

## **APPENDIX A**



# **Leeds (River Aire) Flood Alleviation Scheme**

## **Alternative Options Study Summary Report**

**November 2011**

## Executive Summary

There are no formal flood defences in the city of Leeds and the level of flood risk is very high. Since 2000 alone, the city has come very close to a major inundation on five separate occasions. In 2000, the city was within centimetres of a major inundation and 100 properties were flooded

The consequences of a major flood for Leeds would be extremely disruptive and have a significant impact on the region's economy. The very high level of flood risk faced could also significantly impact business confidence in inward investment. This cannot, however, be taken into account in our economic appraisals, which are primarily based on the number of residential properties protected.

In January 2011 Defra informed the Environment Agency (EA) and Leeds City Council (Leeds CC) that the original comprehensive scheme which we had been developing would have to be reconsidered under the new Partnership Funding arrangements. This message was reinforced at a meeting with the Secretary of State and Team Leeds (a cross party alliance of Leeds MPs) on March 22 2011.

Leeds CC and the EA have worked together to reconsider a number of options since September 2010, with increased resource being applied since 22 March to consider in particular the benefits of replacing existing weirs with movable structures and removing the island between the River Aire and Knostrop cut (called the 'movable weirs option'). This work has included considering alternative sources of funding and the constraints, opportunities and timescales.

We have developed a number of flood risk management options, ranging from linear defences to linear defences in conjunction with movable weirs and the removal of Knostrop cut. The more affordable options and those including movable weirs are focused on protecting the city centre. The cost of the various options varies from £50 to £75 million (whole life costs) for a 1 in 75 year standard of protection.

We have considered future works to provide a further improvement in standard of protection i.e. protect to a 1 in 75 year standard now and increase this to a 200 year standard in the future as funds become available.

All of the options identified are technically possible, but multiple funding streams will need to be secured in order to promote them. Good progress has been made in identifying potential high value contributions and an external funding bid has been made to the ERDF. This fund imposes a significant time constraint for this project; requiring capital expenditure to be complete by the end of 2015.

We intend to present the alternatives to Leeds CC's Executive Board (cabinet) at their meeting on December 14. They will make a decision on whether to proceed, and which option they would prefer. This will rely on significant additional funding being found.

# 1 Introduction

The city of Leeds is located in West Yorkshire on the banks of the River Aire. It is the second largest Metropolitan District in England with a population of 760,000. Leeds has around 24,000 VAT registered businesses making it the third largest employment centre in the UK. The city is also a major economic contributor with Gross Value Added equating to £16.3billion.

Currently, there are no formal flood defences in the city and the level of flood risk is very high. The onset of flooding varies: during a 1 in 5 year event the river escapes from its banks, however, during a 1 in 20 to 1 in 25 years event, properties begin to flood. In 2000 this level of flood inundated 100 properties. In the past decade alone, the city has come very close to flooding on four occasions (2004, 2005, 2007 and 2008). A major flood in Leeds would be extremely disruptive and would take a considerable time to recover from. Additionally, the level of flood risk the city faces, particularly if further flooding occurs, could have a significant impact on business confidence in inward investment. This consequence cannot be accounted for in the economic appraisal of flood alleviation schemes.

In autumn 2010 Defra informed the EA and Leeds CC that the preferred flood alleviation scheme developed for Leeds as presented in the Project Appraisal Report (PAR) of 2010, would need to be reconsidered. That comprehensive scheme proposed a 1 in 200 year standard of flood protection for Leeds extending over 17.5km from the upstream communities around Kirkstall, through the city centre and on downstream to Woodlesford. This scheme had an estimated cost of £149m (£188m whole life cost which includes maintenance).

Following this announcement from Defra, the EA and Leeds CC have been considering alternatives to improve the management of flood risk in the city. These include traditional flood risk management interventions, as well as an innovative movable weir conceptual design based on widely used technology for water management and flood alleviation used in European and North American rivers and navigations. Movable weirs or tilting gates are used in a few small scale water management interventions in the UK. The proposal also involves the removal of the island between the River Aire and the Knostrop cut. This innovative solution was originally proposed by Arup.

Since a meeting between the Secretary of State and Team Leeds (a cross party alliance of Leeds MPs) on March 22 2011, the EA have been working with Leeds CC to examine alternative options and sources of funding.

We committed to:

- (1) within 3 months consider the option, proposed by Arup, to create movable weirs and remove the island between the river Aire and the cut, and;
- (2) have all options appraised within 6 months to allow Leeds CC to make choices.

The project team comprised the EA, Leeds CC, Atkins and Arup, with framework contractor Volker Stevin providing advice on project costs. The wider team included representatives from British Waterways and Yorkshire Water.

We held a Design Vision workshop on 11<sup>th</sup> July 2011 which confirmed a short term objective of identifying a 1 in 75 year standard of protection for the city by 2014/2015 that would be adaptable to meet the longer term aspiration of achieving a 1 in 200 year standard of protection.

This report summarises the work done and the results obtained.

## 2 Option Consideration

Over the past few years, we have tested an extensive list of options to reduce the level of flood risk in Leeds. Following the Defra decision that our proposed comprehensive scheme based on a 1:200 standard of flood protection for Leeds must be considered under the new funding arrangements, we reconsidered some aspects of the comprehensive scheme as well as examining more innovative alternatives. The options we looked at included:

- Reconsideration of upstream storage;
- Replacement of bridges restricting flow in the river;
- A scheme protecting the city centre only;
- The comprehensive scheme with a very basic approach to finishes;
- Possible ways to reduce the cost of the comprehensive scheme;
- A reduced standard of protection for the city;
- An innovative movable weir option and removal of the Knostrop cut, proposed by Arup;

The conclusions which we reached for each option are summarised below.

### 2.1 Upstream Storage

We originally considered a flood storage reservoir at Rodley as part of the comprehensive scheme. As a standalone project we estimated that it reduced water levels by 300mm directly downstream of the reservoir, with a less pronounced reduction in central Leeds. We estimated the costs for this storage at £40m with a benefit cost ratio of 1.63. On its own, the reservoir could provide a 1 in 25 year standard of flood protection to central Leeds. Upstream storage could provide an increased standard of protection in the future for Leeds including areas between Rodley and the city centre.

### 2.2 Removal of Bridges

During our investigations, we identified six bridges that affected river levels. Their removal would provide very local reductions in water levels but would not provide a significant reduction in flood risk in central Leeds. We considered that the potential costs of removal and either replacement or making alternative arrangements would be very high in comparison with the benefits. There would also be secondary impacts upon transport networks, including permanent and temporary diversions, along with important heritage and environmental issues to be considered with two Grade II listed bridges in particular. However, this remains something to be considered, if in future works to any of these bridges is needed.

### 2.3 Reduced Extents Scheme

This considered protecting the city centre only using linear defences, both to the 200 yr and 75 yr standard. Compared to the comprehensive scheme, this had a better benefit cost ratio, a lower cost estimate and could be engineered so as not to increase flood risk in upstream and downstream communities. Recognising that such a scheme could be considered socially divisive, we identified either individual property protection measures or local structural interventions at residential properties upstream of the city centre which could be implemented alongside the city centre scheme for a relatively modest cost.

## 2.4 Basic and Value Engineered Schemes

We considered a the linear defences as a basic scheme which reduced the standard of finishes provided in the expectation that future developers could improve the aesthetics of the scheme over time. We estimated that for the comprehensive 200 year scheme this approach would reduce the cash cost to around £120-130m but carry an increased risk of objections through the planning process.

In the value engineering exercise we identified potential opportunities for a further maximum reduction of around £15-20m through both finding ways to reduce the cost and challenging the scope of the comprehensive scheme resulting in a further reduced cost of £105-110m.

## 2.5 Concept of movable weirs and removal of Knostrop Cut

The original Arup concept was based on maintaining navigation through the river and canal network in the city in ordinary flow conditions, with the ability to lower water levels in advance of higher flow conditions by lowering the weirs.

We anticipated that this would lower the flood profile, reducing the height of any walls needed, the visual impact, the works needed on tributaries, the impact on existing drainage networks and the requirement for new pumping stations and also maintaining connection to the river.

We would replace the existing weirs with movable, lowering weirs such as Obermeyer weirs. Other forms of movable structures were also considered.



**Figure 1** Example of an Obermeyer weir

The proposed works included:

1. Replacement of Crown Point and Knostrop Weirs in the city centre with movable weirs
2. Merging the river Aire and the Aire and Calder Navigation (Knostrop cut) over a circa 800m section where they currently run in parallel
3. Excavation of the bed of the Aire and Calder Navigation
4. Re-profiling the bed of the river Aire over a circa 1km length

Arup originally tested this at a high level in limited timescale at their cost, which suggested that the weir scheme reduced flood risk to a 1 in 75 year standard at an estimated cost of £20m.

Our study refined the understanding of both technical matters and the costs and we identified a number of key considerations to be addressed.

In comparison to the comprehensive scheme, we have undertaken a higher level of study for the movable weirs and other options.

## 3 Key Considerations

### 3.1 Height of flood defences

In 2009, Leeds CC's Plans Panel accepted in principle the linear defences proposed in the original 1 in 200 year comprehensive scheme. We have not considered any option which increases those heights, so we would hope that this acceptance still stands. However, there may still be local concerns at the height of linear defences which should be taken into account in option selection. The scheme will still have to pass through the full planning process.

### 3.2 Rivers response to rainfall

In the initial stage of this study, we developed an understanding of how the river responded to rainfall. A detailed summary of development of the hydraulic model, testing, sensitivity testing and associated results is available.

To progress the study, we made assumptions that may need further clarification at the detailed design stage, meaning that the results may vary.

The weirs, removal of Knostrop Cut to merge the river and canal and re-profiling of the river bed provides a standard of protection of between 1 in 25 to 50 years depending on local ground levels. The exact heights and locations of the defences required to increase the Standard of protection to 1 in 75 will be ascertained when a detailed survey of the whole river bank has been undertaken at detailed design stage. We calculated freeboard, which is the modelling uncertainty, using the EA's Fluvial Freeboard guidance.

### 3.3 Operation and maintenance

The day to day navigation would be unaffected by the scheme, although this would need some local navigation control and an enhanced flow (or velocity) warning system. British Waterways have confirmed that we could put systems in place to manage the risks associated with navigation in regular annual spates.

Since the EA's policy is to provide passive flood defence systems (i.e. those that do not need operation) we would need further discussion with Leeds City Council to agree responsibility for promotion and operation of the movable weirs and associated infrastructure.

### 3.4 Working with partners

Merging and re-profiling of the river Aire and the Aire and Calder Navigation will generate significant surplus material. British Waterways are currently considering reactivating a licensed tip at nearby Woodlesford and have indicated that they have sufficient capacity at the site to take the arisings from these works. This offers significant cost savings (initial estimate £5.4M) and a reduction in the impact on the local road network, through material being transported by barge.

Initial discussions with Yorkshire Water for use of licensed areas within the Knostrop sewage treatment works have been equally favourable

### 3.5 Impacts on existing structures

The modelling has shown that use of movable weirs, merging the river and canal and re-profiling the river bed will increase the river's velocity when the weirs are lowered in storm conditions. This increases the risk of damage to riverside structures and bridges through scour action. We have not studied this in this high level study but have allowed for some simple measures in our cost estimates to help reduce this risk.

### 3.6 Site specific legislation

The Leeds-Liverpool canal and Aire and Calder Navigation were formed under various Acts of Parliament between 1699 and 1794. The nature, scale and impact of the works, particularly those associated with combining the river Aire with the navigation at Knostrop, are likely to result in some formal authorisation to address this. This might be achieved through an Act of Parliament, a Transport and Works Act Order, an Infrastructure Development Consent Order or use of EA powers under the Water Resources Act 1981 to compulsorily purchase the land and then developing an agreement. The timescale for any of these could be in the order of two years.

Crown Point weir and the adjacent Leeds Liverpool Lock structure are both Grade II listed structures. The impacts are greater at Crown Point weir where the whole of the listed structure would need to be removed and replaced by a new structure. Initial discussion with English Heritage suggests that this could be managed by Listed Building Consent through normal planning process which takes a minimum of eight weeks. At this stage EH have not indicated any substantive objection. ..

### 3.7 Water Framework Directive (WFD) assessment

We have undertaken a preliminary assessment of the potential changes to the river environment which would be caused by the movable weirs, channel merging and bed re-profiling. The WFD classification of this section of the river is Heavily Modified. Its current potential is Poor with a status objective of Good by 2027. This option may adversely impact on the watercourse, however, this represents about 2-3% of the water body as a whole and the opportunity exists to mitigate each impact.

Converely the installation of the movable weirs would provide an opportunity for the addition of fish passes and micro hydo installations delivered in combination with the works to install the weirs. ERDF funding bids such as the Leeds FAS bid are strengthened by the integration of such environmental objectives. There is potential to renaturalise the heavily engineered right bank of the River Aire through the removal of Knostrop Cut (option 6). Movable weirs have been used to allow the migration of fish by lowering the weirs to allow movement of specific species at the appropriate time of year.

## 4 Detail of Options Considered

To satisfy the objectives we agreed at the Design Vision Workshop, we have considered a number of options, outlined below and as numbered in the full report, all of which are technically possible.

### 1. Option 3 - Comprehensive 1 in 75 year defences



We have included the 1 in 75 year scheme here as it fulfils the short term objective and will be more affordable than the 1 in 200 year scheme.

**2. Option 4 - 1 in 75 year linear defences aimed at protecting the city centre only**

This is similar to the above option but protects only the city centre.

**3. Option 5 - 1 in 75 year scheme with movable weirs and linear defences to protect the city centre**

This option involves replacing the existing weirs with movable weirs and providing linear defences up to 200mm lower than option 4 in some areas of the city centre to provide a 1 in 75 year standard for the city centre.

**4. Option 6 - 1 in 75 year scheme, with movable weirs, linear defences, removal of Knostrop Cut and re-profiling of the river to protect the city centre.**

This option involves replacing the existing weirs with movable weirs, merging the river Aire with the Aire and Calder Navigation, bed re-profiling works and providing linear defences up to a further 500mm lower than in option 4 in fewer areas of the city centre to provide a 1 in 75 year standard for the city centre.

The heights for the 75 year level of protection for each option is included in the table below.

Location	200 yr Original PAR scheme	75 yr City centre defences Option 4	75 yr Defences and weirs Option 5	75 yr Defences, weirs and cut removed Option 6
Canal Wharf	0.98	0.47	-	-
Brewery Wharf	2.28	1.87	1.67	1.30
Turlock Court	2.50	2.11	1.83	1.35
Navigation Walk	1.48	1.07	0.87	0.50
Fearns Wharf	1.99	1.60	1.27	0.58
Sovereign Place	0.85	0.40	-	-
Water Lane	1.42	0.97	0.78	0.46

Future options for increasing the standard of protection will depend on the initial option chosen. There will be several ways of reducing the risk further as funds become available.

- Install movable weirs
- Merge the canal and river and re-profile the river
- Increase the height and plan extent of the walls
- Provide upstream storage
- Land management in the upstream catchment



## 5 Economics

The table below contains the costs and benefits of each option, the benefit cost ratio and the likely Flood Defence Grant in Aid that it would attract.

An EA framework contractor, Volker Stevin, developed the cost estimates based on the conceptual weir design and costs from the comprehensive scheme.

The economic benefits are consistent with those we calculated using the then current guidance for the comprehensive scheme. The price base for both costs and benefits has been updated to Q1 2011.

Costs and benefits in £millions		200 yr Original PAR scheme	200 yr City centre only	75 yr City centre defences Option 4	75 yr Defences and weirs Option 5	75 yr Defences, weirs and cut removed Option 6
Standard of protection		200	200	75	75	75
Total Build	Present Value	138.0	56.5	51.3	37.2	51.9
	Cash	168.8	68.8	63.5	48.4	75.8
Benefits	Present Value	460.0	191.0	134.0	139.0	144.0
Benefit Cost ratio		3.3	3.4	2.6	3.8	2.8
Partnership funding		27.7	11.5	8.0	8.3	8.4

The most cost effective option is to build defences to levels lowered by using the movable weirs. However, the choice between options may not be based purely on the economics, but will be influenced by the timescales for the external funding, local preferences with regard to wall height, and the constraints with regard to the listed status of Crown Point weir and the legal aspects regarding the canal.

## 6 Funding

All options will require significant external funding.

Leeds CC are exploring potential funding streams and have applied to the European Regional Development Fund (ERDF). This application is still being considered. This fund imposes significant time constraints for this project; requiring capital expenditure to be complete by December 2015.

Leeds CC also pledged a £10m contribution for the comprehensive scheme. They would need to confirm their level of contribution to any other scheme, however, it is very likely that we would need further funds for a scheme to be built.

We have established the level of central government contribution (Flood Defence Grant in Aid) for each option using the Flood and Coastal Erosion Resilience Partnership Funding Guidance.

Yorkshire Water are considering a contribution based on their management of surface water flooding by providing pumping stations. This valuable contribution is potentially worth up to £10m for any scheme with defences, but would require Ofwat approval, and is not included in the cost estimates.

British Waterways have agreed in principle to accept excavated material from merging and re-profiling the canal and river at their Woodlesford facility. This valuable contribution is potentially worth around £5.4m.

For a phased approach to flood risk, one possible option which Leeds CC is considering is a Community Infrastructure Levy to raise funds for the later intervention and also the development of a Business Improvement District (BID) for the waterfront area which could potentially generate income for investment into city centre waterfront areas potentially including expenditure on flood risk management and associated public realm improvements.

Leeds CC have secured a section 106 contribution through private sector development of a site at Knostrop. This represents a £2m saving on construction. We have identified further private development sites within the study area, but the level and timing of any contribution will depend on the economy and is therefore unknown.

It would be possible to explore the potential for further contributions with the local Chamber of Commerce, large private sector employers, and other key beneficiaries in areas at risk of flooding. Some key benefits include the avoidance of disruption to rail operations including the operation of Leeds Train Station and electric supplies.

## 7 Conclusions and Next steps

### 7.1 Conclusions

The work has proved that the options identified above all provide a reduction in flood risk in Leeds City Centre, with varying cost benefit values and costs.

The external funding bid for ERDF places a significant time constraint on the spend profile, with works needing to be completed by end of 2015.

The combination of the canal and the river will need some form of legal process to be carried out which may take up to 2 years

The Crown Point Weir (also known as Leeds Dam) is listed, which will need careful liaison with various heritage groups, and the local authority planners

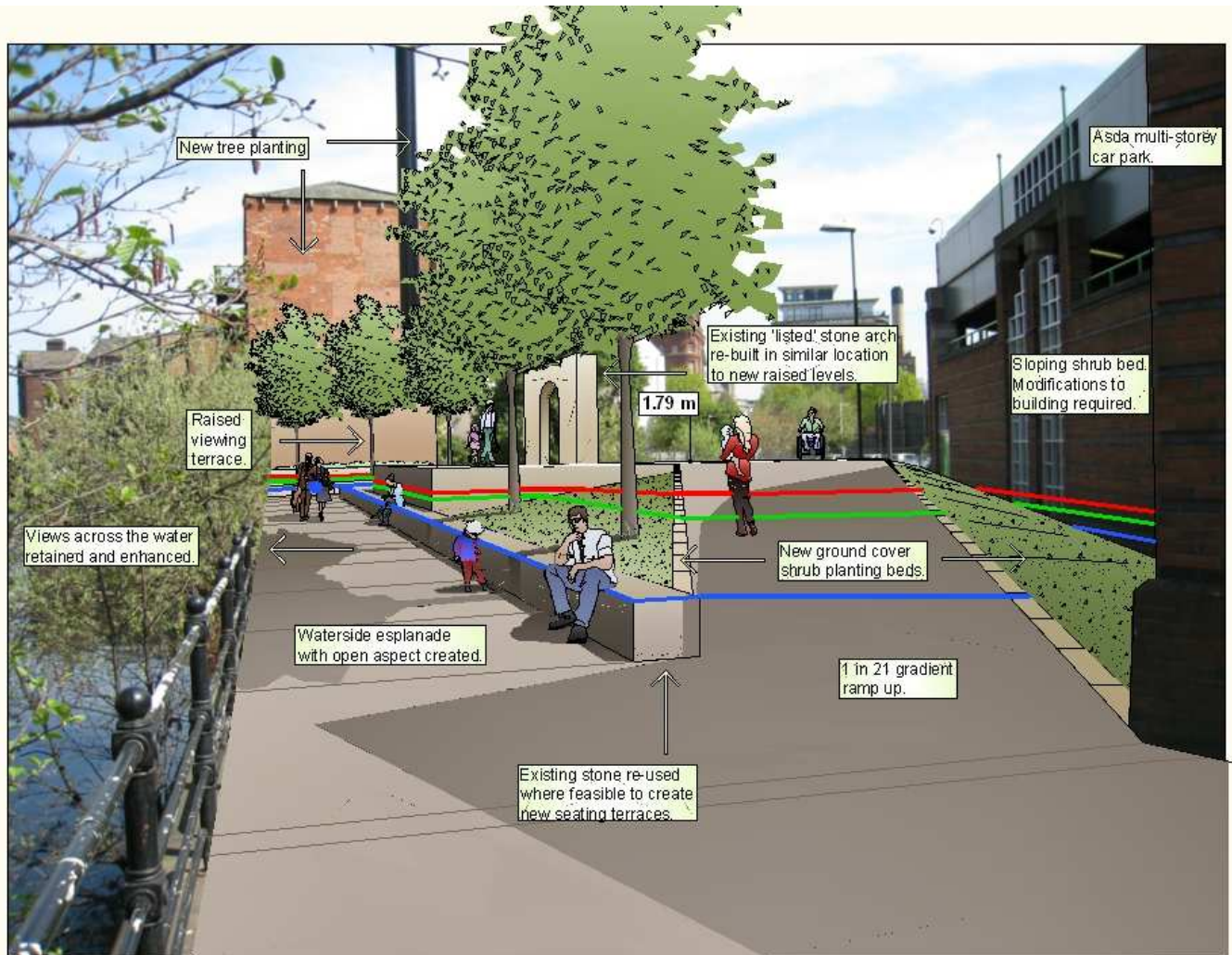
Considerable alternative sources of funding will be needed to progress a scheme

### 7.2 Next Steps

We intend to provide technical support to Leeds CC in presenting the alternatives to their Executive Board (cabinet) at their meeting on 14 December 2011, to decide whether to proceed, and which option they would prefer. This will rely on significant additional funding being found.

## APPENDIX B

Water Lane - 'Multi story car park' - Defence Ref. No. 41 - Total length 471m

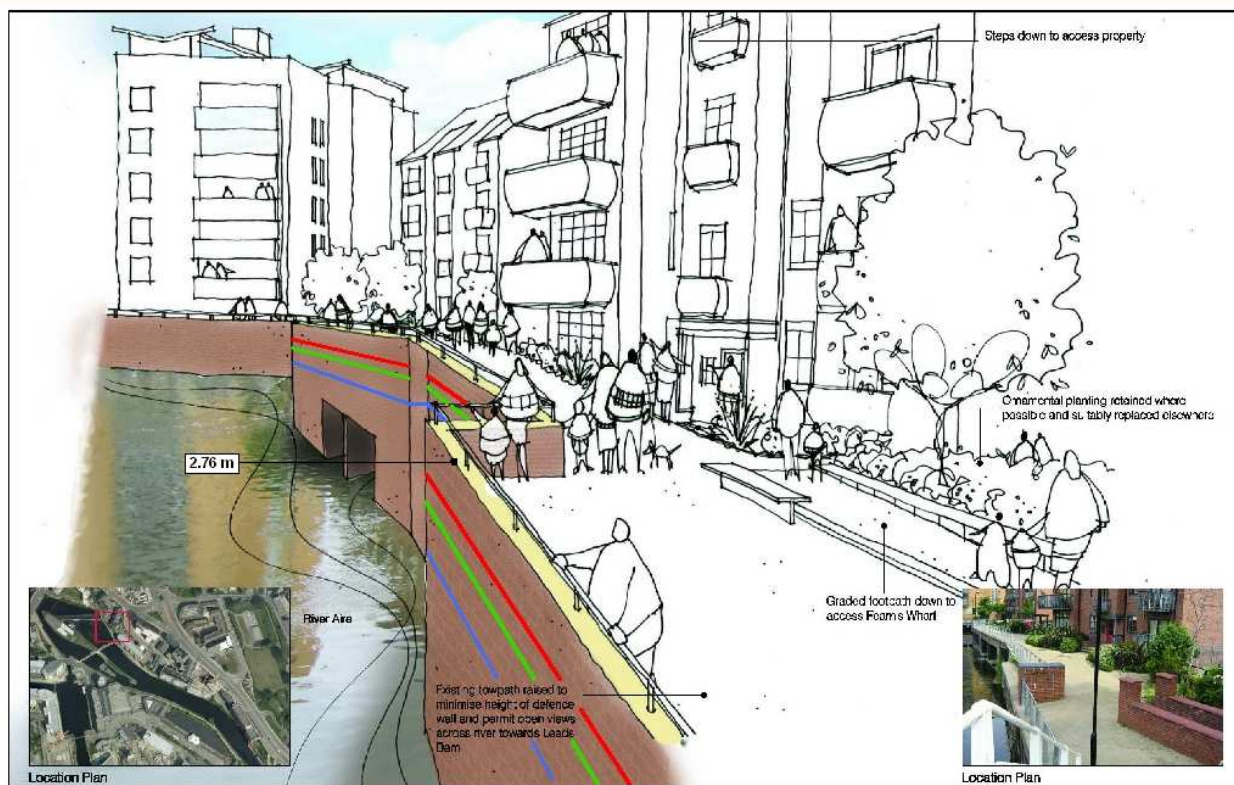


**N.B** New defence heights illustrate a 1 in 75 yr event + 0.4m freeboard (safety margin to account for residual uncertainties in water level prediction)

- Red Line** - Option 4 - City walls only = **0.97 m** defence height
- Green Line** - Option 5 - City walls + weir = **0.78 m** defence height
- Blue Line** - Option 6 - City walls + weir and Knowstrop cut removal = **0.46 m** defence height
- Original scheme** - **1.79 m** Full protection (200 yr + freeboard + climate change)  
**1.21 m** high (200yr + freeboard) or **0.95 m** high (100yr + freeboard)

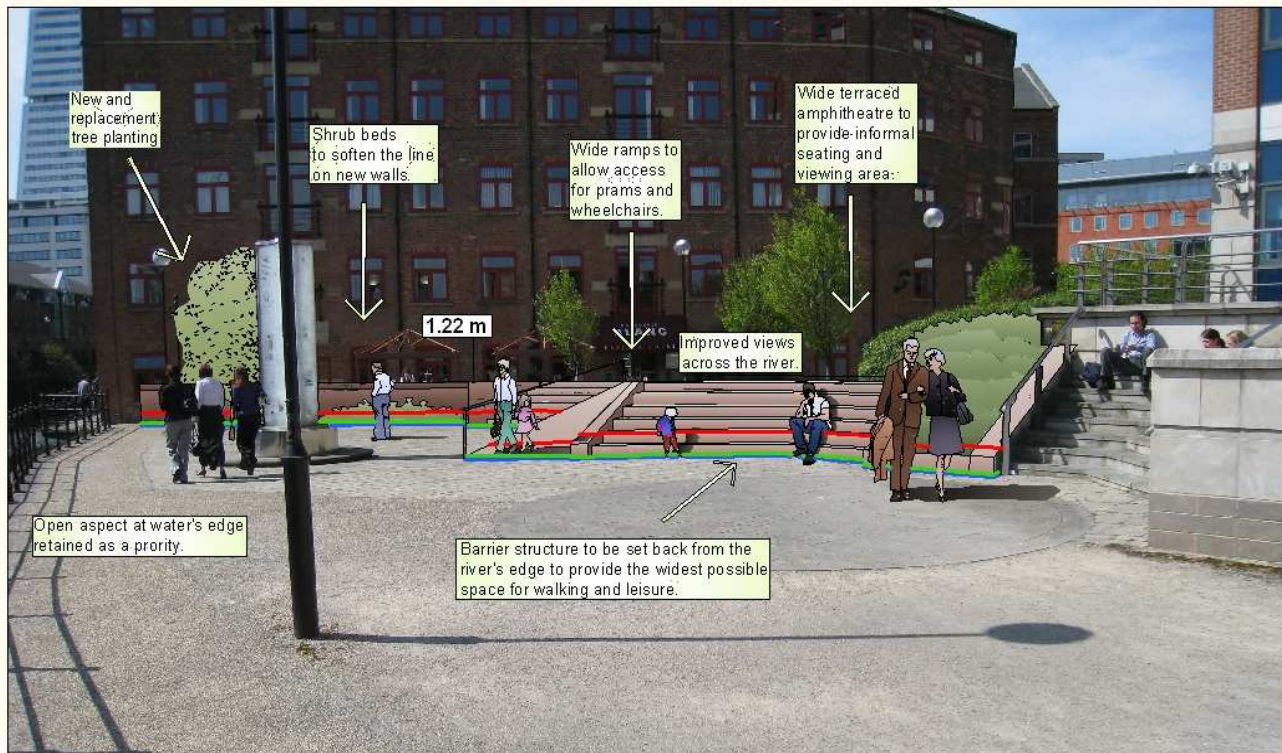


**Turlow Court** - Defence Ref. No. 49 - Total length 571m



- Red Line** - Option 4 - City walls only = **2.11 m** defence height
- Green Line** - Option 5 - City walls + weir = **1.83m** defence height
- Blue Line** - Option 6 - City walls + weir and Knowstrop cut removal = **1.35 m** defence height
- Original scheme** - **2.76 m** Full protection (200 yr + freeboard + climate change)  
**2.31 m** high (200yr + freeboard) or **2.10 m** high (100yr + freeboard)

**N.B** New defence heights illustrate a 1 in 75 yr event + 0.4m freeboard (safety margin to account for residual uncertainties in water level prediction)

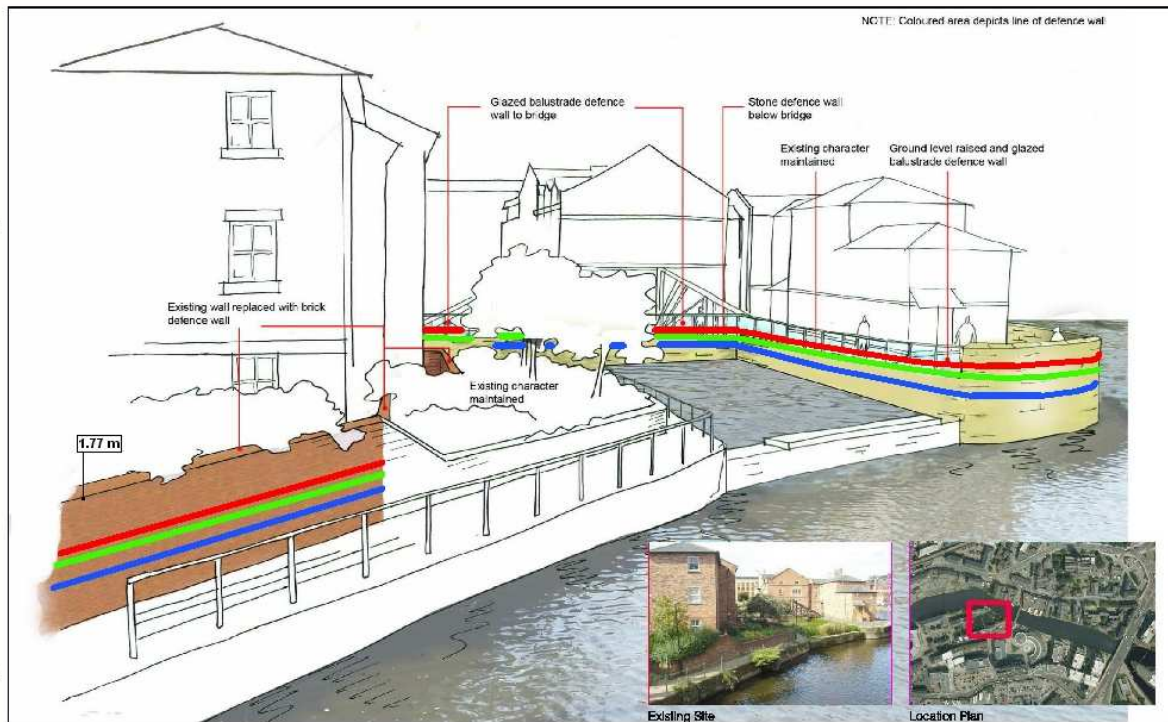


**N.B** New defence heights illustrate a 1 in 75 yr event + 0.4m freeboard (safety margin to account for residual uncertainties in water level prediction)

<b>Red Line</b>	- Option 4 - City walls only = <b>0.40 m</b> defence height
<b>Green Line</b>	- Option 5 - City walls + weir = <b>0.00m</b> defence height
<b>Blue Line</b>	- Option 6 - City walls + weir and Knowstrop cut removal = <b>0.0 m</b> defence height
<b>Original scheme</b>	- <b>1.22 m</b> Full protection (200 yr + freeboard + climate change) <b>0.64 m</b> high (200yr + freeboard) or <b>0.38 m</b> high (100yr + freeboard)

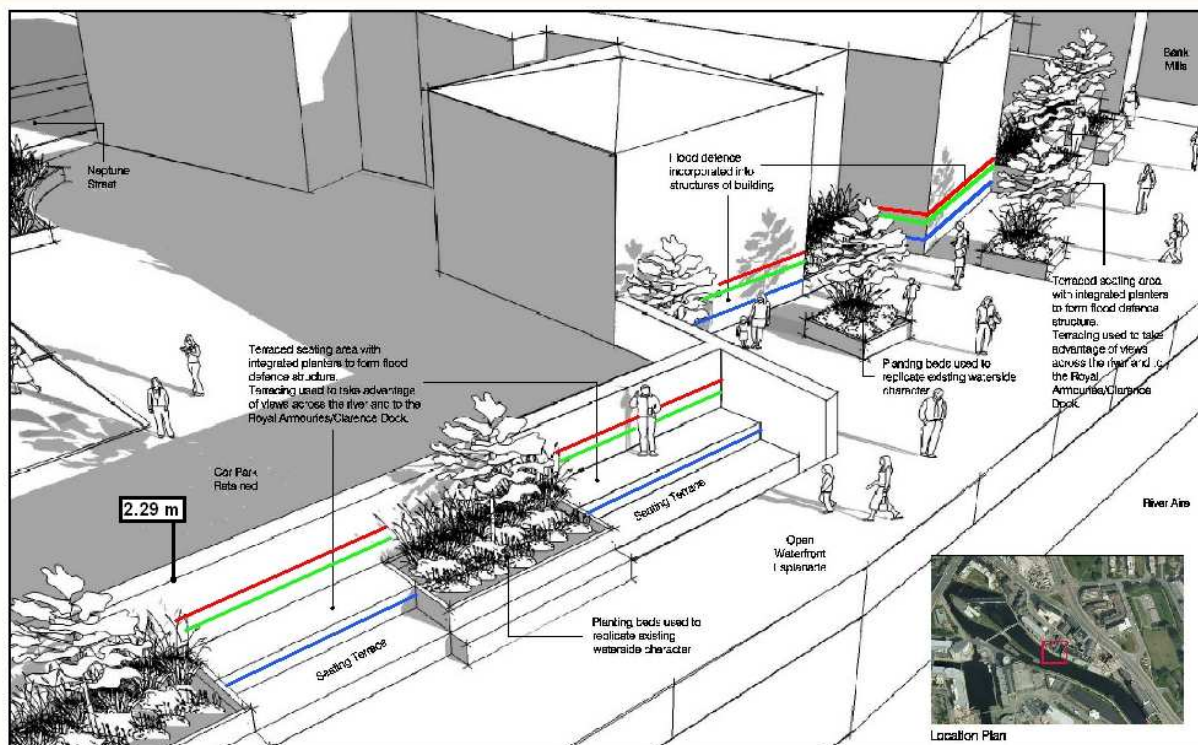


Navigation Walk - Defence Ref. No. 44 - Total length 69 km



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|------------------------|--|
| <b>Red Line</b>        | - Option 4 - City walls only = <b>1.07m</b> defence height   |
| <b>Green Line</b>      | - Option 5 - City walls + weir = <b>0.87 m</b> defence height  |
| <b>Blue Line</b>       | - Option 6 - City walls + weir and Knostrop cut removal = <b>0.50 m</b> defence height   |
| <b>Original scheme</b> | - <b>1.77 m</b> Full protection (200 yr + freeboard + climate change)<br><b>1.26 m</b> high (200yr + freeboard) or <b>1.03m</b> high (100yr + freeboard) |

**N.B** New defence heights illustrate a 1 in 75 yr event + 0.4m freeboard (safety margin to account for residual uncertainties in water level prediction)

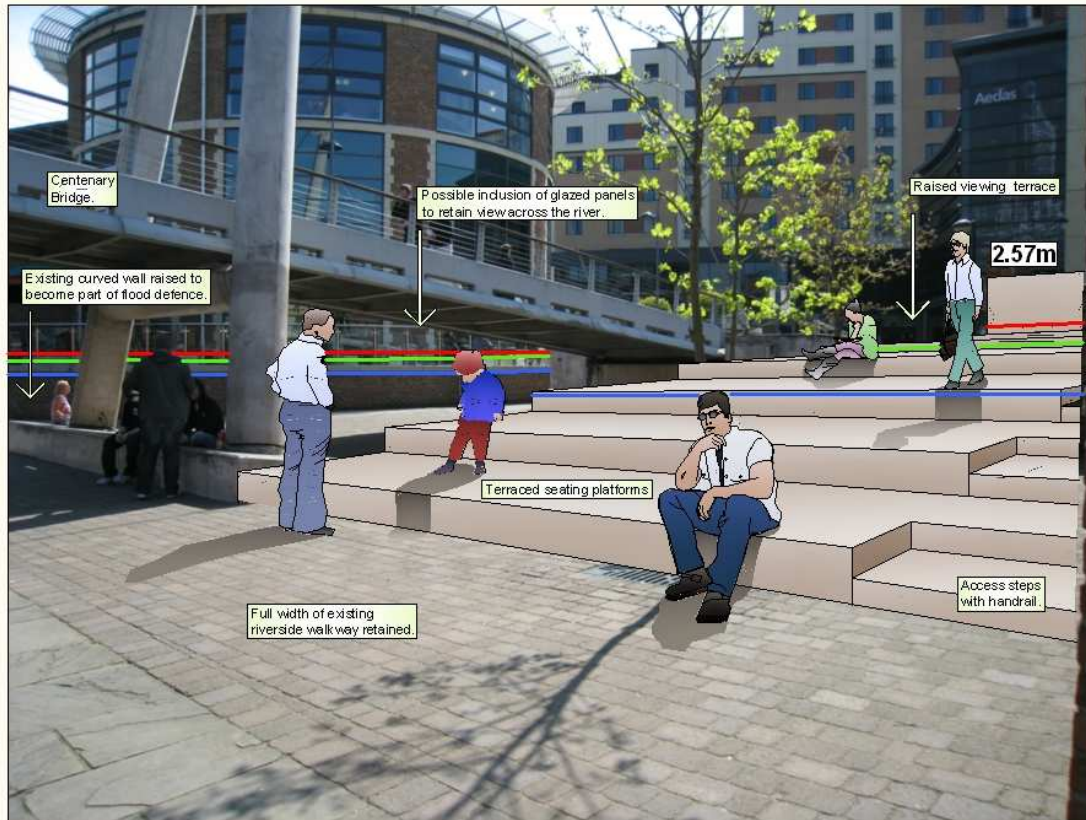


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|------------------------|---|
| <b>Red Line</b>        | - Option 4 - City walls only = <b>1.60 m</b> defence height   |
| <b>Green Line</b>      | - Option 5 - City walls + weir = <b>1.27 m</b> defence height   |
| <b>Blue Line</b>       | - Option 6 - City walls + weir and Knowstrop cut removal = <b>0.58 m</b> defence height   |
| <b>Original scheme</b> | - <b>2.29 m</b> Full protection (200 yr + freeboard + climate change)<br><b>1.87 m</b> high (200yr + freeboard) or <b>1.67 m</b> high (100yr + freeboard) |

**N.B** New defence heights illustrate a 1 in 75 yr event + 0.4 m freeboard (safety margin to account for residual uncertainties in water level prediction)



**Brewery Wharf - 'Centenary Bridge' - Defence Ref. No. 46' - Total length 281m**



**N.B** New defence heights illustrate a 1 in 75 yr event + 0.4m freeboard (safety margin to account for residual uncertainties in water level prediction)

- |                        |  |
|------------------------|--|
| <b>Red Line</b>        | - Option 4 - City walls only = <b>1.87m</b> defence height   |
| <b>Green Line</b>      | - Option 5 - City walls + weir = <b>1.67m</b> defence height   |
| <b>Blue Line</b>       | - Option 6 - City walls + weir and Knostrop cut removal = <b>1.30 m</b> defence height   |
| <b>Original scheme</b> | - <b>2.57 m</b> Full protection (200 yr + freeboard + climate change)<br>2.06 m high (200yr + freeboard) or 1.83m high (100yr + freeboard) |