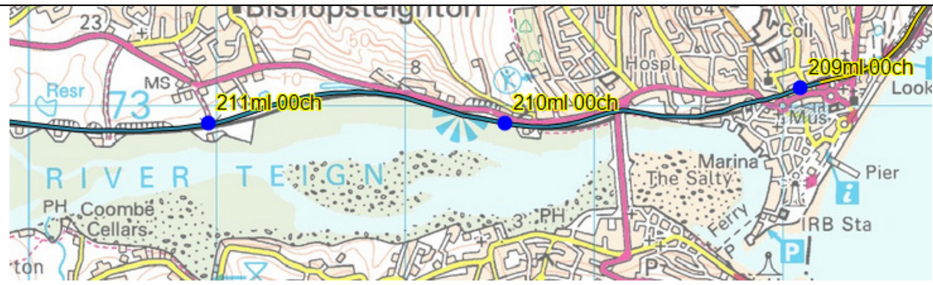
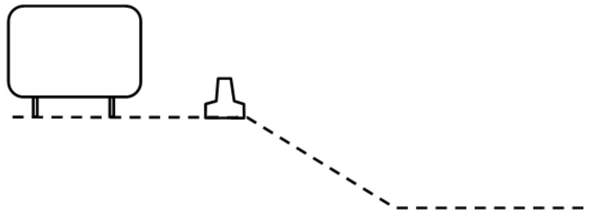
<td>

</td>
<td>£14.2m – £19.2m</td>
<td>This option is recommended because:
Existing defences are in good condition and are in a more sheltered environment than the other areas.
Small upstand wall could either be pre-cast or installed in situ.
All work within railway footprint.
Low-level wall will have no impact on passenger views
Key residual risks:
That existing footprint of track formation and pitching requires more extensive solution where upstand wall needs to be constructed within the down slope.</td>
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<tr><td colspan="3">204m 69ch to 205m 53ch</td></tr>
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<td><u>Includes:</u>

Rockfall barrier at toe, with counterfort drains in talus slopes and face meshing or other protection (dentition) where insufficient space for a toe barrier


</td>
<td>£4.8m - £6.6m</td>
<td>This option is recommended because:

• It will improve the existing resilience of the railway to geohazards
• It has limited impact on the Dawlish Cliffs SSSI as the works are generally not applied to the cliff face.
• It is an extension and upgrade of existing measures so unlikely to meet significant resistance from the public.
• The barrier system can be installed in sections, allowing the work to be phased and implemented over a series of possessions rather than requiring large scale disruptive works.

Key residual risks:

• The design life of the proposed measures is likely to be limited to 50 years owing to the aggressive marine environment.
• The proposed measures may be insufficient to protect the rail against run-out of a large cliff failure, albeit this is considered highly unlikely.
• Proposed works that impact the SSSI (where a barrier is not feasible) may be prevented, leaving the railway exposed to potential rock fall impact, albeit over very limited lengths.</td>
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<tr><td colspan="3">206m 33ch to 207m 18.5ch</td></tr>
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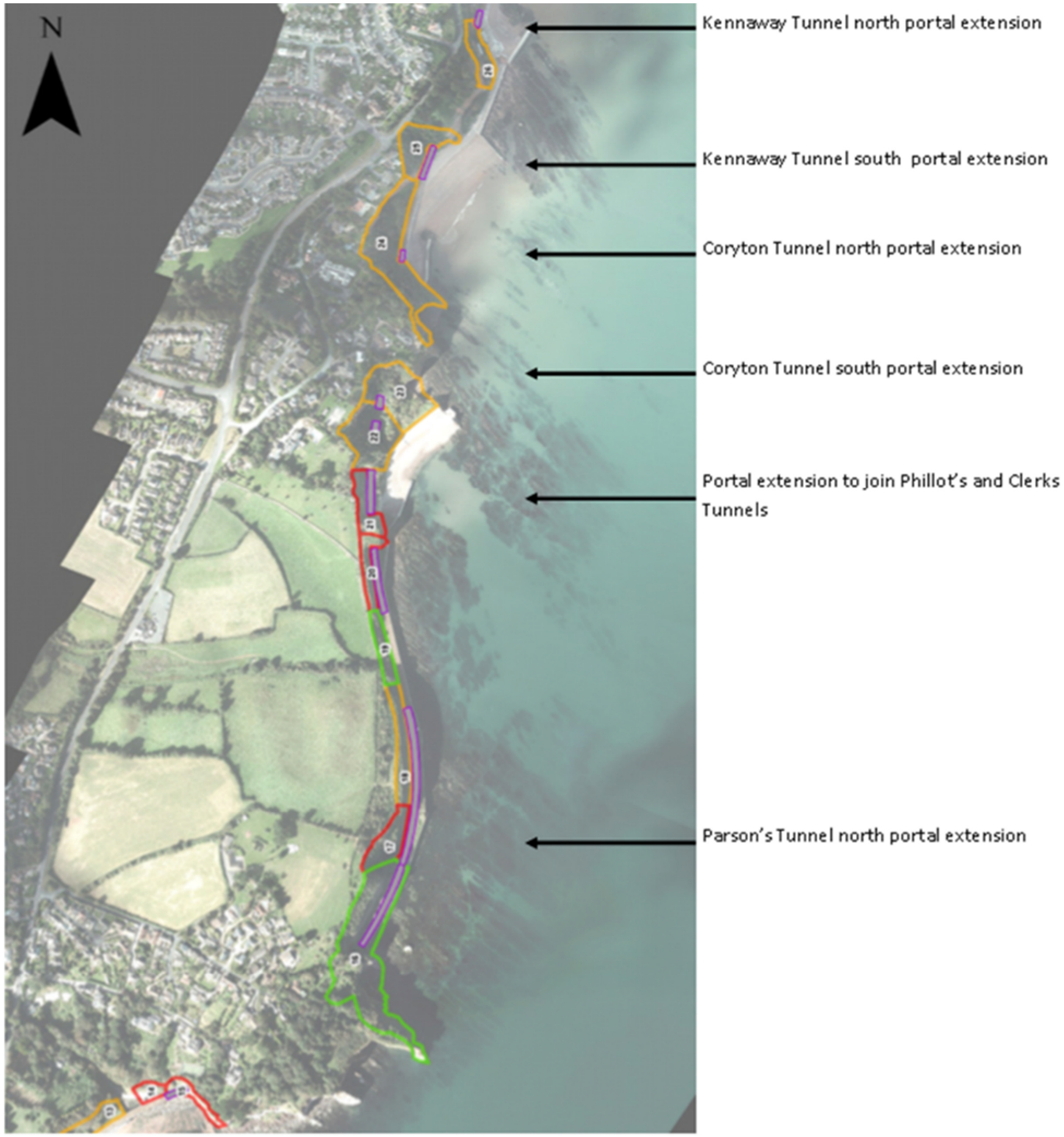
Includes:

Rockfall shelters, meshing and fencing, drainage replacement and rockfall barriers



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<td>£29.2m - £39.4m</td>
<td>

This option is recommended because:

- Construction of portal extensions will mitigate the rockfall hazard over critical lengths and substantially improve the resilience of the railway.
- Other measures will significantly reduce rockfall hazard for sections not protected by shelters.

Key residual risks:

- Lengths of meshing will have limited design life of 50yrs max, albeit the hazard is generally assessed to be low to medium in those areas

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<tr><td colspan="3">207m 42ch to 208m 66.5ch</td></tr>
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<u>Includes:</u>

Rockfall shelter and tunnel mouth works; track realignment; new bridge/culvert structure; meshing and fencing; reclamation, coastal protection, toe buttress and railway realignment

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<td>£250m - £338m</td>
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This option is recommended because:

- Substantially increases the resilience of the railway to geohazards.
- Avoids the need for a major regrade of the cliffs.
- Limits the land take required above the cliffs to achieve a stable slope and therefore has less impact on existing infrastructure and private property.
- Presents the opportunity to create access to the cliffs for maintenance and additional amenity through a wider promenade and cycle path
- Presents the opportunity to construct the new works offline and seaward of the existing railway.

Key residual risks:

- Design of new alignment has to ensure appropriate resilience to marine hazards, which may be elevated compared to current alignment.
- The consenting process (through the Marine Management Organisation) could be complicated and lengthy due to the large area of reclamation, but possibly no worse than obtaining consents for the cliff regrade option.
- Potential to meet resistance due to the scale of the suggested works.
- CBUs not covered by the reclamation will require investment in local cliff stabilisation works and ongoing maintenance and RCM monitoring.

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Asset types	Event-based intervention options	Enhanced specification BAU
Tunnels	Portal protection – covered by geotech solutions.	Headland erosion threat to tunnels – may need to be included in future coastal maintenance if voids in the headlands develop beneath the tunnels.
Bridges	Any minors works required to accommodate coastal protection upgrade to be undertaken as part of those works	Ensure scour included in inspection and maintenance programmes. Ensure major storm flood event included in bridge assessments.
Gantries and footbridges	Interim risk from rockfall or wave action before geotech and coastal options are implemented, Footbridges – None. Generally not present in highest risk locations or modern so designed to adequate standards. Those in medium risk locations appear robust/immune to damage, and if were to be damaged by extreme event are not required for operation of railway and so once debris of bridge and other operations could commence Signal Gantries – Option 1 move to lower risk location Option 2 –install local rockfall protection	Continue maintenance and when replacement eventually needed, provide more corrosion resistance alternative based on whole life cost assessment (marine grade paint system, or FRP where feasible).
GSM-R Mast	Smugglers Lane and Dawlish Station masts not considered high risk (based on comments received from Tony White).	Corrosion-resistant specs in future. System redundancy (200%) or relocation would improve access for inspection and maintenance. ETCS masts will need enhanced management plans.
Stations	None in high risk geotech. Overall protection by coastal, - unmitigated interim risks to be flagged-up (e.g. Dawlish, Starcross). Platform (wooden) at Dawlish	Canopies/roofs vs winds, enhanced inspection frequency, enhanced maintenance.
Drainage	New drainage (including UTX) where enhanced drainage is required as part of geotech CBU solutions	No apparent current evidence of wet track beds etc. within scope, hence restore blocked/overgrown culverts/drainage to service and carry out minor upgrades/new works over time as need established
Off-tracks	No event-based intervention options.	Reinstatement of boundaries, enhanced tree management, enhanced off-track drainage and flood-relief drainage.
Track	Cliff Toe walls to prevent talus on track and tunnel portal protection to reduce risk of blockage by rock fall	BAU - consider coated rails in wet areas in tunnels only Temperature effect – review Stress Temperature specification (NB: low risk on coastal section) Review specification for track clips - corrosion resistant specification
Ballast	Coastal options will reduce frequency of over-topping and geotech options decrease landslip - talus Ballast Contamination – by waves or landslip Ballast shift by waves. See Drainage to avoid "wet beds"	Consider fixed track bed solutions (ballast enclosed in sections of concrete trough) – more frequent ballast cleaning / tamping – consider application of polyurethane resin (gluing) to stabilise ballast in risk areas
Switches and Crossings	Switch Operating Motors – wave action and corrosion. Provide protection against wave action – GRP shroud	BAU – increase specification for switch motors– provide duplex motors – increase redundancy Replace hardwood slide pads
Signalling	Equipment Rooms & Location Cases – protect from rockfall – localised protection walls in high risk areas Relocate Location Boxes above flood height Signal Head gantries (see above)	Replace all track circuits with axle counters (prioritise flood risk areas). Review specification for location cases and axle counters Cabling (see E&P) Provide Bi-directional signalling (constrained by out dated signals controls)
Telecoms	Telecoms Equipment Room - move to safe location (away from rock fall or flood level) Or local protection walls against rock fall	Ensure sufficient air-con to meet higher peak temperature
E&P	Location Boxes - (impact of current Cable Renewal Project) Local protective walls to prevent mechanical damage by waves or rock-fall Cable Trough Flooding No Power Supply Point in scope	BAU - replace with GRP cabinet –Raise above flood level or use cable – ensure cable water resistant and no joints Replace with cable supports – set height above rail level (in estuary section)

References

CH2M (2015a), Phase1: Baseline Report.

CH2M (2015b), Hydrogeological Report.

CH2M (2015c), Non-technical geotechnical briefing report.

Network Rail (2015), Western Route Study

Appendix A
Localised Long List for Coastal Assets

Appendix B
Localised Long List for Geotechnical Assets

Appendix C
Localised Long List for Rail Assets

Appendix D
Costing Information

Appendix E
Coastal Options Development