Assessing and managing risks with transitions in flood defence infrastructure

Development of top-down methods for identifying and prioritising asset transitions based on risk

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Dr Robert Bradburne
Chief Scientist

Foreword

This report signposts potentially relevant considerations for practitioners when managing portfolios of flood risk assets with transitions. It is not intended to be, and should not be read as, prescriptive, exhaustive, or a statement of best practice.

The research findings presented in this report were commissioned by the Environment Agency for this project. This document is one of four outputs from this project and must be read alongside those other research outputs, rather than considered in isolation.

The outputs from this project are being used by the Environment Agency to review and improve our internal management processes. We apply a risk-based approach to all our activities, ensuring public money is targeted in a way to achieve the most benefit. This means that we may conclude that some of the techniques set out in this document are not appropriate for the Environment Agency to use.

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1. Introduction

1.1. Project overview

Transitions between flood defence assets and components introduce irregularities which increase the chance of failure, as seen in many historic flood events. Current guidance in England and Wales on the visual inspection of flood defence assets to determine condition does not explicitly account for the potential effects of transitions on defence performance. As such, where transitions do increase the probability of defence failure above that of the adjoining defence assets, the associated risks are missed from local, regional and national flood risk assessments. This research supports identifying, prioritising and assessing flood defence asset transitions to determine if they form a weak spot compared to the neighbouring assets and therefore could lead to increased flood risk. Quantifying the increased failure risk due to the transitions then feeds into a next step of prioritisation for improvement works.

The aims of the project are to:

- consider the presence of transitions when assessing flood defence condition
- quantify the effects of transitions on defence performance (fragility) and flood risk
- manage the risk of transitions with improved design and retrofitted solutions for existing defences

The research outputs have been divided into 4 reports. Each report focuses on a different stage of managing assets at transitions (Figure 1-1). This report focuses on identifying and prioritising transitions to inform the inspection process.

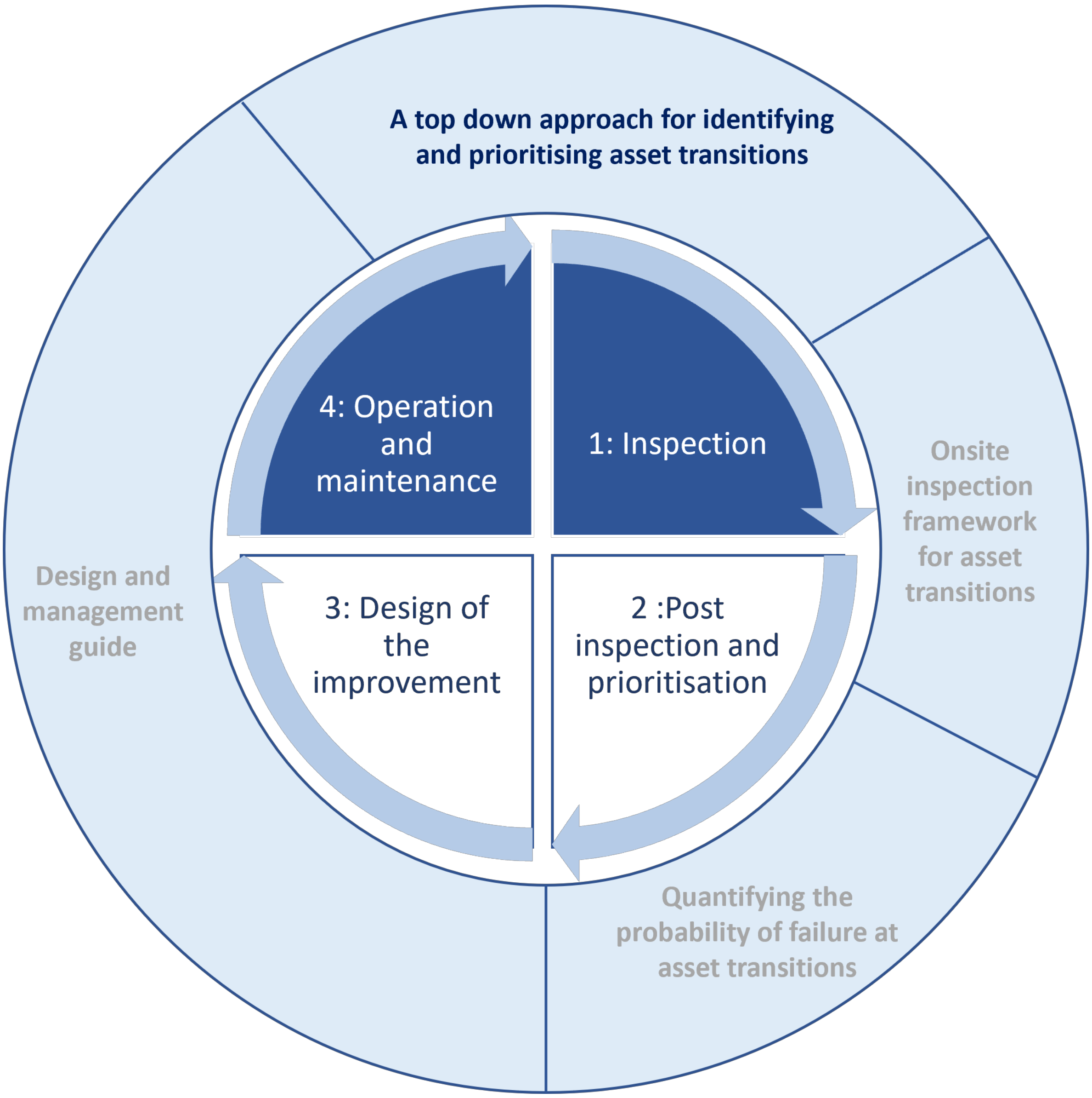

Figure 1-1 Project overview

1.2. Scope of report

This report describes work HR Wallingford carried out to define and test an automated initial method for identifying main transitions that should be prioritised for initial (tier 1) field inspection. This approach is described here as a 'tier 0' prioritisation method.

This work is an amendment to the original project scope and was identified as important following a series of 'learning' steps the project team made on identified transition assets, the current asset inspection processes and those assets proposed for transitions, together with the data required to carry out an analysis of the probability of transition failure. This learning was linked to:

- the spatial analysis of transition locations and types, carried out as an additional piece of work under stage 2 of the project, which identified over 150,000 transitions between flood defence segments of different types across England
- the piloting exercise of the onsite inspection and evaluation report (Environment Agency, 2022b), (that takes flood defence asset managers through the process of identifying whether asset transition elements should be considered for improvements) taking up to 30mins per transitions
- the development and piloting of the (updated hr*RELIABLE* tool) that accounts for transition characteristics in determining transition specific asset fragility curves, taking up to 2 hours per transition
- Discussions with the National Engineering and Innovation Panel (NEIP) and its concerns over the practicality of asset inspectors carrying out bespoke inspections at every transition

Reporting of the spatial analysis work, carried out as part of stage 2 of the project, is included as Appendix A to this report and is summarised in section 2.

1.3. Who is this report for?

The envisaged users are the teams responsible for managing the performance of flood embankments and other soft raised linear defences. In particular those involved in identifying the need for asset improvement and creating prioritised work plans.

1.4. Using this report

The methods described in this report are reliant on data and toolsets employed by Environment Agency for flood risk asset management and may not be suitable for direct use by other flood risk asset management organisations. The principles behind the methods can however be used to develop approaches for other organisations.

1.5. Report structure

This report is divided into 3 sections. The first looks at identifying transitions and the spatial analysis required to carry out a top-down approach. The second section looks at prioritising transitions, based on their potential consequence of failure once they have been identified and applies this approach to a pilot case study, the Tidal Trent. The third section focuses on the evaluation of the approach, identifying characteristics that may increase failure probabilities at transitions and recommendations for future Identification, prioritisation & screening processes.

2. Identifying transitions

2.1. A spatial analysis of transitions across England

A spatial analysis (described in Appendix 9) of Environment Agency asset data sets (AIMS) was carried out to support the understanding of the total number and most frequent types of transitions in England. The analysis was carried out using the data underpinning the current National Flood Risk Assessment (NaFRA), which was downloaded from AIMS in October 2016.

The study concluded that the total number of transitions between flood risk assets is 167,500. Of those, 20,709 involve transitions with an embankment. If considering only transitions between embankments and hard structures (4,506) and between embankments with a hard and a soft revetment (2,149), the number of transitions is 6,655, which corresponds to 10% of the total number of assets which are not high ground. Three-quarters of transitions between embankments and hard structures correspond to vertical walls and one-third of embankment transitions are between hard and soft revetments.

Other types of transitions that the project team have considered, but not included in Table 1, are transitions between embankments and:

- partially included structures
- longitudinal pipelines
- pipelines up and above the embankment
- their own revetment
- other embankments with different internal layers

These additional transitions were not considered because they:

- involve some knowledge of internal layers of the embankment which is not available with the current inspection methods (for example, longitudinal pipelines and embankments with different internal layers)
- have been considered infrequent by stakeholders (for example, partially included structures and pipelines up and above the embankment)
- are already considered in the overall condition of the embankment (transitions of internal layers with revetment of embankments)

If links between assets and high ground are ignored, then the relevant transitions are identified by light grey boxes in Table 1 – numbering 4,506 in total. High ground transitions are identified in dark grey boxes and white font in the table and have not been taken forward as part of this generic prioritisation work as high ground is insufficiently well-defined in the AIMS database. It is also not represented as a breachable defence type within the system flood risk models (consequently there are no fragility curves for high ground).

Table 1 Number of transitions for each combination of assets

	Barrier beach	Beach	Dunes	Embankment	Wall	Bridge abutment	Simple culvert	Complex culvert	Flood gate	Demountable defence	High ground	Total
Barrier beach	0	-	-	-	-	-	-	-	-	-	-	**0**
Beach	0	178	-	-	-	-	-	-	-	-	-	**178**
Dunes	0	6	56	-	-	-	-	-	-	-	-	**62**
Embankment	2	56	21	8,398	-	-	-	-	-	-	-	**8,477**
Wall	1	75	21	3,362	6,440	-	-	-	-	-	-	**9,899**
Bridge abutment	0	0	0	524	444	14	-	-	-	-	-	**982**

	Barrier beach	Beach	Dunes	Embankment	Wall	Bridge abutment	Simple culvert	Complex culvert	Flood gate	Demountable defence	High ground	Total
Simple culvert	0	2	0	484	735	12	4,660	-	-	-	-	**5,893**
Complex culvert	0	0	0	4	20	0	287	184	-	-	-	**495**
Flood gate	0	0	1	94	1,726	7	6	0	43	-	-	**1877**
Demountable defence	0	0	0	38	344	2	0	0	2	7	-	**393**
High ground	1	13	5	7,825 (high ground)	3,842 (high ground)	1,378 (high ground)	23,982 (high ground)	259 (high ground)	67 (high ground)	42 (high ground)	101,807	**139,221**

	Barrier beach	Beach	Dunes	Embankment	Wall	Bridge abutment	Simple culvert	Complex culvert	Flood gate	Demountable defence	High ground	Total
Total	**4**	**330**	**104**	**20,729**	**13,551**	**1,413**	**28,935**	**443**	**112**	**49**	**101,807**	**167,477**

2.2. Additional needs in identifying transitions for inspection

The number of transitions identified by interrogating the AIMS asset database, as described in section 2.1, can be very large for some catchments. This was demonstrated for the Tidal Trent pilot study (pilot study 2), for which a total of 220 transitions were identified over an 85km length of river. However, when these transitions were studied in detail, it was clear that a large number of these assets represented outfalls below ground level and/or in very rural areas. Discussions with the National Engineering and Innovation Panel (NEIP) earlier in the project had highlighted its concerns over the time it would take for asset inspectors to carry out bespoke (tier 1) inspections at every transition location in order to determine any improvement needs. This pointed to the need for a desk-based process for identifying transition assets that should be prioritised for inspection.

The pilot studies also identified:

- ‘missing’ transitions where transitions are as a result of Environment Agency flood defence assets linking with non-flood defence infrastructure, for example, road/highway bridge abutments, which aren’t represented in existing Environment Agency or Natural Resources Wales’ asset databases (where they aren’t directly performing a flood defence function)
- ‘multi-transitions’ where a single transition location may comprise more than one transition type, for example, a crossing pipeline (type 3) with large outfall and wingwalls (type 1 characteristics)

The project team developed 2 strands of work to address the identified prioritisation needs:

- A method of evaluating the consequence of failure associated with individual transitions (and therefore their relative importance in terms of maintenance).
- Sensitivity analysis (using the hrRELIABLE transition reliability tool developed in the Quantifying the probability of failure at asset transitions report (Environment Agency, 2022c) of this project to look at the contribution of a number of transition ‘characteristics’, for example, geometry and soils to the asset failure vulnerability.

  This work is reported fully in in the Quantifying the probability of failure at asset transitions report (Environment Agency, 2022c) , but the conclusions relevant for transition prioritisation are set out in section 6.2 of this report.

In addition, incorporating additional transition asset ‘knowledge’ within the prioritisation process is discussed in sections 6.1 and 7 of this report.

3. Prioritising transitions based on consequence of asset failure

3.1. Background

The premise for developing an automated initial method for prioritising transition elements was that elements would be prioritised where any increased likelihood of failure (resulting from its characterisation as a transition) would mean a significant increase in associated consequences.

The analysis for this study draws on the results from 3 sets of national flood risk model runs, all of which were carried out during the State of the Nation (SoN) project. These are:

1. National Flood Risk Assessment (NaFRA). These results provided a present day evaluation of risk given the presence and performance of the current set of flood defence assets. This is a ‘system risk’ approach; all defences protecting a flood area are considered to act as a ‘system’ where one or more defence may overflow or be breached in an extreme event, and the risk from the area inundated is apportioned back to the assets according to their relative contribution.
2. Creating Asset Management Capacity (CAMC): These model runs explored the system risk associated with a number of potential defence scenarios:
   - no defences – the system risk model run with no flood defence assets
   - condition grade 5 – the system risk model run with all flood defence assets set to be in ‘very poor’ condition
   - target condition - the system risk model run with all flood defence assets at target condition
3. Risk Assessment Field Tool (RAFT): These model runs used a non-system-based approach to assess the risk associated with each individual flood defence being breached, without inflow to the flood plain from any other defence asset in the system. The scenarios modelled were for each asset in:
   - condition grade 4
   - condition grade 5
   - target condition

To evaluate the risk associated with flood defence assets in order to prioritise maintenance and capital spend, 2 metrics of risk are considered to be of interest:

- Existing Benefit: the value of the reduction in risk that is provided by the presence and condition of the flood defence asset (compared to the ‘no defences’ situation)

- residual risk: the value of the risk that remains given the presence and current condition of the flood defence asset

Plotting these 2 metrics against one another enables the assets to be ranked in terms of their importance for capital and maintenance investment. This is often divided into 4 sections and investment priorities of each sector are described.

Assets that have high Existing Benefit but low contribution to risk have a higher maintenance priority. These assets can be described as in current good condition, but if they were unmaintained and deteriorated to a poor condition, this would result in a considerable amount of risk. Similarly, assets which have high Existing Benefits and a high contribution to risk have a higher maintenance and capital priority. These assets are accountable for considerate risk in their current condition. If the assets' current condition is poor, then there are considerable benefits in improving target condition. Those assets which have low Existing Benefit and low contribution to risk are not accountable for large risk and further deterioration would not increase risk significantly. Finally, those assets which are low in Existing Benefits but high in contribution to risk account for considerable risk in their present condition. There may be small benefit gained from improving these assets' conditions, and capital works such as raising crest level may offer significant benefits for risk reduction (HR Wallingford).

In general terms, assets with a low residual risk but high Existing Benefit should have a higher maintenance priority, and those with high residual risk but low Existing Benefit should be prioritised for capital investment. It is considered that the type of works required to be carried out at transition assets as a result of a bespoke transitions inspection programme would be described as maintenance rather than capital works, and therefore 'Existing Benefits' has been used to rank the transitions' assets.

To rank the assets, 3 different data sources/methods have been trialled. These are described in section 2. For all 3 methods, the following metric was used to calculate the Existing Benefit:

$$\textbf{Existing Benefit} = \textbf{risk}_{\textbf{CG5}} - \textbf{risk}_{\textbf{currert CG}}$$

This defines the reduction in risk associated with the asset in its current condition compared to if it were in a substantively weakened state. The logic is that assets with a high level of Existing Benefit will be most important in terms of the need to maintain their standard of protection and condition grade.

The methods are implemented using CG5 (rather than 'no defences') to calculate the benefit since this is readily available in the 3 data sets, whereas a 'no defences' scenario is only possible with option 2. The project team considered this to be appropriate given that CG5 represents an asset being in very poor condition, and accordingly the fragility curve gives a far higher likelihood of failure under load than the curve for any other condition.

Consistent data needs to be available for the whole area the tier 0 prioritisation is applied to, in the context of the EA intended application this means nationally available data (the Existing Benefits). However, during tier 2, detailed reliability assessments are made to evaluate the change in annual probability of failure given the presence of the asset transition. It follows therefore that, after tier 2, further prioritisation can be carried out which considers the actual increase in annual failure probability due to the transition and the associated increase in risk.

The work did not produce a definitive ‘prioritisation’ because:

- the limited breach depths predicted by the RAFT run meant that the depths of flooding and therefore risks associated with larger assets were unexpectedly (and considered unrealistically) low
- the flood spreading model used in the approach meant flooded areas could be remote from the asset and therefore potentially inaccurate (and/or not include flood conveyance pathways)
- ‘important’ infrastructure was not sufficiently well identified and therefore not considered to generate a sufficient level of risk
- the asset definition in SoN is old and, in some areas, has now been updated, so the model is out of date

The work carried out for this project therefore considered a number of alternative options (and sub-options) for evaluating the potential significance of transition assets in terms of ‘risk’, taking into account the limitations of the earlier work. Three options are presented in section 3.2 and these were applied individually as part of an option evaluation process to the Tidal Trent pilot study area. The differences are discussed in section 3. The prioritisation method is described in section 3.4.

3.2. Alternative options for evaluating risk

3.2.1 Option (1) RAFT, ‘Existing Benefits’

This option uses the RAFT data to calculate the ‘Existing Benefit’ as defined in section 3.1. The RAFT data underpinning this method has results for all flood defence assets in England for each of the Condition Grades; CG3, CG4 and CG5. If an asset is currently in a condition that is better than CG3, the data for CG3 is used.

The same breach extents and depths are assumed for each scenario (and these match the ones underpinning the current EA analysis). However, the likelihood of failure increases (and consequently the risk increases) as the condition of the assets deteriorate. The Rapid Flood Spreading Model used to derive the flood extents may produce flooded areas that are remote (not connected) to the defence assets since this spreading engine gives a final extent rather than a flood pathway. In addition, as with current Environment Agency methods , the approach focuses on the failure of individual assets at a time. This can provide misleading results for events where several assets in system contribute significant volumes to the flood plain simultaneously (ether through overtopping or breach failure) since they are assessed individually rather than in combination.

To improve representation of the 'consequences' within the Existing Benefits evaluation, this was amended as follows:

- Rather than applying an economic value based on flood depth, consequence was based on the number and type of property within the flood extent.
- The receptor layer was supplemented with evaluation of the count of trunk and A roads within the flood extent.
- The receptor layer was supplemented with counts of 'strategically important infrastructure' in order that these assets could be captured explicitly.

3.2.2 Option (2) CAMC, 'Existing Benefits'

This option uses the CAMC system risk scenario results, while also adopting the 'Existing Benefit' metrics.

The benefit of using system risk rather than RAFT is that the consequence modelling takes account of all overflow into the flood area due to overflow and breach of any assets in the system. It then attributes proportions of that total risk back to the individual assets. However, since many thousands of simulations are carried out for each flood area, the consequence modelling is embedded within the existing model runs and pre-reported in the form of Estimated Annual Damage (EAD). It is not therefore possible to obtain flood extents and property counts associated with a single defence, and so recalculating critical properties, important infrastructure or road networks as described for option (1) at the asset level is also not possible.

3.2.3 Option (3) Breach Head Extents clipped to Flood Zones 2 (RAFT+ manual tool)

The RAFT+ app is a web tool which gives the Environment Agency access to the RAFT data along with a set of additional tools to re-evaluate the risk after calculating a bespoke set of fragility curves. The app has a user-defined option that, based on the breach head, creates a semi-circular flood extent around the point of breach on an asset. This is then refined to remove parts of the extent that are outside of the flood plain (defined by Flood Zone 2 (FZ2) and any parts that may fall into different flood cell due to meanders in the river or confluences and bifurcations). This method can be referred to as a ‘parametric spreading approach’. For this study, this approach was automated so that it could be run rapidly for all relevant transitions.

The SoN database includes asset location and height of the asset above the ground level (the full breach head). The data were downloaded from the AIMS defences in October 2016. The data were cleansed during the State of the Nation update to the NaFRA and were provided back to the Environment Agency as the SoN product named ‘Business as Usual Continuous Defence Line’ in 2018. The breach point was taken as the end of the asset at the transition location. The calculation method (calculate the extent distance, create the zone and clip it against FZ2 and flood area) was carried out for each transition point, and then all residential, non-residential, critical buildings (for example, substations, hospitals, schools) and main roads and rail lengths within the zones were identified, characterised and counted.

By including both the flood extent and transfer path, and by clipping the extent to the FZ2 boundary, this addressed several of the flooding location concerns associated with the previous SIA study. However, the method is only a simplified representation of reality - it assumes a flat flood plain and does not take into account any variation in the topography. Furthermore, factors such as catchment properties, system characteristics and contributions, and above bank volumes of hydrographs are not accounted for.

3.3. Comparing options

3.3.1 Summary of differences

A high-level summary of the characteristics of each option is given in Table 2. The flood spreading method drives many of the observed differences in location of flooding – options 1 and 2 using the Rapid Flood Spreading Method (RFSM) and option 3 using the parametric method. With the parametric approach, the flood depths are spread directly behind the asset from the breach point and there is no conservation of volume or routing. With the RFSM approach, the volume is conserved and routed across the Digital Terrain Model (DTM) according to flood plain slope.

Table 2 Summary comparison of options

<table>
<tr><th>Property</th><th>Option 1</th><th>Option 2</th><th>Option 3</th></tr>
<tr><td>Method</td><td>RAFT automated method.</td><td>CAMC system risk.</td><td>RAFT+ user defined method.</td></tr>
<tr><td>Data source</td><td>State of the Nation (see HR Wallingford, 2018a).</td><td>State of the Nation.</td><td>The RAFT+ web server has been used to calculate the user defined extents and risk for each transition.

The method used by the user defined RAFT+ method replicates that of the original RAFT (spreadsheet) tool.</td></tr>
<tr><td>Risk calculation</td><td>Each asset considered in turn without any volume contribution from others in the system.</td><td>All assets in the same condition and acting as a ‘system’ with risk apportioned to each contributing asset.</td><td>Consequence calculated for each asset for RAFT flood extent only. Risk is product of annual probability of failure and the consequence for all properties located within the RAFT extent.</td></tr>
<tr><td>Flood spreading method</td><td>RFSM for 40 RPs.</td><td>RFSM for 40 RPs.</td><td>RAFT spreading method. The extent is based on a lookup table that gives radius of flood extent associated with asset height for the breached asset. The lookup table is:
<table>
<tr><th>Asset height (m)</th><th>Flood radius (m)</th><th>Asset height (m)</th><th>Flood radius (m)</th></tr>
<tr><td>0</td><td>0</td><td>4</td><td>3,000</td></tr>
<tr><td>0.5</td><td>250</td><td>5</td><td>3,500</td></tr>
<tr><td>1</td><td>1,000</td><td>6</td><td>4,000</td></tr>
<tr><td>2</td><td>1,500</td><td>16</td><td>9,000</td></tr>
<tr><td>3</td><td>2,500</td><td></td><td></td></tr>
</table>
</td></tr>
</table>

Property	Option 1	Option 2	Option 3
			The RAFT+ tool interpolates between these values. The breach radius is centred on the transition point on the asset.
Consequence method, risk	Integration of event encounter probability, asset failure probability and depth damage tables from MCM-Online[1] for residential and non-residential properties in the flood extent for each return period.	Integration of event encounter probability, system state probability and depth damage tables from MCM-Online[1] for all simulation realisations and all return periods. (see HR Wallingford 2018a for comprehensive details).	Integration of event encounter probability, asset failure probability and damage for each return period where damage is calculated using the RAFT method: that is, summation of the product of properties in the RAFT flood extent and the property damage, where residential property damage is assumed to be £16,700 and non-residential properties use the housing equivalent value (residential value uplifted by a factor of 1.21) (HR Wallingford, 2018b).
Consequence method, other receptors	Assessment of receptors in 100yr breach extent.	Not possible – no breach extents from CAMC method.	Assessment of receptors in RAFT breach extent.
Extent observations	Often disconnected from the asset and watercourse, location based on topography, size	N/A.	Always centred on the transition point and size relative to the asset height. Assumes a flat terrain. The extent is clipped by Flood Zone 2 and if this creates multiple flooded

[1] Online application of the Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal' https://www.mcm-online.co.uk/handbook/

Property	Option 1	Option 2	Option 3
	relative to MDSF2 (Environment Agency, 2013) breach volume and RFSM spreading.		areas, only the portion connected to the transition is retained.
Assessment of the value/constraints in use of the method for transition prioritisation	The data underpinning this method has already been assessed nationally. The defence is treated in isolation of others in the system, so the total inflow volume may be underestimated but the asset's contribution to flooding may be overestimated. A flood envelope for the 100-year event is produced so other metrics of exposure can be assessed. Despite using a spreading method that conserves volume, it is observed that, particularly in the pilot area, the flood envelopes are often either very small or not directly connected to the flood defences. Consequently, the results are not deemed to be very reliable.	The data underpinning this method has already been assessed nationally. The defence is treated as part of a system, so the total inflow volume tends to be accurate but the asset's contribution to changes in risk associated with decreasing the reliability is complicated by the influence of other assets on the overall system risk (for example, sometimes flood risk for an asset may decrease with deteriorating condition due to the system effect of redistributing the risk to assets that have a more dominant change (increase in risk) with deteriorating condition). Due to this method being based on Monte Carlo simulation of combinations of possible failures, no flood envelopes for the 100-year event are produced so other metrics of exposure cannot be assessed.	Option 3 uses a parametric spreading method and a more simplistic risk calculation method. A flood envelope for the asset is produced using the RAFT simplistic approach so other metrics of exposure can be assessed. The flood envelopes are more intuitively reliable for the pilot area (which is relatively flat) in that they are centred on the breach point and the extent is intuitively sensible since they are a function of the asset height and are clipped to Flood Zones 2. Given that the extents for the pilot area look sensible and there are no depth functions used in calculating risk, this approach seems less prone to asset specific limitations of the other 2 methods and is therefore likely to be more rigorous for the purpose of ranking the relative importance of transition-related impacts on asset reliability.

Property	Option 1	Option 2	Option 3
		Although no flood extents exist, the same volume spreading method used for option 1 is used here, so this option is also likely to suffer from the same reliability limitations.	

3.3.2 Comparing the approaches to generating 'Existing Benefits'

When it comes to evaluating benefits, there are 5 important factors that come into play.

- The consequences are a function of the number of properties that are within the calculated flood extent. For options 1 and 2, the flood extents differ for each of the 40 return period events that are assessed in the NaFRA. For these options, there will be a return period event, below which no flooding occurs and for each successive return period event above this, the flood extent will be larger. In contrast, for option 3, RAFT flood extent is used to calculate benefit.
- The damage component of the risk is calculated using the detailed MCM depth versus damage curves for options 1 and 2 which take into account not only the depth of inundation but also the specific type of property and its size (Flood Hazard Research Centre, 2013). Additionally, due to first point above, the damage associated with each successive return period will typically increase non-linearly as a result of both the growth in flood extent, giving rise to additional properties being inundated, and the increase in depth, causing more damage to those properties that were inundated at lower return periods. In contrast, for option 3, the damage is not a function of the depth of inundation, nor the size and type of the property (except for a small mark-up made to non-residential properties to convert them to 'housing equivalents'). Simply, if a property is inundated, the damage is given to be £16,700.
- Risk is defined as probability x consequence. There are important differences in the methods used to calculate the risk. For options 1 and 2, the evaluation of risk, conditional on return period, is made for each of the 40 return periods. The probability is the product of the event probability and the probability of breach (or system state in the case of option 2 (see point 4) given the event. The consequence is based on depth damage. The RP conditional risk is calculated for each of the 40 return periods and the asset risk is found by integrating the conditional risk through all return periods. For option 3, however, the risk is the product of the annual probability of failure for the asset and the £16,700 damage per property within the RAFT flood extent.
- The benefit is the difference between the risk with the asset at condition grade 5 and that with the asset in its present condition. A low value of Existing Benefit indicates simply that there is a low amount of increase in residual risk from CG present to CG5. It gives no measure of the underlying residual risk which may be very high.
- Option 2 is based on the system risk approach which means that a Monte-Carlo simulation approach is used to evaluate tens of thousands of flood realisations. The risk may result from one or more assets in the system failing (or overflowing). For each flood realisation the flood pathways established during the flood spreading

process are used to trace the damage back from the receptors to the assets, enabling, over the full set of realisations, each asset's contribution to the risk to be evaluated. It is possible for an asset to report less risk as its condition decreases. This is a function of the system approach; it is possible, as the system condition decreases, for the risk to swing towards the assets close to areas of flood consequence and consequently away from those that are more remote from communities and other areas of consequence.

3.3.3 Evaluating commonalities and differences

The following examples show how difficult it is to determine a pattern of commonalities and differences between the methods.

Example 1: Transition 149, AssetID: 24288.

For this transition, there are flood extents produced for both option 1 and option 3. These are shown in Figure 3-1.

It can clearly be seen that the option 3 flooded area spreads from the transition point, inland and laterally up and down the flood plain. In contrast, the extent from option 1 is very small and is disconnected from the inflow point at the transition. The benefit from options 1 and 2 are zero, whereas the benefit from option 3 is very large due to approximately 600 properties in West Butterwick being located within the flood extent (Table 3).

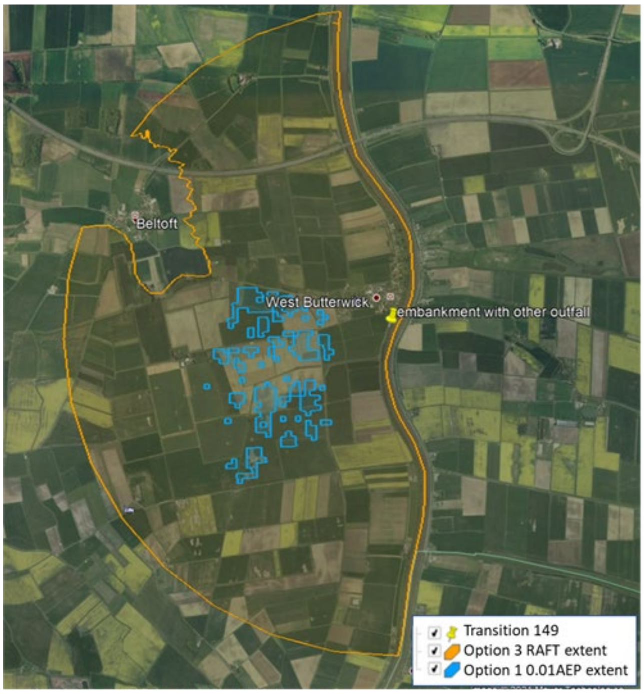

Figure 3-1 Comparison of flood extents for Transition 149 (HR Wallingford)

Table 3 Table of benefits for Transition 149 (HR Wallingford)

149: TransID	149
149:Transition	Embankment with other outfall
149:AssetID	101990
149:CurrentCG	3
149:TargetCG	2
149:Option1_nrp_benefit	0
149:Option1_res_benefit	0
149:Option2_nrp_benefit	0
149:Option2_res_benefit	0
149:Option3_nrp_benefit	2354720.54
149:Option2_res_benefit	2974034.12

Example 2: Transition 111, AssetID: 23874.

For this transition, the flood extents produced for option 1 and option 3 (Table 3) both look sensible in that they are both connected to the transition location and cover the area directly behind the potential breach point. It is evident that the option 3 flood extent is smaller than that of option 1. The option 3 extent contains no residential properties and only one non-residential property. Consequently, option 3 gives very little benefit for this transition. Option 1, on the other hand, has around £106,000 of benefit; the extent contains 34 residential properties, 10 non-residential properties and over 60 unaddressable properties (for example, agricultural barns). Note also that this extent is for the 0.01AEP event. Option 1 includes the risk contributions from larger events which may inundate additional properties in the 3 communities on the edge of the mapped flood extent.

The other thing to note is that there is negative benefit of ~£7,500 from option 2. This is due to the reallocation of risk away from the transition asset to others in the system using this option.

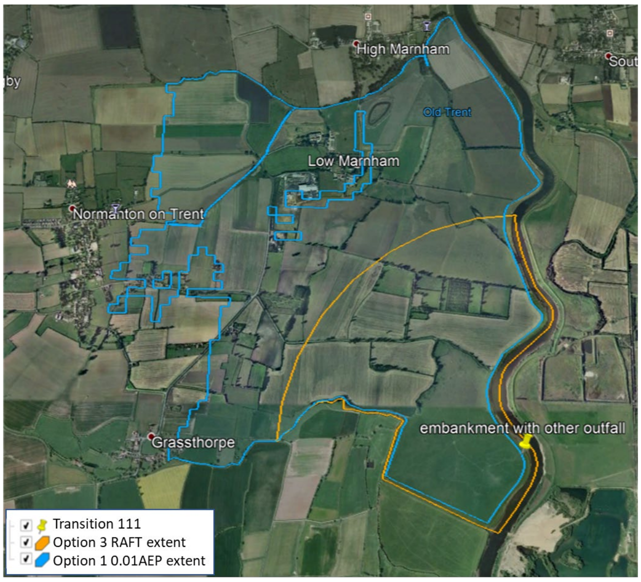

Figure 3-2 Comparison of flood extents for Transition 111

Table 4 Table of benefits for Transition 111 (Source: HR Wallingford)

111: TransID	111
111:Transition	Embankment with other outfall
111:AssetID	23874
111:CurrentCG	3
111:TargetCG	3
111:Option1_nrp_benefit	92606
111:Option1_res_benefit	14807
111:Option2_nrp_benefit	-6523.5
111:Option2_res_benefit	-1006.41
111:Option3_nrp_benefit	8537.07
111:Option2_res_benefit	0

Example 3: Transition 15, AssetID: 51398.

The results for this transition highlight the complexity involved in comparing the 3 methods (Figure 3-3: Comparison of flood extents for Transition 15). Option 1 has produced disconnected flood extents but given sensible looking benefits. Option 2, which does not produce flood extents, also gives benefits that appear sensible. Option 3 produces a plausible looking flood extent, but despite there being 71 properties located within the flood extent, the benefit is small (see table 6). This is a result of the annual probability of failure for the asset being very low through all return periods (see Table 5)

Table 5 Annual probability of failure for AssetID 51398 (Source: HR Wallingford)

Condition grade	Probability of failure
1	0.0000
2 (current condition)	0.0000
3 (target condition)	0.0000
4	0.000
5	0.0000081161

(Source: HR Wallingford (Raft plus flood modelling)

For options 1 and 2 the flood extents increase with increasing severity of event. It is likely that the risk is higher for these options due to the community of Owston Ferry being close to the asset, and at some return period above 0.01AEP a large number of properties may be inundated. With option 3 using a fixed extent for all events, the increasing consequence of larger events is not accounted for by this method.

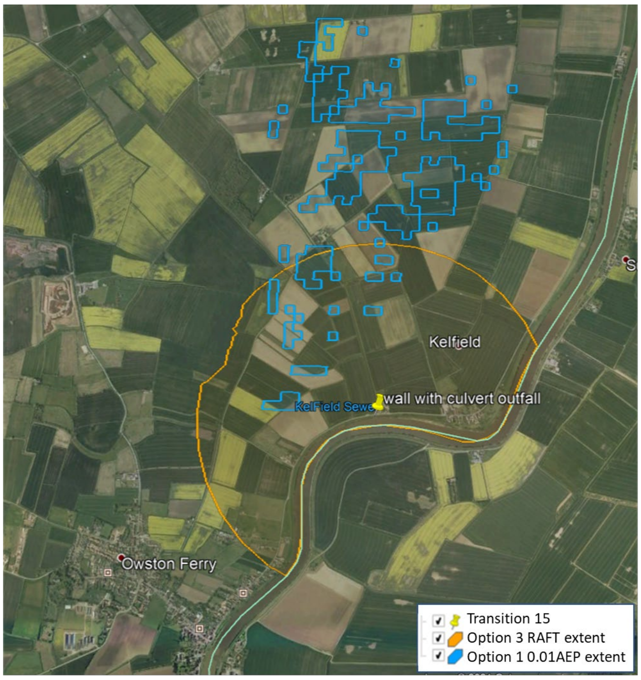

Figure 3-3: Comparison of flood extents for Transition 15
(Source: HR Wallingford)

Table 6 Table of benefits for Transition 15 (Source: HR Wallingford)

15: TransID	15
15:Transition	Embankment with other outfall
15:AssetID	51398
15:CurrentCG	3
15:TargetCG	3
15:Option1_nrp_benefit	10745
15:Option1_res_benefit	10626
15:Option2_nrp_benefit	3172.93
15:Option2_res_benefit	616.13
15:Option3_nrp_benefit	8.69

15:Option2_res_benefit	2.44

3.4. Prioritisation method

For each of the options, the following method was applied:

3.4.1 Transition identification

The outputs of the spatial location mapping (see figure 4-1) for each of the transition's assets in the Tidal Trent pilot study area were used as the location to allocate each of the Existing Benefit metrics described in table 2.

3.4.2 Benefit attribution

For each transition, the benefit was calculated for each option. As described in Table 3, 3 very different methods were used to calculate the risk associated with a failure at each transition. For all options, the benefit was calculated by finding the risk at CG5 minus the risk at the asset's present condition.

The benefit was calculated for direct damage to residential and non-residential properties and for agricultural losses initially. When reviewing the results, the agricultural (financial) benefits were an order of magnitude lower. Consequently, for this project they were not used any further.

Consequence mapping

In addition to assessing the economic benefit to properties, for options 1 and 3, it was possible to identify and count critical and vulnerable assets that are exposed to flooding in the event of breach. This is to recognise that certain properties, for example, electricity sub-stations and hospitals have far more value to the community and society than that of just the building and its contents. Therefore, in addition to counting their contribution to the economic benefit, for options 1 and 3, certain properties were identified and listed as a separate 'consequence' result for each transition. These properties were identified using the NRD 'Class_description' field to identify the function of the building.

Certain transport infrastructure (such as roads by class and railways) were also counted since these are not represented in the benefit metrics but they are important assets that are protected by the defence assets nonetheless.

The consequence types that have been counted are residential and non-residential property, agricultural land, road and rail infrastructure, critical and vulnerable infrastructure. Options 1 and 3 capture all consequence types lists and option 2 only looks at residential and non-residential property. The transport infrastructure and property types that have been identified and counted are those given in Table 7: Categories of critical and vulnerable infrastructure. The importance associated with these infrastructure assets can only be established locally and therefore it is considered most appropriate to identify them separately and suggest that all transitions protecting these properties should be identified and considered for inspection.

Table 5: Categories of critical and vulnerable infrastructure

Infrastructure type	Identified categories within the consequence mapping
Road infrastructure	A road: count A road: length B road: count B road: length
Rail	Rail line: count Rail line: length Rail bridge: count Rail bridge: length
Critical service infrastructure	Emergency / Rescue Service Fire Station Power Station / Energy Production Pump House / Pumping Station / Water Tower Telecommunication Water / Waste Water / Sewage Treatment Works Water Distribution / Pumping

Infrastructure type	Identified categories within the consequence mapping
Vulnerable infrastructure	Boarding / Guest House / Bed And Breakfast / Youth Hostel Caravan Care / Nursing Home Children's Nursery / Crèche College Further Education General Practice Surgery / Clinic Health Care Services Health Centre Holiday Let/Accommodation/Short-Term Let Hospital / Hospice Hotel / Motel / Boarding / Guest House Non State Primary / Preparatory School Preparatory / First / Primary / Infant / Junior / Middle School Privately Owned Holiday Caravan / Chalet

(Source: HR Wallingford)

Risk prioritisation

The transitions were ranked based firstly on their residential equivalent Existing Benefit (£) and then secondly considering the wider flood receptors listed in table 7.

4. Applying the approach to the Tidal Trent pilot study area

4.1. Identifying transition locations

The following transition asset types were identified from the Asset Information Management System (AIMS) database for the Tidal Trent pilot study area:

- longitudinal (type 1) transitions, that is, embankments tied into walls (84 nr)
- internal (embedded object) transitions (type 3) that is, culverts/outfalls through embankments (99 nr), embankments tied into flood gates (6 nr), culverts/outfalls through walls (31 nr)

Other transition types such as changes in surface type (type 4) (for example, revetment) could not easily be identified from the available data sets. In addition, there were no transverse transitions (type 2), that is, composite defences such as walls on top of embankments that could be identified from the asset data (Environment Agency’s Asset Information Management System) in the pilot study area. While there may be some composite structures present in the pilot study area, it would be necessary to identify them through other analytical means or via survey

The locations of the 220 transitions within the Tidal Trent pilot study area are indicated on Figure 4-1.

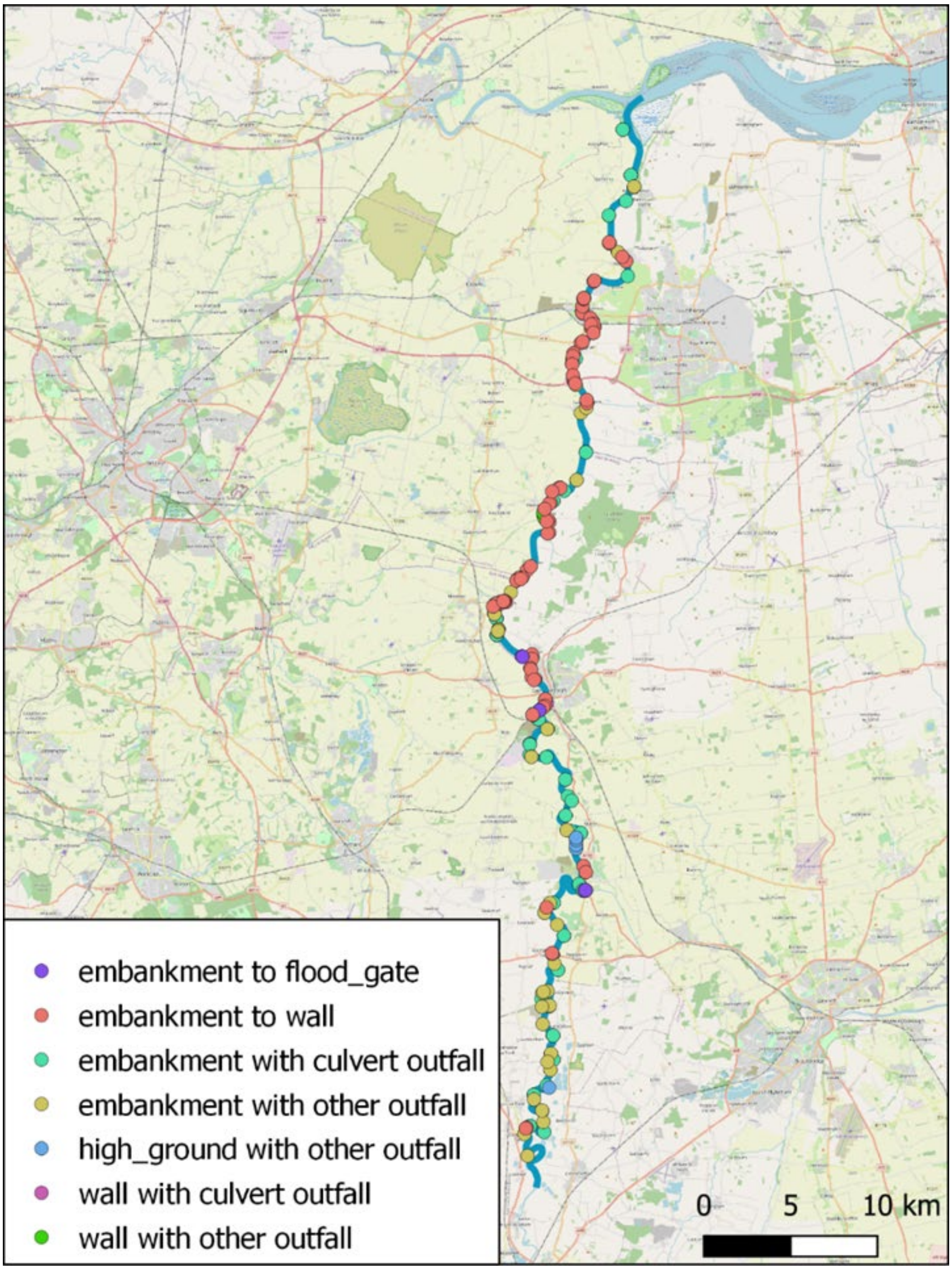

Figure 4-1 Transition asset locations within the Tidal Trent pilot study area

4.2. Comparison of consequence mapping results

To help compare the options and to inform the prioritisation of transitions for inspection, a Google Earth project was created to enable a fast review of the tier 0 results. As well as giving the type and condition of each asset, it gave the metric results for the 3 options and displayed the flood extents for options 1 and 3. By viewing the flood extents in the map for each transition it enabled a better understanding of the benefits and shortcomings of the

RFSM and parametric based spreading models for each transition, see the bottom row in Table 2 and the examples given in section 4.3.

4.3. Risk modelling outcomes

The Existing Benefit values associated with each of the transitions in the Tidal Trent pilot study area for each of the risk modelling options are presented in Figures 4.2 to 4.6 below. These benefits are associated with the protection of residential and non-residential property only and do not include the protection of agricultural land or any enhanced value attributable to critical service or vulnerable infrastructure, or road or rail infrastructure (see the justification set out in section 3.4).

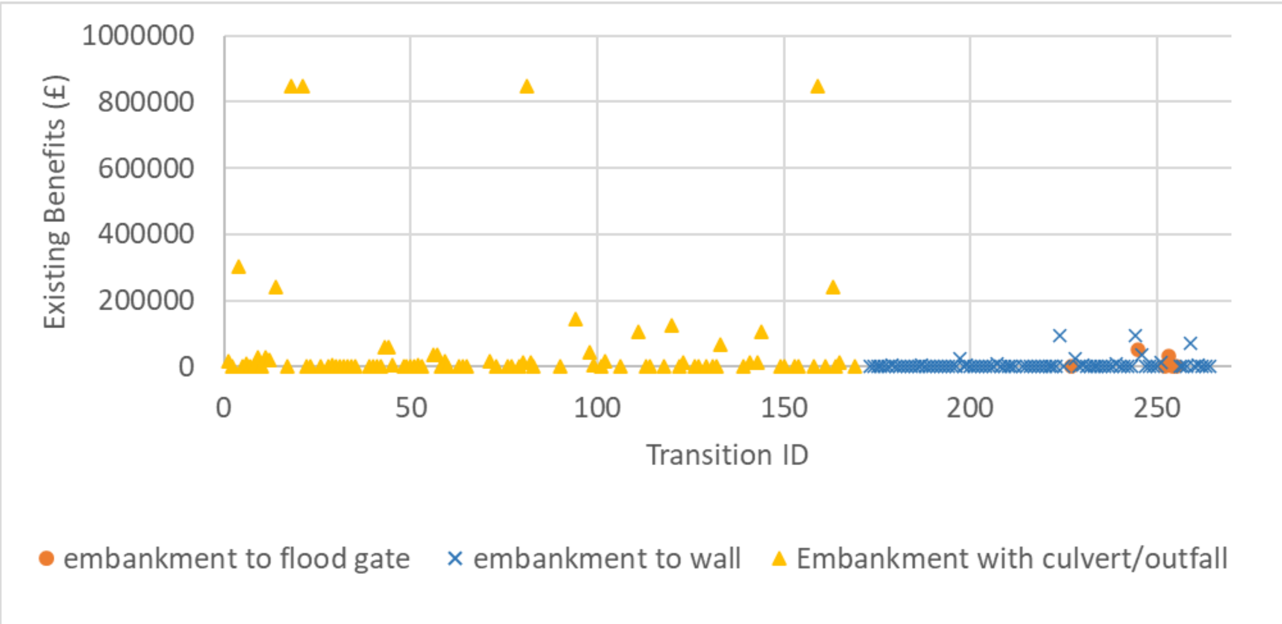

Figure 4-2 Option 1: risk modelling results

(Source: HR Wallingford)

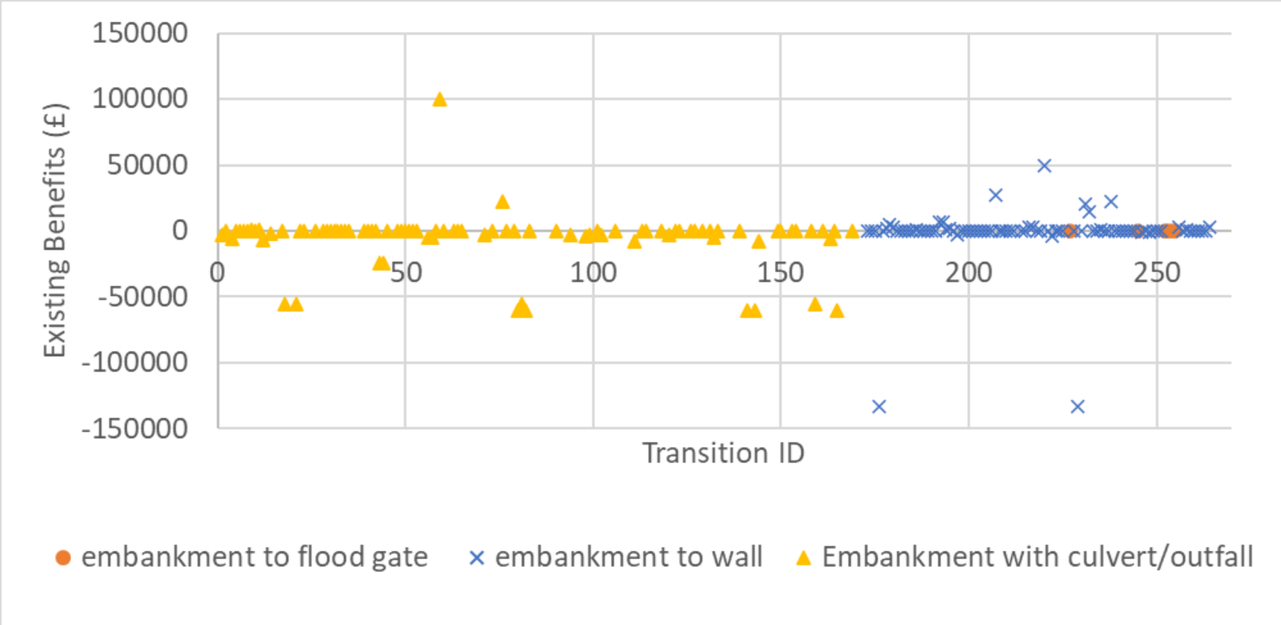

Figure 4-3 Option 2: risk modelling results

(Source: HR Wallingford)

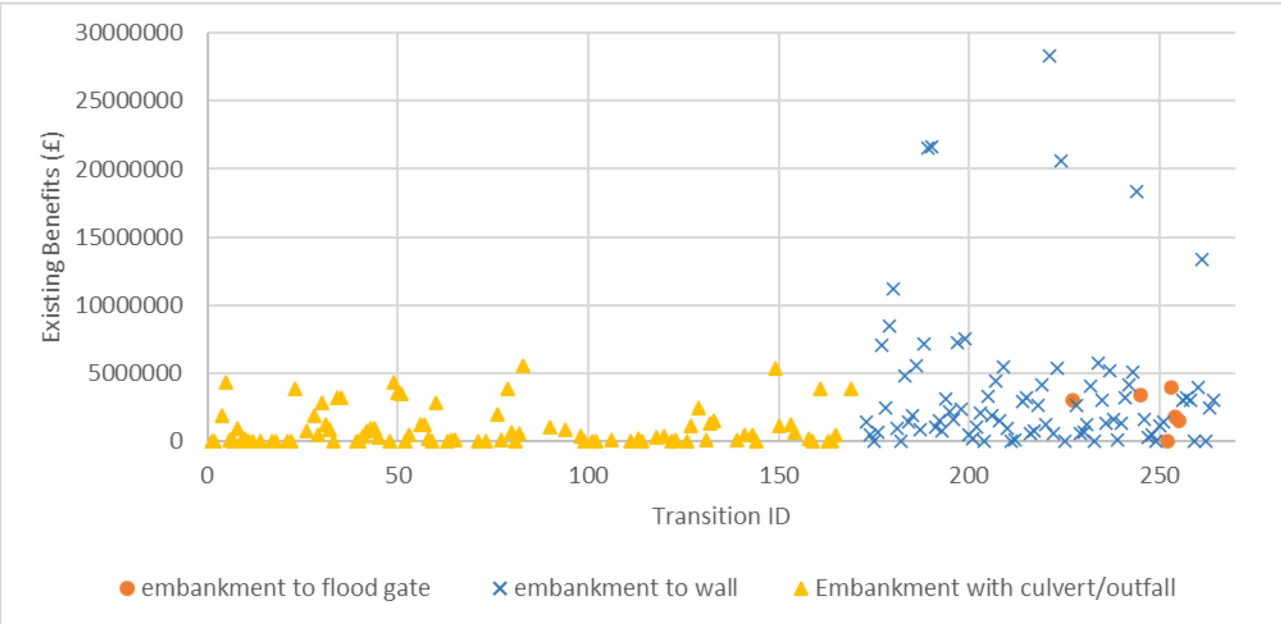

Figure 4-4 Option 3: risk modelling results

(Source: HR Wallingford)

There is no consistency in the predicted level of benefit associated with individual transitions between the 3 methods.

Broadly:

- **using option 1**: a higher number of embankments with culverts/outfalls have high associated benefits than embankment to wall transitions
- **using option 2:** a significant number of transitions are associated with negative predicted benefits. The cause of this result is explained in section 3.2
- **using option 3:** a higher number of embankment to wall transitions have high associated benefits than embankments with culverts/outfalls. In addition, the scale of predicted benefit is 1 to 2 orders of magnitude greater than for options 1 and 2. This is due to the parametric spreading model generally giving larger flood extents than the RFSM in the Tidal Trent pilot site and the differences in the methods used to calculate the risk. Particularly that options 1 and 2 used the MCM depth damage functions, whereas option 3 assumed a flat rate of £16,700 damage for any property inundated

The transitions were ordered in terms of level of Existing Benefit, based solely on the consequences associated with flooding of residential and non-residential property. Figure 4-5 shows the top 50 transitions for each modelling option, with those transitions featuring in the top 50 for more than one option highlighted.

TransID	OPTION 1		TransID	OPTION 2		TransID	OPTION 3	
18	849713		59	100151.5		221	28312076	1
21	849713		220	49710.32		190	21640897	2
81	849713		207	26819.25		189	21489681	3
159	849713		76	26280.87		224	20603840	4
4	304050		238	26280.87		244	18313312	5
163	242392		184	22652.51		261	13399941	6
14	239067		198	22652.51		180	11220075	7
94	143527		231	20006.89		179	8446503	8
120	125659		232	14351.72		199	7565179	9
111	107413		142	10434.77		197	7258877	10
144	107413		160	10434.77		188	7167422	11
224	94974		54	7359.4		177	7085141	12
244	94974		55	7359.4		234	5702085	13
259	71680		192	6974.73		83	5547395	14
133	65317		193	6974.73		186	5530997	15
43	60925		179	5290.12		209	5439240	16
44	60925		216	4168.43		223	5347660	17
245	50529		217	4168.43		149	5326179	18
98	42189		13	3789.06		237	5214572	19
246	37795		15	3789.06		243	5068879	20
56	34126		256	3121.43		183	4800816	21
57	34126		264	3121.43		207	4415934	22
253	32412		180	2524.99		49	4303521	23
9	28232		195	2208.1		5	4280930	24
11	28232		178	1738.53		242	4162107	25
228	26188		9	883.52		219	4122712	26
197	23736		11	883.52		232	4046028	27
12	19234		194	853.08		260	3976216	28
59	17630		78	761.02		253	3941834	29
1	16397		86	761.02		79	3789697	30
71	16397		109	761.02		161	3789697	31
102	16397		119	761.02		169	3789697	32
123	14010		168	761.02		23	3787735	33
251	13791		171	761.02		50	3536085	34
80	11929		27	545.59		51	3485400	35
82	11929		235	523.53		245	3363468	36
141	11929		258	523.53		205	3311899	37
143	11929		186	461.4		241	3227828	38
165	11929		237	449.87		35	3227086	39
6	9596		133	128.97		34	3219987	40
239	9596		182	56.3		215	3161195	41
207	7270		249	4.66		257	3153884	42
179	6582		20	0		194	3078451	43
199	6257		254	0		227	3055010	44
52	4847		257	0		235	3046881	45
29	4815		259	0		258	3046881	46
45	4791		260	0		264	3033909	47
230	4791		261	0		256	2996396	48
187	4750		262	0		214	2933765	49
99	4295		263	0		60	2868205	50
	All 3 options							
	Options 1 and 2							
	Options 2 and 3							
	Options 1 and 3							

Figure 4-5 Top 50 transitions, prioritised by Existing Benefit (for residential and non-residential property only)

(Source: HR Wallingford)

Within the Tidal Trent pilot study area, in addition to residential and non-residential property, assets protect lengths of road and rail infrastructure, rail bridges, and wideranging critical and service infrastructure, including healthcare facilities, water supply assets, power stations and electricity sub-stations, pumping stations and wastewater treatment works. These facilities do not have standardised benefit metrics and cannot therefore be directly compared with the rankings established based on protected residential and non-residential assets.

Transitions protecting critical and service infrastructure are often located in isolated geographical locations with limited nearby property. The relative value of this infrastructure therefore needs considering separately when defining any prioritisation process.

4.4. Recommended risk assessment method

Following discussions and agreement with the project and Environment Agency team, option 3 was selected as the most appropriate risk assessment method to use in prioritising transition assets.

The justification for this decision is set out in detail in section 3.3. In summary, the main reasons for selecting option 3 are:

- the flood extents that the parametric spreading approach gives compared to the RFSM approach are more rationally intuitive for asset inspectors and catchment engineers
- the outcomes from option 3 were felt to allow the most consistent comparison between transition assets to feed into the ranking process
- option 2 sometimes gives negative benefit values due to the risk calculation being based on the asset's contribution to the system risk
- options 1 and 2 are based on risk integrated across 40 return periods, but it is not possible to validate the risk contribution from any of the single return period model realisations since the extents and the damage data are not saved at that level of granularity

5. Applying the risk assessment method to prioritise transitions

Ranking the top 50 prioritised transitions in decreasing order of their associated Existing Benefit, as assessed using option 3 (see Figure 5-1), it is clear that there is rapid (approximately 75%) reduction in Existing Benefit across approximately 20% of the prioritised transitions (5% of the total transitions), and a subsequent gradual reduction across the remainder.

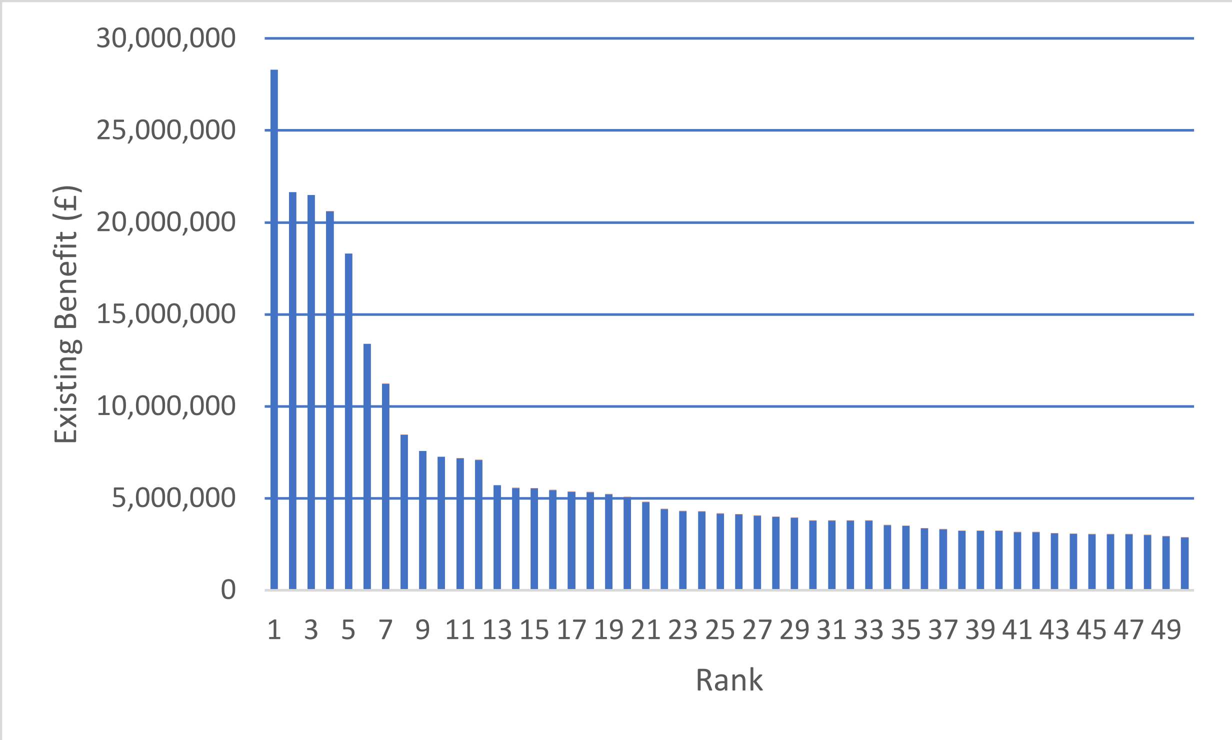

Figure 5-1 Top 50 Existing Benefits for Option 3

(Source: HR Wallingford)

On this basis, prioritisation could be carried out by selecting transitions with the top 'X' Existing Benefit levels or by selecting transitions for which the associated Existing Benefits are > '£Y'. Any prioritisation activity for a specific area would also need to consider those transitions protecting road and rail infrastructure and critical service and vulnerable infrastructure separately so that, where they were deemed of particular importance, the assets could be included in any inspection programme.

6. Evaluating and developing the prioritisation approach

6.1. Constraints of the initial approach

A number of weaknesses in the approach used for this piece of work were identified during and following the inspections carried out as part of the Tidal Trent pilot study:

- A number of transitions were identified on site that were not in the AIMS database (and therefore not included in the benefit assessment and prioritisation work).

- The approach identifies all locations where a pipe or small culvert passes beneath or within the embankment as a transition. However, no data is available with which to screen out locations where this crossing lies at a depth beneath the embankment (and will therefore have no impact on asset vulnerability to failure) or where the pipe is of such a small diameter that it is highly unlikely to impact on asset performance.
- The prioritisation relies heavily on consequence and does not evaluate the relative probability of failure of a potential 'weak' point in the defence at the transition. The overall transition assessment approach promoted by the project facilitates evaluating this through the tier 2 assessments (that is, once a transition is inspected and if the inspection identifies a potential area of weakness).

6.2. Identifying transition characteristics and hydraulic loading conditions that may increase failure probabilities

Based on the weaknesses of the initial approach described in section 6.1, the project team and Environment Agency client team agreed to progress a complementary piece of work to try and establish whether any particular physical characteristics (either recorded within the AIMS database or known by catchment engineers or inspectors) might mean the transition is more prone to failure.

A sensitivity testing exercise was therefore carried out looking at the impact of a range of asset and hydraulic loading characteristics on the fragility (failure vulnerability) of a particular transition. This analysis was carried out using the new transition reliability tool in the Quantifying the probability of failure at asset transitions report as part of this project (Environment Agency, 2022c)

The objectives of the testing were to:

- explore the sensitivity of the annual failure probability to a number of parameters (for example, geometry, soils) using a generic hydraulic loading condition
- evaluate the impact of a range of plausible hydraulic loading conditions on the outcomes

The English national scale sensitivity testing established that it was reasonable at tier 0 to screen out any transitions with an associated embankment height (crest level minus landward ground level) less than or equal to 2m (see sensitivity analysis within the Quantifying the probability of failure at asset transitions report (Environment Agency, 2022c). The AIMS database consistently contains height data if used in conjunction with LiDAR data. Ruling out embankments of 2.0m height or less is a significant saving, since these represent some 65% of all the embankments in England (15,631 assets out of 23,976).

7. Transition prioritisation process

The research and trialling of a potential tier 0 assessment method has drawn conclusions leading to a recommended approach for the Environment Agency to consider further in its asset inspection prioritisation programme. The method involves the following steps:

- Risk mapping and modelling to determine distribution of benefits to transition assets using the option 3 approach described in section 2. Option 3 automates the RAFT+ manual approach to defining breach extents, using a parametric flood spreading tool with breach extents clipped to Flood Zone 2, and a simple risk attribution process (using residential and non-residential property values).
- Identifying and evaluating road and rail infrastructure, critical service infrastructure and vulnerable assets protected by transitions to determine the relative importance of the transition with respect to inspection and which transitions should be prioritised for inspection (note: this may well be all of them).
- Identifying (using wider mapping tools, local asset 'knowledge' and onsite visits) and evaluating transitions associated with 3rd party assets that are not identifiable within the standard Environment Agency asset database (AIMS).
- Develop and implement methods/data to screen out of culvert and outfall transitions where the crossing infrastructure is below the toe level of the embankment. (for awareness: this project did not develop automated processes for this)
- Screening out of any transitions with an associated embankment height (crest level minus landward ground level) less than 2m (see sensitivity analysis part in the Quantifying the probability of failure at asset transitions report (Environment Agency, 2022c). The AIMS database consistently contains height data if used in conjunction with LiDAR data. Ruling out embankments of less than 2.0m height is a significant saving, since these represent some 60% of all the embankments in England.
- Plot the benefit curve for the top 25% of transitions and evaluate a suitable threshold above which transitions should be prioritised for inspection.
- Put forward those transitions with associated benefits greater than the defined threshold plus all those transitions protecting critical or vulnerable infrastructure, including any transitions at 3rd party assets for inspection and evaluation.

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Acronyms

AIMS- Asset Information Management System

BaU – Business as Usual

CAMC – Creating Asset Management Capacity

CDL – Continuous Defence Line

EA- Environment Agency

EAD – Estimated Annual Damage

DTM – Digital Terrain Model

FME- Feature Manipulation Engine

LiDAR- Light Detection and Ranging

MCM – The Multi Coloured Manual

MDSF2 – Modelling Decision Support Framework 2 (the name of the software that produced NaFRA)

NaFRA – National Flood Risk Assessment

NCERM – National Coastal Erosion Risk model

NEIP – National Engineering Innovation Panel

RAFT – Risk Assessment Field Tool

RFSM – Rapid Flood Spreading Model

SoN – State of the Nation

9. Appendix A: Spatial analysis of transitions

9.1. Introduction

Technical discussions of the initial stages of this project highlighted the need to identify the number of possible transitions in England. This information was considered useful in steering further developments of the project such as the way transitions are considered during inspections and flood risk analysis.

This note explains the methodology applied and the results obtained to identify the number of transitions.

The first set of results relates to identifying transitions between embankments and hard structures, while the second set analyses in more detail the transitions between embankments with different types of revetments.

9.2. MethodologyApproach

Choosing the most appropriate input data set

In deciding the most appropriate input data set for identifying transitions in flood defence type, nationally, 2 possible databases were available: AIMS Flood Defences and Business as Usual (BaU) Continuous Defence Line (CDL). For the reasons discussed here, and following a discussion with the Environment Agency, we proceeded with the analysis using the AIMS flood defences.

AIMS Flood Defences

The AIMS defences data set is, in principle, the ideal data set with which to perform this analysis. It is nationally consistent, it contains many useful attributes with which to determine transitions in type, and it is relied on heavily by the Environment Agency Flood Risk Management and Asset Management teams. However, the data set is not continuous in as much as the ends of the polylines that represent neighbouring defences are often not snapped together. This would make any spatial analysis require higher tolerances to achieve a desirable result. This increases the computational requirements as well as introducing more uncertainty into the results. This is because by applying a search tolerance you are assuming that neighbouring defences found within that search tolerance are adjacent to each other in reality; conversely, neighbouring defences that are found to be outside the search tolerance are assumed not to be adjacent in reality, when perhaps they are just poorly spatially represented in AIMS.

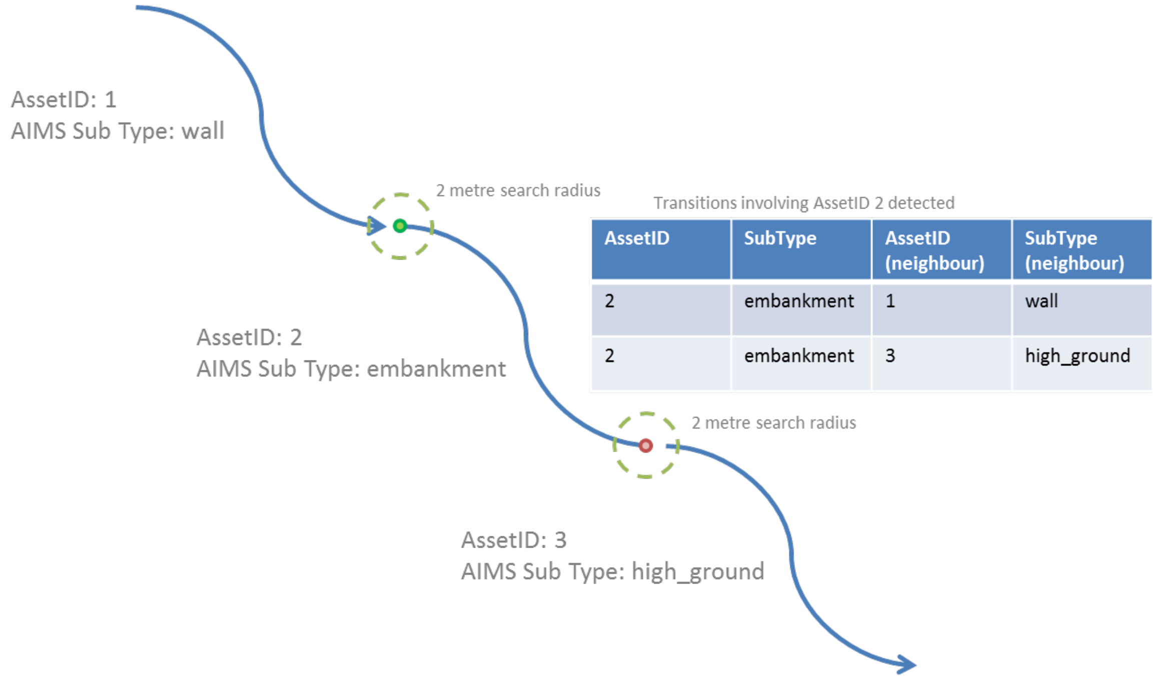
Business as Usual (BaU) Continuous Defence Line (CDL)

The BaU CDL represents a continuous bank line from source to sea for every watercourse that was modelled in State of the Nation. It has been composed of primarily AIMS line-work, but then gap-filled with supplementary line-work from other sources, such as OS Mastermap and NCERM. Given that the CDL has continuous geometry, the process of determining adjacent features, and therefore identify transitions, is much more reliable as all of the polylines are snapped together and so the ends of neighbouring polylines are coincident.

However, there are problems with using the BaU CDL to identify transitions; firstly, the presence of the supplementary line-work within the CDL may have underestimated the number of transitions by assuming that, as there is a supplementary feature in between the 2 AIMS features, these features are not adjacent in reality, and so are not considered for the transitions analysis. A simple digitising error may have been the cause of the gap between the AIMS features. Secondly, the CDL includes the AIMS features that form what has been defined as the primary defence line for each watercourse. The CDL therefore does not contain every single defence in the AIMS database. Using the CDL to detect the presence of transitions may again have underestimated the number of transitions for this reason.

Data processing to identify transitions

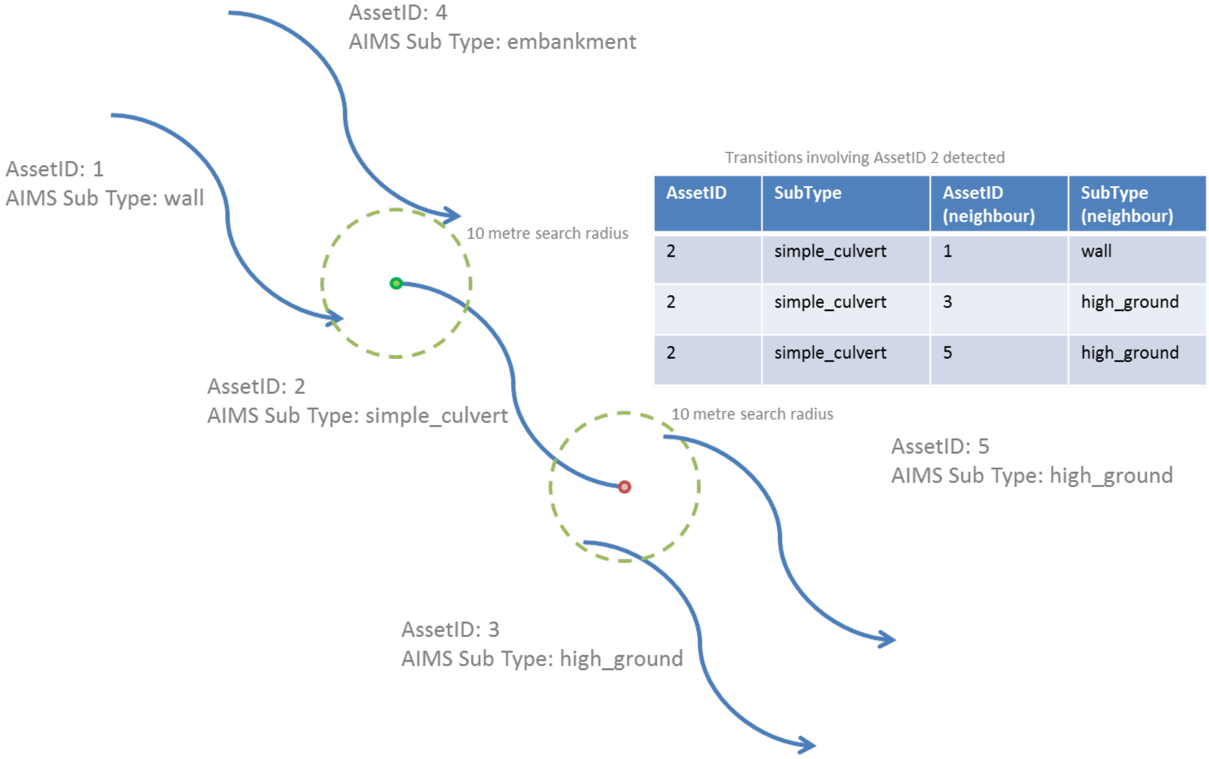
A data processing workflow was developed using the Feature Manipulation Engine (FME) that performed the primary spatial tasks involved in detecting transitions. The process involved creating a point at the start of each defence feature and then finding the 2 nearest defence features to it, using a 2 metre search radius. One of the features found would be itself, the other would be its neighbour. The AIMS sub type for both the neighbouring defence features was recorded as this would determine the nature of the defence transition. This process was repeated for the end of the defence feature. Figure 9-1 shows this process diagrammatically.



AssetID	SubType	AssetID (neighbour)	SubType (neighbour)
2	embankment	1	wall
2	embankment	3	high_ground

Figure 9-1 Schematic diagram of the transition detection process

For culverts, the search radius was increased to 10 metres. This is a consequence of the way culverts are represented in AIMS as a single line running approximately along the centre of the watercourse. In order to record the transition between the culvert and its asset(s) immediately upstream and downstream, which would usually be aligned along or close to each bank of the watercourse, a larger search radius had to be used. Figure9-2 demonstrates this slightly modified method when analysing culverts.



AssetID	SubType	AssetID (neighbour)	SubType (neighbour)
2	simple_culvert	1	wall
2	simple_culvert	3	high_ground
2	simple_culvert	5	high_ground

Figure 9-2 Schematic diagram of the transition detection process involving culverts

Once all of the transitions had been recorded for each end of each AIMS defence, the workflow applied a number of duplicate filters, based on both location and attributes, in order to ensure that each particular transition was only recorded once in the final output.

The whole process was piloted on a subset of the AIMS defences comprising approximately 450 features. Once the process produced a satisfactory result for the subset, the workflow was run against the national data set.

Figure 9-3 provides an example of a defence transition between an embankment (eastern section of coast) and a wall (western section of coast).

Figure 9-3: An example of a transition in defence type

Identifying transitions in embankment exposed face composition

Further analysis took place on the embankment to embankment transitions to determine potentially critical changes in the composition of the exposed face of each neighbouring embankment. This entailed extracting the element data, in particular the exposed_face element data, for each embankment involved in an embankment to embankment transition. The material of each embankment exposed face element was recorded against the feature and the findings were summarised in a table.

During the analysis, where no exposed_face element was found for a particular embankment, a material value of ‘not known’ was recorded against the feature. Conversely, if more than one exposed_face element was found for a particular embankment, a material value of ‘multiple’ was recorded against the feature.

Figure 9-4 provides an example of a transition between an embankment with an exposed face consisting of earth (section to the south-west of the yellow point) and an embankment with an exposed face consisting of pre-cast concrete (section to the north-east of the yellow point).

Figure 9-4: An example of a transition in embankment exposed face composition

10.2.6 Types of assets

As a reminder, the types of assets identified in AIMS data set are presented in Table 8.

Table 6 AIMS subtypes

Fluvial and Tidal	Coastal
Barrier beach	Barrier beach
Beach	Beach
Bridge abutment	Bridge abutment
Cliff	Cliff
Demountable defence	Demountable defence
Dunes	Dunes
Embankment	Embankment
Flood gate	Flood gate
High ground	High ground
Promenade	Promenade
Quay	Quay
Wall	Wall
Open channel	
Simple culvert	
Complex culvert	

Validating the analysis

A simple validation exercise followed the detection of the asset transitions to help provide credibility of the results. The locations of approximately 30 of the transitions between embankment and wall were interrogated, by eye, using aerial imagery to see if the transition could be recognised from the imagery. In a number of cases, it was difficult to accurately locate the transition due to overhead trees and other features, but there was more success at transitions around the coast, as Figure 9-4 demonstrates. A large proportion of the embankment to wall transitions were seen to have been recorded at road intersections with the watercourse, where, typically a retaining wall is built underneath the road bridge, which is then adjoined on each side by embankments.

Ultimately, the quality of the results of the transitions analysis relies on the spatial accuracy of the AIMS defence linework as well as the feature attribution. The spatial accuracy of the AIMS defence features has improved considerably in recent years, but there are still a great number of examples where adjoining defences are not snapped together in the data set. This makes analyses such as this troublesome to design and validate. Additionally, this analysis has completely relied on the AIMS subtype to determine a representative defence type for each feature. The subtypes are a clearly defined set of values, but not every AIMS defence can be completely described by one of these values. For example, a number of embankments have been assigned an AIMS subtype of 'wall' (for example, Asset ID 28144) because the asset inspector has, quite justifiably, decided that the primary protective element of the defence is the wall built on top or the sheet piling that protects the front face of the embankment. We would therefore recommend attempting to refine the transitions identified here by using more of the AIMS attribute information, although this is not a trivial exercise as the main attributes that would need to be interrogated are the 'Description' and 'Comments' fields, which, unlike AIMS subtype, do not contain a predictable finite set of values to search for.

9.3. Results

Total number of transitions

The analysis of the number of transitions shows that the majority involve high ground. This is consistent with the fact that the number of high ground asset (131,996) represents 66% of the total number of assets in the AIMS database (198,382). These figures are taken from a snapshot from the October 2016 AIMS database. In the appendix, a table summarises the total number of transitions.

The types of transitions between embankments and hard structures (4,506 in total) are summarised in the following table.

Table 7: Number of transitions between embankments and hard assets

Transition between embankment and	Number	Percentage (%)
Wall	3,362	75
Bridge and abutment	524	12
Simple culvert	484	11
Complex culvert	4	0
Flood gate	94	2
Demountable defence	38	1
Total	**4,506**	

This figure represents 9% of the total number of transitions (excluding those involving high ground) and 7% of the total number of assets which are not high ground (66,386).

Transitions between embankments with different revetments

The total number of transitions between embankments with different face protection elements is 8,378. From those, there are up to 2,532 revetment type transitions that involve soft to hard revetment changes. We say 'up to' because this includes transitions where one of the pairing element descriptions includes 'multiple' or 'not known'. We have conservatively assumed that these asset transitions include an earthen component and therefore may be vulnerable to erosion and/or damage.

9.4. Conclusions

The total number of transitions between assets is 167,500. Of those, 20,709 involve transitions with an embankment. If considering only transitions between embankments and hard structures (4,506) and between embankments with a hard and a soft revetment (2,149), the number of transitions is 6,655, which corresponds to 10% of the total number of assets which are not high ground. Three-quarters of transitions between embankments and hard structures correspond to vertical walls and one-third of transitions between embankments are between hard and soft revetments.

These types of transitions were also identified by stakeholders during the workshop as the most frequent ones.

9.5. Additional table

Table 8: Number of transitions for each combination of assets

	Barrier beach	Beach	Dunes	Embankment	Wall	Bridge abutment	Simple culvert	Complex culvert	Flood gate	Demountable defence	High ground	Total
Barrier beach	0	-	-	-	-	-	-	-	-	-	-	**0**
Beach	0	178	-	-	-	-	-	-	-	-	-	**178**
Dunes	0	6	56	-	-	-	-	-	-	-	-	**62**
Embankment	2	56	21	8,398	-	-	-	-	-	-	-	**8,477**
Wall	1	75	21	3,362	6,440	-	-	-	-	-	-	**9,899**
Bridge abutment	0	0	0	524	444	14	-	-	-	-	-	**982**
Simple culvert	0	2	0	484	735	12	4,660	-	-	-	-	**5,893**
Complex culvert	0	0	0	4	20	0	287	184	-	-	-	**495**
Flood gate	0	0	1	94	1,726	7	6	0	43	-	-	**1,877**
Demountable defence	0	0	0	38	344	2	0	0	2	7	-	**393**
High ground	1	13	5	7,825	3,842	1,378	23,982	259	67	42	101,807	**139,221**
Total	**4**	**330**	**104**	**20,729**	**13,551**	**1,413**	**28,935**	**443**	**112**	**49**	**101,807**	**167,477**

	Asbestos cement	Bagwork	Blockwork	Brickwork	Clay	Complex	Concrete	Earth	Gabions	Masonry	Mud silt	Multiple	None	Not known	Other	Piling	Rock	Sand	Shingle	Steel piling	Timber	TOTAL
Asbestos cement		-	-	-	1	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	**3**
Bagwork	-	-	-	-	-	-	2	3	-	-	-	1	-	-	-	-	-	-	-	-	-	**6**
Blockwork	-	-	-	-	-	-	2	6	-	-	-	7	-	-	-	-	11	-	-	-	-	**34**
Brickwork	-	-	-	-	-	-	3	1	-	-	-		-	-	-	-	-	-	-	-	-	**4**
Clay	-	-	-	-	693	6	20	170	2	-	-	206	-	165	1	-	12	-	1	6	-	**1,282**
Complex	-	-	-	-	-	-	-	46	-	1	1	6	-	1	1	-	-	-	-	-	-	**73**
Concrete	-	-	-	-	-	-	48	127	1	4	-	68	1	4	2	1	15	2	2		1	**276**
Earth	-	-	-	-	-	-	-	-	-	76	-	871	23	156	20	9	46	5	8	26	9	**4,677**
Gabions	-	-	-	-	-	-	-	-	3	1	-	3	-	-	-	-	1	-	-	1	-	**9**
Masonry	-	-	-	-	-	-	-	-	-	-	-	13	-	1	-	-	1	1	-	1	-	**41**
Mud	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	1	-	-	-	-	**1**
Multiple	-	-	-	-	-	-	-	-	-	-	-	1,39 4	6	24	3	-	35	-	7	12	21	**1,502**
None	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	**24**
Not known	-	-	-	-	-	-	-	-	-	-	-	-	-	389	-	-	2	1	-	1	1	**394**
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	1	-	**3**
Piling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37	-	2	-	-	**39**
Rock	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Sand	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	**3**

	Asbestos cement	Bagwork	Blockwork	Brickwork	Clay	Complex	Concrete	Earth	Gabions	Masonry	Mud silt	Multiple	None	Not known	Other	Piling	Rock	Sand	Shingle	Steel piling	Timber	TOTAL
Shingle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
Steel piling		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	**6**
Timber	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	**1**
TOTAL	**0**	**0**	**7**	**0**	**695**	**17**	**81**	**3,766**	**22**	**106**	**1**	**2,569**	**51**	**742**	**29**	**10**	**162**	**11**	**21**	**54**	**34**	**8,378**

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