Belfast Tidal Flood Risk Study

Feasibility Study Report

Rivers Agency

27 June 2016

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Table of contents

Tables

Figures

Introduction

This report summarises the findings of Stage 2 of the Belfast Tidal Flood Risk Study. It includes optioneering and assessment of viable flood alleviation options for tidal flood risk areas in Belfast and proposes a preferred option following economic appraisal.

Executive Summary

Background

Belfast is at risk of flooding from a number of sources, notably tidal, fluvial and surface water. Tidal flood risk is of most concern, with potentially over 560 residential and 460 non-residential properties at risk from a 1 in 200 year return period (0.5% Annual Exceedence Probability (AEP) Event). Such an event would also cause serious disruption to commerce, the transportation network, and the social fabric of the city. The impact of climate change will increase the number of properties at risk to over 3,400 by 2060 and over 7,900 by 2115.

The highest tidal surges recorded within Belfast Harbour have occurred within the past 20 years, most recently on the 4th and 7th January 2014. Without the close coordination and intervention of all the statutory and voluntary agencies and the city's emergency plan, serious damage to property and key infrastructure would have occurred.

The 2014 "near miss" flooding event, concerns over the numbers of "near misses" within a relatively short time period (the 5 highest tidal surges have been recorded since 1994), and the opportunity to build in a "flood risk element" into the York Street Interchange project are reasons why this tidal flood risk study has been commissioned by Rivers Agency.

Atkins was commissioned to develop a mitigation strategy to deal with tidally dominant flood risk for the areas of Belfast at risk taking account of the short, medium and long term. We identified and assessed flood risk management options to guide future investment and streamline flood risk management strategies. The preferred strategic option includes a Mitigation Action Plan with short, medium (5 to 10 years), and long (10 years+) term structural (e.g. flood defences / embankments) and non-structural (e.g. land use planning, early warning, emergency plans) measures. The preferred option includes associated cost estimates for the short, medium and long term measures proposed.

Study Area

The project study area is located in Belfast, Co Antrim from Belfast Lough to the Stranmillis Weir on Lockview Road; the extent of the tidal influence on the River Lagan. Data obtained during the course of the study is presented in Section 2 on land use, flooding history, topography, local geology, environment, infrastructure and H&S.

Study Methodology

The key steps and stages of this feasibility study were:

- Collecting and assessing site data including:
  - Topographic surveys of affected property thresholds
  - Topographic surveys of river banks at key flood risk spill points.
- Hydraulic modelling of tidal flood risk for a range of future epochs and return period tidal events to determine onset of flooding and flood extent.
- Identifying existing potential flood damage and associated costs.
- Consulting with the significant number of stakeholders to capture critical infrastructure and constraints / opportunities for any proposed works.
- Identifying potential upgrading options and assessing to identify a shortlist of suitable options.
- Appraising shortlisted options to identify a preferred option.
- Completing a Feasibility Study Report recommending the most economically advantageous option.

Flood Model

In 2010, Rivers Agency commissioned Aecom to carry out the first stage of the modelling strategy to inform the Belfast Flood Risk Management Plan (FRMP). The impact of tidal inundation along the Belfast frontage from tidal surge events occurring in Belfast Lough was of particular importance to this study. A linked 1D-2D hydraulic model was developed in Infoworks-RS covering the River Lagan from Stranmillis Weir to Lagan Weir and the River Connswater (incorporating the Knock and Loop watercourses). In 2012, this model was updated to include more detailed bank top survey along the River Lagan. In each of the commissions the tidal events were modelled with a baseflow from the fluvial watercourses.

In 2014 JBA were commissioned by Rivers Agency to convert the existing Infoworks-RS model to an Infoworks-ICM model to allow it to be used efficiently internally on their GPU modelling platform. As part of this conversion the existing model schematisation was retained with the exception of the River Lagan and

Belfast Lough downstream of Lagan Weir; previously this area was included in the 2D mesh; however, to improve model stability and run times this area was converted to be included in the 1D “in channel” model.

Additional changes to this revised model were agreed with Rivers Agency at the commencement of the Belfast Tidal Flood Risk Study commissioned in January 2015 (inclusion of under–construction East Belfast Fluvial Scheme and inclusion of additional topographic survey data for key spill locations). These changes were made and the revised flood mapping output was used as the base / existing scenario in the study.

Further epoch model runs were performed for 2065 and 2115 to inform the damage assessments with anticipated climate change in the economic appraisal and provide design flood levels for the options.

Flood Mechanism & Flood Extent

For the purposes of producing detailed flood hazard mapping for the tidal inundation of Belfast, the extreme sea water levels for a range of return periods were derived. The table below gives the estimated value of the extreme sea levels for a range of scenarios. It should be noted that the Rivers Agency’s normal design standard for sea defences is to protect to the 1 in 200 year (0.5% AEP) level with appropriate freeboard.

	Present day	Year 2065	Year 2115
Annual Exceedence Probability (Return Period)	**Max Tide Level (mAOD)**	**Max Tide Level (mAOD)**	**Max Tide Level (mAOD)**
10% AEP (1 in 10 year)	2.50	2.78	3.14
1% AEP (1 in 100 year)	3.07	3.35	3.71
0.5% AEP (1 in 200 year)	**3.17**	**3.46**	**3.82**
0.1% AEP (1 in 1000 year)	3.30	3.58	3.94

Using these tidal boundary conditions the tidal simulations for Belfast Lough and the lower, tidally dominated reaches of the River Lagan and Connswater River were undertaken.

For the most part, the height of the Belfast frontage (which is comprised of the quay walls and channel-side revetments on the River Lagan) is typically greater than 3.0m OD, although there are a number of distinct areas where the levels dip to as low as 2.6m OD. Behind the quays / river banks there are significant areas of the city centre and other areas to the east as far as Victoria Park that are very much lower than the quays / river banks, in some cases up to 2m lower. This low lying basin is occupied by some of the province’s most valuable commercial / retail property and residential areas with extremely high density housing.

The flood route mechanism for coastal flooding in the city centre is primarily one of overtopping of the dock quaysides, flowing south and west into Corporation Street and York Street into the commercial areas of the city centre as ground level falls behind the dock area(s). The other flood route into the commercial area is at a low spot in the quay wall just upstream of Lagan Weir on the left bank[1] of the River Lagan. The flood mechanism in the other flood risk areas is local overtopping of river banks.

The reaches of the River Lagan identified with current and future tidal flood risk from the modelling assessment were divided into flood cells for the purposes of the economic appraisal and assessment of flood alleviation options. The flood cells were:

- Flood Cell 1 - Belfast Harbour & City
- Flood Cell 2 - Titanic Quarter
- Flood Cell 3 - Sydenham / East Belfast
- Flood Cell 4 - Ravenhill
- Flood Cell 5 - Ormeau Embankment
- Flood Cell 6 - Lockview, Stranmillis

Optioneering

Rivers Agency commissioned this feasibility study to review and identify flood alleviation options for the key flood risk areas of Belfast City with consideration of future sea level rise and adaptability to meet these future needs. An assessment was made on flood depths and flow routes at each of the tidal flood risk areas in Belfast and this guided the selection of appropriate flood alleviation options. The preferred overall strategic

[1] Left bank by convention is deemed to be the bank on the left looking downstream in the channel.

option includes a Mitigation Action Plan with short, medium (5 to 10 years), and long (10 years+) term structural and non-structural measures.

A Standard of Protection (SoP) of 1 in 200 years (0.5% AEP) was selected to assess the current quay walls / river banks along the River Lagan from Belfast Harbour to Stranmillis Weir. If the current SoP was less than 1 in 200 year (0.5% AEP), a short – medium term flood alleviation option was assessed for the area at risk with consideration of future sea level rise in the sizing of the option. If the current river bank / quay wall provided a 1 in 200 year (0.5% AEP) SoP flood alleviation options were developed for construction in the long term to provide further protection for future sea level rise.

High level strategic options were identified to provide the required SoP (1 in 200 year (0.5% AEP)) across the tidal flood risk areas in Belfast. The options represented flood alleviation approaches from the most comprehensive global solution to the most immediate local protection measures. The strategic options were subsequently assessed at the flood cell level to determine the exact defence types etc. along the alignments required.

The Lagan Weir, constructed in 1993, was designed primarily as an impoundment to cover the mudflats in the River Lagan thereby creating an attractive water based amenity to complement the Laganside Regeneration Project. The weir can also be operated to close on receipt of a tidal surge warning, and therefore act as a tidal barrier for flood risk areas upstream using the gate level of 3.0mOD (SoP equivalent of a 1 in 75 year – 1.33% AEP event). This opportunity was initially identified as an option to be considered for the next stage of assessment. However, recent joint probability analysis of the fluvial and tidal extremes (refer to **Appendix M**) indicates that, although the joint probability factor is relatively low, it is still sufficiently high to place a significant risk that the fluvial flow concurrent with an extreme tidal surge event would overwhelm the storage capacity between the Stranmillis Weir and the Lagan Weir. This would cause an increased risk of flooding than if there were no tidal barrier. This option has, therefore, not been taken further forward to the Shortlisted Options.

Shortlisted Options

The following strategic options were taken forward for detailed assessment at each of the flood cells:

- Option 3 – Riverside Permanent Defences
- Option 4 – Riverside Temporary Defences

The review of these strategic options at a flood cell level identified the following options for economic appraisal:

- Flood Cell 1 - Belfast Harbour & City:
  - Option 3 – Riverside Permanent Defences; Route ‘a’ and Route ‘b’
  - Option 4 – Riverside Temporary Defences; Route ‘a’ and Route ‘b’
- Flood Cell 2 – Titanic Quarter
  - No options considered – further assessment to be considered in future separate study.
- Flood Cell 3, 4, 5 & 6 – Sydenham, Ravenhill, Ormeau Embankment and Lockview, Stranmillis:
  - Option 3 – Riverside Permanent Defences
  - Option 4 – Riverside Temporary Defences

Economic Appraisal of Preferred Options

The cost of flood damage to property is calculated using a methodology developed by Middlesex University Flood Hazard Research Centre, set out in a book commonly referred to as the “Multi-Coloured Manual” (MCM). The methodology requires the analyst to develop a detailed database of all properties at risk of flooding and to categorise each with codes set out in the manual. Flood water levels were extracted from the hydraulic model for the various return periods considered under the existing conditions. These flood levels were used to derive flood depth for each return period at each property subjected to flooding. This data was used to calculate the cumulative flood damages of all properties.

In addition to the direct damage caused by flooding, some indirect damages have been included. These included evacuation costs, emergency service costs and vehicle damages. These costs were estimated from guidance provided in the MCM.

A capping figure of the property market value was applied to all of the properties included in the damage assessments. The purpose of capping is to ensure that the total (present value) damage for any one property does not exceed its market value.

For the temporary defence options a reliability assessment was completed to better understand the risks affecting their successful operation. A range of the most likely risks to affect successful operation were considered and their likelihood estimated. The sum of these independent risks generates a total failure probability of 10.5%. This figure was incorporated into the benefit assessment.

The cumulative costs and benefits of the scheme were discounted over the 100 year appraisal period of the project, at a representative discount rate (3.5% for years 0 – 30, 3.0% for years 31 – 75, and 2.5% for years 76 - 125) to provide a Net Present Value (NPV) of the scheme. The price date used for all benefits and costs is Q3 2015.

To assess the economic viability of the options, it is necessary to compare the costs and benefits, calculated against those of the baseline option. Under guidance from the NI Guide Expenditure Appraisal and Evaluation (NIGEAE), the baseline was the Status Quo option, where the input necessary to maintain services at, or as close as possible to, their current level, was applied. For Belfast there is no existing asset serving a tidal flood risk purpose, and, therefore, there is no cost to the Status Quo option.

To ensure that intervention was justified in each Flood Cell, the economic appraisal assessed each cell and also assessed the Belfast Harbour & City Flood Cell and combined River Flood Cells. This assessment would permit each flood cell to standalone and could allow phasing of construction should funding for the overall project not be available.

The decision rule was to select the option that offers to maximise NPV whilst providing a flexible and sustainable solution for the future.

The option for Belfast Harbour & City Flood Cell with the highest NPV is Option 3 (Route ‘a’) with a value of £107.2m. This option was selected as the preferred economic option. The uncertainty assessment showed the selection was robust.

The option for the River Flood Cells with the highest NPV is Option 3 with a value of £32.8m. This option was selected as the preferred economic option. The uncertainty assessment showed the selection was robust.

Conclusions

The most significant tidal flood risk to Belfast is to the Belfast Harbour & City Flood Cell. An extreme event would cause serious disruption to commerce, the transportation network, and the social fabric of the city. Much of the centre of Belfast area is about 1m to 2m below extreme tide levels. Any significant depth of tidal flooding within the city centre is likely to drain slowly as the drainage network capacity is exceeded. This also raises the likelihood of contamination as tidal flooding overwhelms and mixes with the foul sewerage system. Flooding of the city centre may cause major disruption for several days or weeks, with increased clean-up and recovery consequences.

There are a further four separate flood cells upstream of the Lagan Weir (Sydenham, Ravenhill, Ormeau Embankment and Lockview). These cells include more residential areas. The Titanic Quarter development area on the east side of Belfast is largely above current flood risk concerns due to the implementation of a Strategic Flood Risk Assessment across the area approved by Rivers Agency acting as the competent Flood Risk Authority; however, this area should be reviewed in more detail in subsequent studies utilising new ground level survey data.

The total numbers of properties at risk are shown in the table below.

	Year 2015		Year 2065		Year 2115	
Return period (year)	Residential	Non Residential	Residential	Non Residential	Residential	Non Residential
2	-	3	8	33	293	104
10	6	31	170	67	636	448
50	143	69	818	544	4,214	1,239
75	183	131	1,288	643	5,061	1,431
100	237	176	1,708	685	5,421	1,537
200	564	461	2,636	770	6,050	1,858
1000	1,211	617	3,820	1,090	7,053	2,120

An economic analysis of the total potential damages that would be caused from tidal flood events was undertaken using standard flood depth damage methods of analysis. This indicated that for the Status Quo option, the Present Value of damages (discounted over the next 100 years) for the Belfast Harbour & City Flood Cell was approximately £196m, and for the flood cells upstream of the Lagan Weir a further £47m.

For the Belfast Harbour & City Flood Cell, the preferred solution is Option 3, comprising new flood defence walls and structures along the riverside and following Route ‘a’ (Corry Road and Pollock Road) as the alignment to high ground. This option also scored the highest value within the non-monetised multi-criteria assessment. The alignment for Route ‘a’ will require some active flood defence in the form of demountable barriers / flood gates at road and access crossing points. These active structures will require resources in future to operate and maintain them to ensure they are implemented when required on receipt of a tidal flood warning. Route ‘a’ will not provide flood risk reduction for about 36 properties which will be to the north of the proposed flood defence alignment. A consultation process will be required to discuss the level of risk with these property owners / occupiers to determine whether individual property level protection (PLP) or changes to their operational procedures can reduce their level of risk.

The preferred option for the River Flood Cells is Option 3. This option had the strongest business case and provided a minimum 1 in 200 year (0.5% AEP) SoP for the next 100 years.

Overall Option 3 is the preferred option for both the Belfast Harbour & City Flood Cell and River Flood Cells, with a preference to follow Route ‘a’ in the Belfast Harbour & City Flood Cell. The overall preferred option is, therefore, Option 3(a).

Recommendations

Several recommendations arose in this study:

- Obtain new DTM / LiDAR data for Titanic Quarter area to allow flood risk to be assessed and options to be developed / confirmed.
- Consultation with Belfast Harbour Commissioners to agree the detailed alignment and finish of the flood defence prior to detailed design.
- Consultation with property owners / occupiers in the harbour area outside defended areas to determine whether individual PLP or changes to their operational procedures can reduce their level of risk.
- Following confirmation of funding, the implementation of Option 3(a) should be progressed, including site investigation, consultation, detail design and planning, followed by construction and commissioning of the new flood defence assets.
- Undertake an assessment of all available drainage network information and then site survey to determine location and condition of all existing culvert outfalls. Assess need and suitability to incorporate flap valve (or similar) to reduce risk of backing up, or requirement for over-pumping if risk of ponding behind existing (or new) river bank / flood walls.

It is recommended that these works are undertaken as high priority as Belfast is vulnerable to significant flood damage and potentially loss of life from moderate probability tidal events.

1. Project Background

1.1. Background

Belfast is at risk of flooding from a number of sources including tidal, fluvial and surface water. Tidal flood risk is of most concern, with potentially 560 residential and 460 non-residential properties currently at risk from a 1 in 200 year return period (0.5% Annual Exceedence Probability (AEP) Event). Such an event would also cause serious disruption to commerce, the transportation network, and the social fabric of the city. The impact of climate change causing sea level rise will increase the number of properties at risk to over 3,400 by 2060 and over 7,900 by 2115.

The highest tidal surges recorded within Belfast Harbour have occurred within the past 20 years, most recently in early January 2014. Without the close coordination and intervention of all the statutory and voluntary agencies and the city's emergency plan, serious damage to property and key infrastructure would have occurred.

The 2014 "near miss" flooding event, concerns over the numbers of "near misses" within a relatively short time period (the 5 highest tidal surges have been recorded since 1994), and the opportunity to build in a "flood risk element" into the York Street Interchange project are reasons why this tidal flood risk study has been commissioned by Rivers Agency.

1.2. Study Aims

Atkins was commissioned to develop a mitigation strategy to deal with tidally dominant flood risk for the vulnerable areas of Belfast taking account of short, medium and long term considerations including, inter alia, economic regeneration, risk to life, climate change and emergency planning protocols.

We have identified and assessed flood risk management options to guide future investment and streamline flood risk management strategies. A Mitigation Action Plan with short, medium (5 to 10 years), and long (10 years+) term structural and non-structural measures was developed. The preferred option includes associated cost estimates for the short, medium and long term measures proposed.

This study embraces two of the three core flood risk management principles i.e. prevention, and protection; the preparedness element of flood risk management is being dealt with through other inter-governmental protocols.

1.3. Methodology

The key steps and stages of this feasibility study included:

- Collecting and assessing site data including:
  - Topographic surveys of affected property thresholds
  - Topographic surveys of river banks at key flood risk spill points.
- Hydraulic modelling of tidal flood risk for a range of future epochs and return period tidal events to determine onset of flooding and flood extent.
- Identifying existing potential flood damage and associated costs.
- Consulting with the significant number of stakeholders to capture critical infrastructure and constraints / opportunities for any proposed works.
- Identifying potential upgrading options and assessing to identify a shortlist of suitable options.
- Appraising shortlisted options to identify a preferred option.
- Completing a Feasibility Study Report recommending the most economically advantageous option.

1.4. Report Format

This report presents the findings of the Belfast Tidal Flood Risk Study. It is divided into a number of sections which describe the key stages of the study. The early sections of this report summarise the details of the data collection and assessment process. The report later describes the flood alleviation options, shortlisting process and the detailed assessment of the preferred options including costing. The report makes clear recommendations on the preferred option to be adopted.

2. Study Area

The project study area is located in Belfast, Co Antrim from Belfast Lough to the Stranmillis Weir on Lockview Road; the extent of the tidal influence on the River Lagan.

The location of the study area is shown in Figure 2-1.

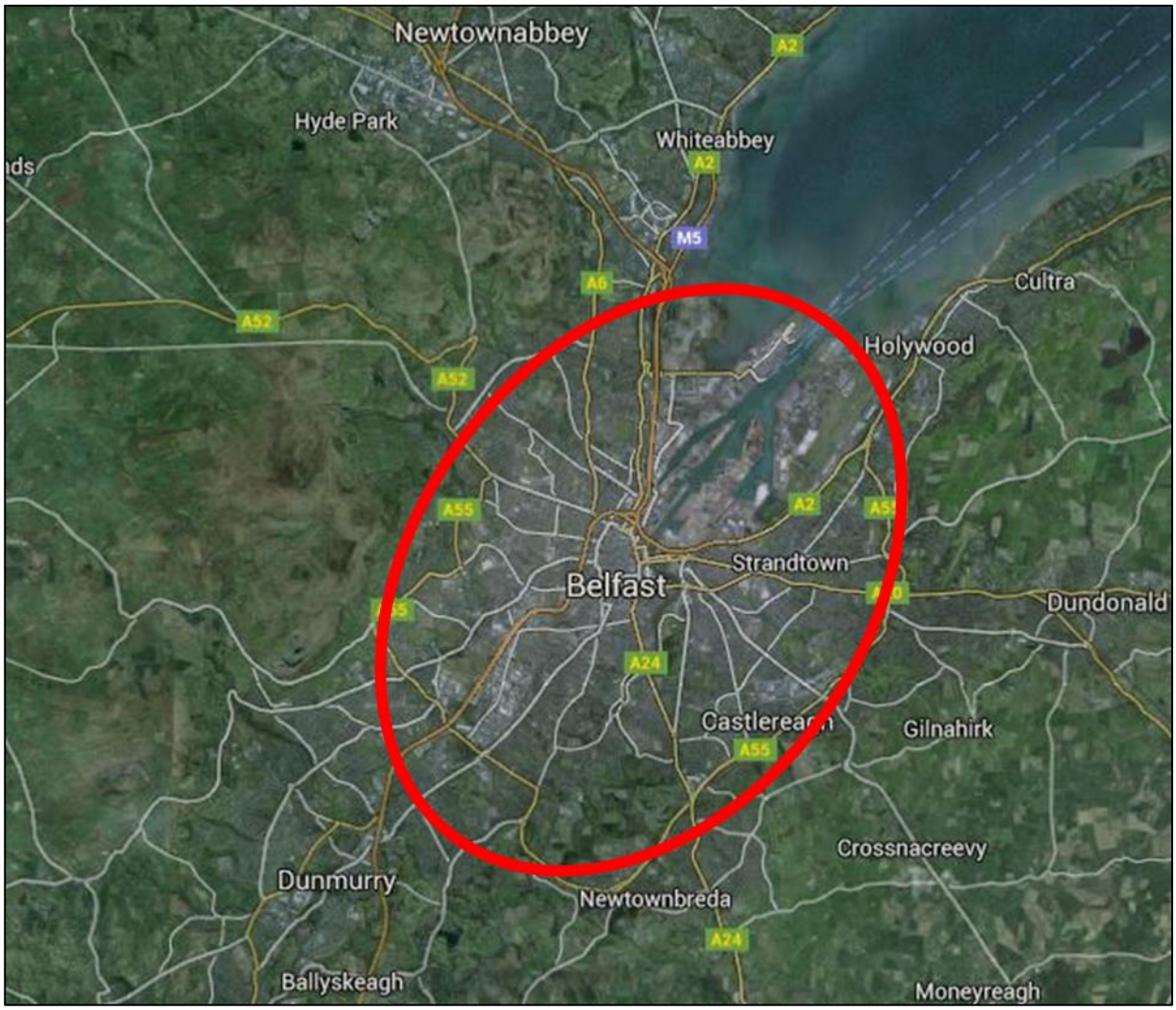

Figure 2-1 Site Location Map

2.1. Land Use

The land use within the predicted flooding envelope is predominantly urbanised with a mix of commercial, industrial and residential land uses. Some areas of open space exist within the flooding envelope; however, these do not form a substantial proportion of the areas flooded.

The city centre and nearby residential and industrial areas have been historically developed and are likely to comprise significant made ground and subsurface contamination / features.

2.2. Flooding History

Belfast City Centre has been subject to occasional flooding in the past. An extensive review of the historic flood events was completed by JBA Consulting for the hydrological assessment for the tidal model build for Belfast. The Hydrological Report was obtained and Annex 2 Historical Flood Review examined. A copy of this Annex is provided in **Appendix A**.

Other historic flood data has been viewed on ArcGIS stakeholder viewer and Flood Maps NI.

2.2.1. Coastal Flood Defences

The Lagan Weir is owned and operated by the Department of Social Development. The Lagan Weir was constructed in 1993 to retain water in the channel upstream during the lower part of the tidal cycle.

The structure contains a series of moveable gates and a regime is in place to operate the gates to maintain water quality in the Lagan. During normal tidal and river flow conditions the weir gates are raised on each falling tide to impound the river upstream. The gates are then lowered when, on the next tidal cycle, the sea level rises above the impounded control level for the river. The weir gates create an impoundment between Donegall Quay and Stranmillis Weir.

The objective of the weir was to improve water quality in the river for the development of the riverside; however, the weir could potentially have a secondary use as a tidal barrier to assist in flood protection to the city. No formal operation manual exists to define how the weir should be operated as a tidal barrier. All historic operations for previous tidal management have been performed based on the experience of the operators.

There are no existing specific tidal flood defence structures in Belfast City Centre; however, there are significant lengths of quay walls and informal bank defences.

2.2.2. Flooding Mechanism

The flooding envelope identified for a 1 in 200 year (0.5% AEP) tidal event encompasses approximately 2km^2 of the Belfast City Centre, as modelled by JBA for the Belfast Flood Risk Management Plan (FRMP). Other areas impacted include:

- Sydenham,
- Strandtown and Lower Ravenhill Road,
- The Markets,
- Lower Ormeau, and
- Lockview / Stranmillis area.

An extract of the Rivers Agency 1 in 200 year (0.5% AEP) tidal flood event flood envelope for Belfast is provided in Figure 2-2.

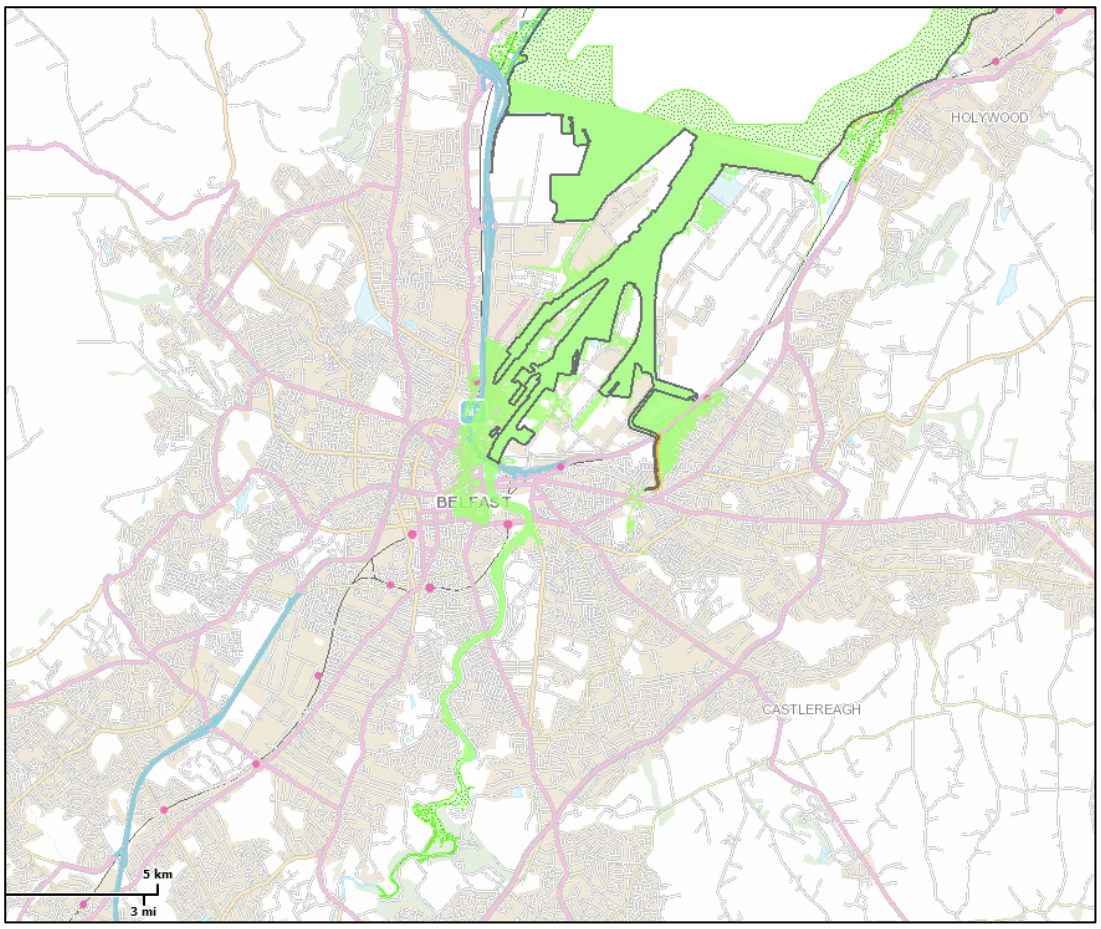

Figure 2-2 1 in 200 year (0.5% AEP) Coastal Flood Extent (Courtesy of Flood Maps NI)

For the most part, the height of the Belfast frontage (which is comprised of the quay walls and channel-side revetments on the River Lagan) is typically greater than 3.0m OD, although there are a number of distinct areas where the levels dip to as low as 2.6m OD. Behind the frontage there are vast areas of the city centre and other areas to the east as far as Victoria Park that are very much lower than the frontage, in some cases up to 2m lower. This low lying basin is occupied by some of the province's most valuable commercial / retail property and residential areas with extremely high density housing.

The flood route mechanism for coastal flooding in the city centre is primarily one of overtopping of the dock quaysides, flowing south and west into Corporation Street and York Street into the commercial areas of the city centre as ground level falls behind the dock area(s). The other flood route into the commercial area is around the Lagan Quay just upstream of Lagan Weir on the left bank of the River Lagan. Flood water routes down Oxford Street, May Street and Cromac Street to fill areas of low elevation in the city centre.

The flood mechanism in the other flood risk areas is local direct overtopping of river banks.

The right bank of the tidal River Lagan is known to have negligible tidal flood risk due to raised ground levels within developed areas such as Titanic Quarter and the application of acceptable development levels for the planning approvals of new developments. This should be confirmed by procurement of detailed Digital Terrain Model (DTM) data and a follow-up study. The flood risk in this area is low at present.

Flood defences at Victoria Park were recently constructed as part of the Connswater Community Greenway Project in East Belfast. These defences remove a flood path through the underpass across the Sydenham Bypass to the residential area beyond. The remaining residential area will be protected from fluvial flooding at high tide by flood walls on the Connswater River which are currently under construction. This area has been excluded from this Belfast Tidal Flood Risk Study for the short-medium term; however, the future / long term flood risk from tidal events will be considered.

2.3. Topography and Levels

2.3.1. Harbour Area & City Centre

A large part of Belfast's commercial city centre is approximately 1m to 2m below the predicted 1 in 200 year (0.5% AEP) still water level of 3.17mOD.

Currently defence of the commercial centre is provided by the raised ground levels at the harbour quaysides; Barnett Dock, Pollock Dock, York Dock and Clarendon Dock. The Belfast Harbour Commissioners Port of Belfast Plan Archive Quay Levels Drawing obtained for this study provides quay levels for the four quays of 5.10m Harbour Datum (H.D), 4.88m H.D, 4.65m H.D and 4.88m H.D respectively. These convert to 3.09m Ordnance Datum (OD), 2.87m OD, 2.64m OD and 2.87m OD. These are all below the current 1 in 200 year (0.5% AEP) predicted tide level.

No specific low spots have been identified from review of the plan drawing; it appears that problems arise from generally low ground levels across the harbour area.

The right bank of the tidal River Lagan has raised ground levels at developed areas such as Titanic Quarter and, therefore, is expected to pose negligible flood risk. However, in the absence of accurate current LiDAR / topographic ground level data for this area this cannot be confirmed in the modelling performed for this study. For the purposes of the assessment of damages and options, the Titanic Quarter area has been excluded. This area should be addressed in later studies used to inform subsequent FRMPs and need for flood management.

The drainage of surface water from the city centre is a gravity network and outfall system. A significant depth of tidal flooding within the city centre is, therefore, likely to drain slowly as the network capacity would be exceeded. This also raises the likelihood of contamination as tidal flooding overwhelms and mixes with the foul sewerage system. Flooding of the city centre may cause major disruption for several days or weeks, with increased clean-up and recovery consequences. This additional long duration flooding combined with sewage contamination is likely to increase the standard damage and disruption costs calculated for flood events in the economic appraisal.

2.3.2. Upstream of Lagan Weir

Sections of river bank upstream of the Lagan Weir (Laganbank (left bank), Ravenhill, Lockview) do not provide the 1 in 200 year (0.5% AEP) SoP and the banks are predicted to overtop in a tidal flood event.

There are also known drainage issues in these areas which will require addressing as part of any flood alleviation works.

2.4. Geotechnical

Desk study research performed for the harbour and city centre areas is provided in **Appendix B** and is summarised below.

Geology Background

The Belfast Harbour and City Centre area experienced sedimentation during the early Palaeozoic and then faulting and folding during the Caledonian orogeny. The Quaternary was mainly dominated by at least two glaciations causing little erosion in the Belfast area but the widespread deposition of two distinct glacial clays.

The retreat of ice in the late glacial period, followed by fluctuating sea levels and isostatic uplift, combined to result in formation of a thin peat bed followed by the deposition of the Estuarine Clay or Sleech during a subsequent period of relative submergence of the city centre area. These deposits infill the much less deeply incised buried channels created by the Lagan and Blackstaff rivers.

Ground Conditions

The published geological maps indicate the surface geology in the harbour area to be Quaternary deposits overlying bedrock, namely:

- Made ground is likely to be encountered as a consequence of the long history of industrial and urban development in the area, particularly associated with development and reclamation of the estuarine margins, backfilling of old excavations, etc.
- Sleech (Estuarine Clays) and peat (Recent) and
- Glacial deposits (Pleistocene), two separate Boulder Clay units (Fluvial Glacial and Glacial Till) separated by the Malone (or 'Middle') Sands.

Underlying the Quaternary drift deposits, the bedrock geology along the route generally comprises:

- Sherwood Sandstone and Mercia Mudstone (Lower Triassic) and
- Upper Permian Marls (Upper Permian).

The estimated stratigraphic thicknesses are presented below; however, as a result of the pre-existing bedrock valleys, various glaciations and post glacial depositional events, the thickness of each soil formation can be expected to be variable often with some geological units being locally absent. The preferential erosion of the Sherwood Sandstone to form the Lagan Valley floor indicates its low strength compared to the under and overlying strata which outcrop to south and north.

Table 2-1 Generalised Strata Thicknesses

Stratum	Typical Thickness of Stratum (m), where found
Made Ground	0.0 - 4.0
Estuarine Alluvium (Sleech)	0.0 - 15.0
Peat	0.0 - 0.9
Sand and Gravel	0.0 - 20.0
Boulder Clays	0.0 - 20.0
Sherwood (Bunter) Sandstone	>100.0
Upper Permian Marls	>10.0
Intrusive Dykes	0.1 - 6.0

Hydrogeology

The main aquifer beneath Belfast comprises the Sherwood Sandstone. The sandstone aquifer is confined by the glacial clays or the alluvium. It may still have sub-artesian pressures which were witnessed in the past (Manning et al, 1970). Manning et al reported that work by Hartley (1935) indicated a minimum of 900m^3/hour should be available from the sandstones. Yield from the sandstone is strongly influenced by the presence of faults, numerous dykes, mainly those trending NW, and marl horizons.

Saline groundwater intrusion into the sandstone is only reported in reclaimed areas, including one at Whitla Street (Manning et al, 1970).

Ground Contamination

Potential contamination may be encountered during flood defence construction works:

- Tars are present at shallow depth near the docks (locally to old gas works site); and
- There were substantial tip sites in the dock area once the area was already developed as well as part of the whole earlier reclamation process.

Particular care must be taken during excavation to avoid cross-contamination between different geological formations and aquifers. This is especially important for the Sherwood Sandstone, the main aquifer in the area. This formation can be in hydraulic continuity with the overburden drift deposits especially where the glacial clays are absent. In such cases the Sherwood Sandstone is particularly vulnerable to contamination.

Unexploded Munitions

Belfast was subjected to aerial bombing raids during World War II. Considerable damage was inflicted over the strategic areas of the harbour and docklands, particularly the Harland and Wolff shipyards, and aircraft factories in the east of the city. Damage was also sustained in other business and residential areas. A UXO risk assessment may need to be undertaken for works in or adjacent to the docks area.

Site Investigation

Given the nature of the Belfast Tidal Flood Risk Study and extent of potential flood alleviation works, it is likely that site investigation will be required for the detailed design and construction stage of the project. This further investigation will be included in the recommendations of this report.

2.5. Environment

A review of the environmental constraints within the flood extent was performed for Stage 1 and is provided in **Appendix C1**.

An environmental scoping exercise was performed in Stage 2 of the study in consultation with the Rivers Agency Conservation Officer. A copy of this is provided in **Appendix C2**.

2.6. Key Infrastructure and Services

The project team is aware of the presence of electricity sub-stations, BT exchanges, tunnels, pumping stations, underground utilities, and major traffic routes within the flood extent and in areas where flood defences may be constructed and has taken these into consideration during option development. Other critical assets such as properties with basements, ambulance stations, schools, listed buildings, protected sites, police stations, and emergency support centres are also found within the flood extent.

An identification and mapping exercise of critical infrastructure and assets was performed across the flood risk area in Stage 2 of the study to inform the subsequent design stages of the project. The susceptibility and vulnerability to flooding of these assets was discussed with the utility providers / asset owners during Stage 2 stakeholder consultation to identify any resilience / individual property protection measures that are currently employed at the assets and to advise the asset owners of the risk to individual assets from the coastal flood. The utility providers are very aware of the need for flood protection to their assets and all appear to have made significant efforts to plan and provide such defences / resilience measures.

The critical infrastructure and asset desk study data for Belfast is provided in Figures 2-3 and 2-4.

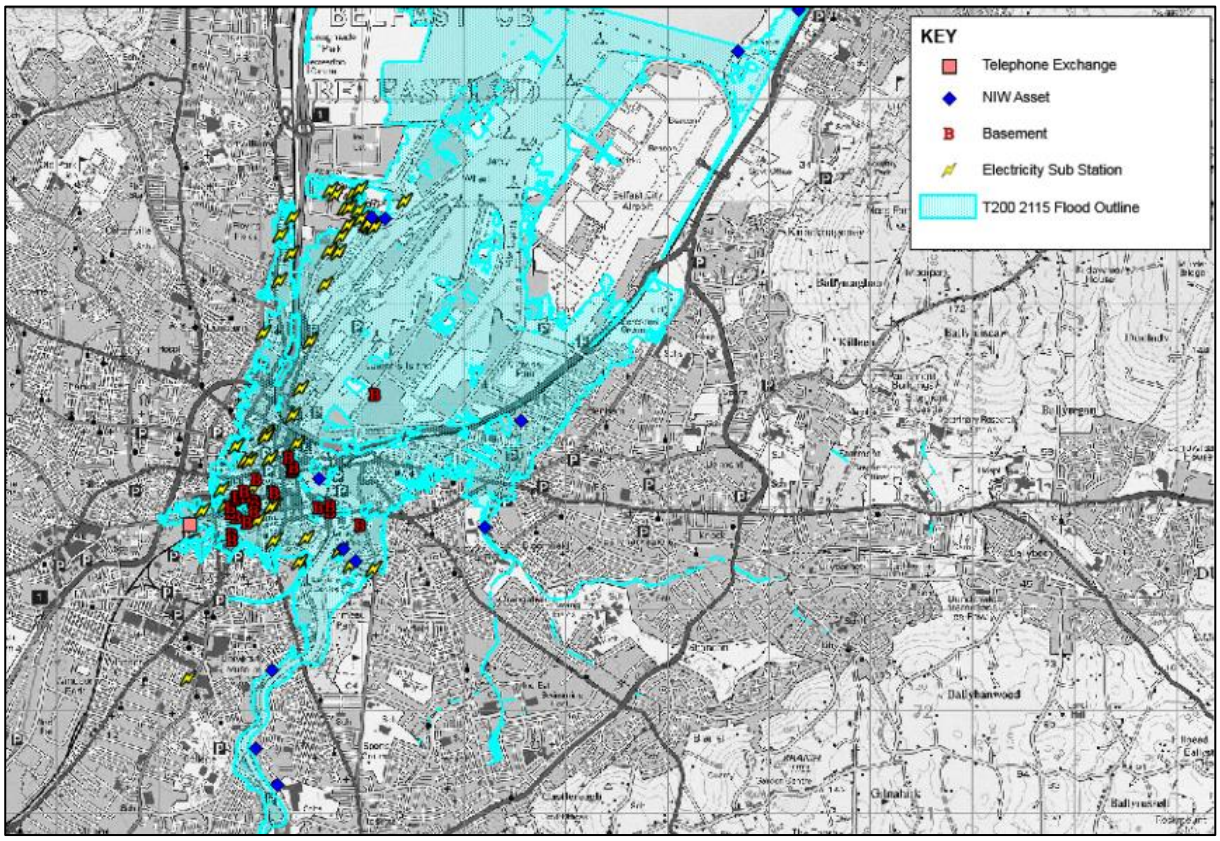

Figure 2-3 Critical Infrastructure Assets within Tidal Flood Outline

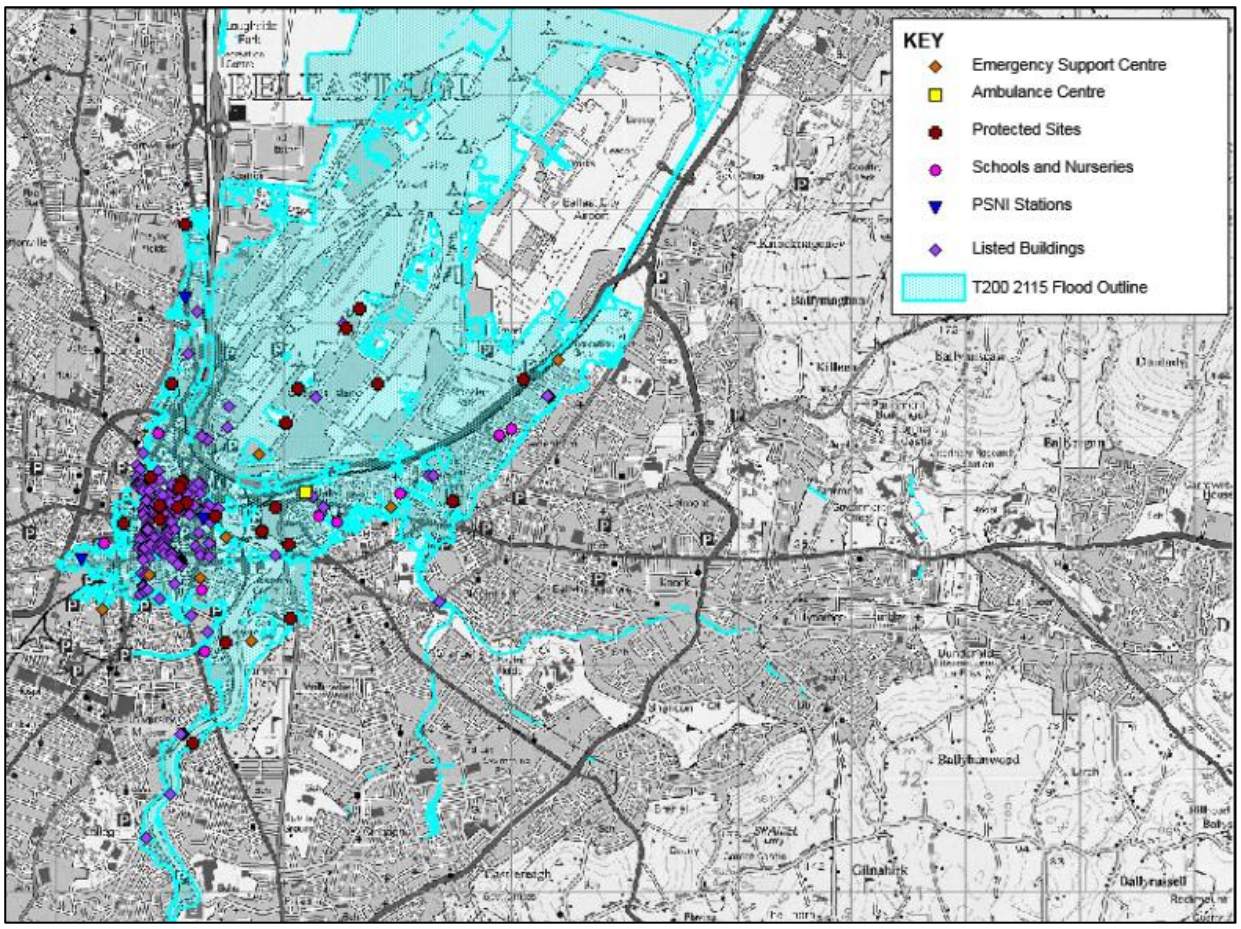

Figure 2-4 Other Critical Assets within Tidal Flood Outline

2.7. Health & Safety Issues

Should a high surge tide be forecast for Belfast then a warning should be issued allowing time for evacuation. However, should no warning be received and an extreme event occur, then the centre of Belfast could quickly be inundated to a significant depth; up to 2m deep. This will result in an immediate risk to life. Evacuation and traffic flow would need to be rapidly managed.

As Belfast relies on a gravity drainage system, then the city centre could take several weeks to be completely drained. This long period of inundation increases the risk of foul contamination, as well as chemical and biological contamination from the contents of shops and warehouses, and all the affected buildings will be thoroughly saturated in such flood waters.

After the city has been drained, there remains the risk to health from damp and contamination which would remain for the duration of the clean-up process and could last up to two years.

During construction of any proposed scheme, consideration needs to be given to the potential for tidal surges and velocity of water inundating the land. Local access and pedestrian management during any construction works are likely to require traffic management plans and liaison with neighbours.

3. Data Collection

One of the fundamental aspects of the overall Feasibility Study was to collect accurate and current data for the flood risk area.

3.1. Review of Existing Data

The following data has been obtained during the course the study for review to determine viable potential short, medium and long term coastal flood defences for Belfast. This data is in addition to the Belfast tidal model and historic flood data provided on Rivers Agency's mapping portal.

Table 3-1 Data Collection

Description	Originators Ref	Rev	Format	Date Received	From
York Street Interchange orthophotography and topo survey data	NA	0	Electronic Files	05/02/2015	URS - Robbie Lough
Belfast transport interchange - Option 12A	NA	0		13/02/2015	Atkins - Sean Foy
Harbour Commissioners est. 847 The Harbour Office A Visual Guide			Document	02/02/2015	Joe Nicholson - RA
River's Agency Newcastle, Newry & Cranfield Extreme Tides Boundary Conditions	IBE0533 R01 CR (RPS)	0	Document	02/02/2015	Joe Nicholson - RA
Undefended Flood Plain Mapping with Climate Change Conclusions & Recommendations	IBE0119_AS_RW02	B	Document	02/02/2015	Joe Nicholson - RA
Framework for Co-ordination of Flooding Emergencies	Final - Sept 2014		Document	02/02/2015	Joe Nicholson - RA
HP TRIM DARD Container: DA2-14-18665: Flood Defence & Drainage			Document	02/02/2015	Joe Nicholson - RA
Predicted High Tides in 2014 and 2015	RA Briefing Note		Document	02/02/2015	Joe Nicholson - RA
National Flood Map for Northern Ireland - Methodology Report (Draft)	5790.00/AS/RW03	C	Document	02/02/2015	Joe Nicholson - RA
NI Tidal Surges 2014 Multi-agency Structured debrief report - PSNI		1	Document	02/02/2015	Joe Nicholson - RA
York Street Interchange - Discussion Paper (Draft)			Document	02/02/2015	Joe Nicholson - RA
Strategic Planning Unit Settlement flood Risk - Referral Form - Belfast Tidal Hazard			Document	02/02/2015	Joe Nicholson - RA
Port of Belfast Plan, Archive Quay Levels dated 27/05/2011	B1578		Drawing	16/02/2015	J Nicholson RA
Belfast Harbour Benchmark Plan 2011 (Draft)			Drawing	16/02/2015	J Nicholson RA
Building Polygons, Pointer & LidAR data			GIS Files	02/04/2015	M Calvert

3.1.1. GIS and Mapping Data

Rivers Agency holds a range of asset management and mapping data that was critical to the development of this project. This data included:

- Ordnance Survey mapping.
- LiDAR / DTM data.
- Designated Watercourses GIS Files.
- Building Polygon datasets.
- Utility provider records.

3.1.2. Points of Note from Data Review

Issues identified from the review of the above data of note to the study are:

- The presence of ongoing construction works on the Connswater River for the Connswater Community Greenway Project / East Belfast Flood Alleviation Scheme,
- The initial public consultation on the York Street Interchange Proposals ongoing at the time of the study,
- The variety of quay wall levels at the various docks in the harbour area,
- The frequency of high tide surges over the last 20 years, and
- The need to consider events up to the 2115 year epoch to cover the full length of the economic appraisal.

3.2. Site Inspections

Three site inspections were performed for the project:

1. Initial walkover survey, 25th February 2015, entire project team present.
2. Options Walkover, 27th April 2015, PM and Technical Lead present.
3. Site Inspection by Boat, 1st June 2015, PM, Graduate Engineer and Client representatives present.

3.2.1. Walkover Survey

The project team carried out a survey and inspection of the site identifying existing buildings, services, site and access constraints, general topography (i.e. low lying floodplain), general land use, and the presence of any structures, river channel / culvert features etc. relevant to the study. A copy of the walkover meeting notes is provided in **Appendix D1**.

Key points of note from Walkover Survey

We noted site characteristics that may impact on proposed works or which may affect the engineering options for the project. Of general note are:

- Multiple road crossings in the harbour area which would limit construction of continuous permanent flood defence structures.
- General low topography across the harbour area – overtopping likely to occur at numerous locations during a flood event.
- No specific low spots were identified, therefore, no ‘easy win’ solutions.
- Vulnerable industries in the harbour area such as grain stores and paper storage.
- Initial review suggests upgrading the Lagan Weir to provide a tidal defence is unlikely or prohibitively expensive.
- A tidal barrier downstream at the dock ‘entrance’ would be approximately 350-400m span. This is unlikely to be viable and may interfere with dock functions.
- The north-east end of the dock arms are active docks, it is unlikely that improved tidal flood defence would be desired for much of these industrial storage type land use areas, beyond the current natural ground levels. Preference would be to leave these areas as they are and inform operators of their flood risk level to develop their own mitigation plans as deemed appropriate.
- The major constraint to preventing water entering commercial centre is the considerable length of dock / quayside which could overtop and route into the city centre. Approx. 1.5-2km long quayside, depending on levels and viable ‘improve’ route that could be taken.
- Existing land use on any defence route will be made ground. This should have a low risk potential for contaminants or archaeology given the past disturbance and likely shallow foundation requirement.

3.2.2. Options Walkover

The PM and Technical Lead carried out a survey and inspection of the various flood risk areas identifying access constraints, general topography, defence tie-in points and any structures / features which need to be

accommodated within any proposed options. A copy of the options walkover survey notes is provided in **Appendix D2**.

Key points from Options Walkover

The following constraints have been identified in the key flood risk areas during the walkover survey:

- Belfast Harbour & City
  - Access to the quays for boats docking is necessary so removable (sections of) defences or local access gates would be required – this requires further liaison with Belfast Harbour Commissioners (BHC).
  - Landscaping and aesthetic connectivity to the river must be in keeping with current and proposed development / land use of the area.
  - Low walls would need to have an additional non-structural upstand / fencing or railing to prevent trip hazards.
  - Dock gates would require detailed assessment for potential to increase flood protection – modelling of impact of leaving gaps in the defence would be required to determine risk.
  - Significant quay infrastructure and utilities to consider for construction / surveys.
  - Redevelopment proposals for City Quays and need to consult with BHC to ensure the proposed buildings have an adequate SoP for the future.
  - Existing cantilever structure at the El Divino public house needs to be considered in solution and tie-ins to any option along quay included.
  - Laganbank Road – significant office buildings and residential area – construction issue for site traffic and pedestrian management.
- Ravenhill
  - Limited access to landward side of quay wall in some locations.
  - Unknown condition of existing river wall and ability to use as a foundation of further flood defence works.
  - Several buildings form part of the river wall and, as such, would require resilience measures or more complex tanking etc. to act as flood defences.
- Ormeau Embankment
  - The tow path is a vital pedestrian link between the city centre and the Ormeau area – pedestrian management and maintaining access as far as possible should be considered for construction of any option.
  - Any flood wall option would need to incorporate access points to connect the tow path to the wider area, such as flood gates or other localised measure, to complete flood defence.
  - Congested narrow residential terrace streets may restrict access for construction vehicles.
- Lockview, Stranmillis
  - Access to the river for boats to and from boat houses is required.
  - Landscaping and views of the river are important from an aesthetic viewpoint.
  - Low walls would need to have an additional non-structural upstand / fencing or railing to prevent trip hazards.
  - Significant vegetation and mature trees limits access and route for potential flood defences. It is likely that some mature trees would have to be removed to facilitate construction on the tow path.
  - Liaison with Belfast Boat Club and tenants would be required to determine desire for flood protection in this area or if resilience and PLP is preferred.

3.2.3. Site Inspection by Boat

Members of the project team accompanied by the Rivers Agency Regional and Area Engineers carried out a survey and inspection of the various flood risk areas by boat to inspect the river bank frontage. A copy of the boat survey notes is provided in **Appendix D3**.

Key points from Site Inspection by boat

The following issues were raised during the boat inspection:

- Belfast Harbour & City
  - Cantilever section at El Divino public house at Laganbank requires further detailed consideration in terms of tying in protection.
  - Likely that demountable flood defences would be most appropriate at Laganbank left bank given the relatively short length of defence required and the cost of permanent works may not be justifiable in this flood cell. This is to be tested in the economic appraisal.
- Ravenhill
  - The existing river wall from No. 17 – No. 43 Ravenhill Road is of questionable condition and will be assumed unsuitable for an extension flood wall constructed on top of the existing. Construction of a

new river / quay wall is unlikely to be economically / environmentally viable so a stepped back defence may be appropriate.
  - The existing basin on the left bank at the rear of Central Station is planned for infilling for further development so any flood risk caused by this feature should be removed when the infilling is performed and the tow path is unbroken.
- Ormeau Embankment
  - A large number of unflapped outfalls were identified during the inspection and it was agreed that back flow of water behind flood defences was a significant risk to the project and should be considered in any options.
  - Tracing / CCTV surveys may be required along the watercourse to determine the outfalls which pose greatest risk to flows bypassing flood defences.
- Lockview, Stranmillis
  - A historic surface water flooding problem exists at Lockview which is not related to high tide events. Water is susceptible to ponding at Cutters Wharf with water trapped between the speed humps and unable to drain away.

3.3. Topographical Survey Data

The primary objective of the topographic surveys is to:

- Acquire property level data for use in the economic appraisal assessments of property damage and to identify the flood extent, and
- Collect quay / bank level data along the River Lagan and within the Belfast Harbour Estate to verify the data in the hydraulic model for “spill” points of tidal flooding.

3.3.1. Floodplain / Property Threshold Survey Data

The results of initial hydraulic model simulations were used to identify the key flood risk areas in Belfast. This permitted the targeting of the floodplain survey in the key areas of flood risk. The survey obtained property floor level data to permit the economic assessment of flood damages. 1147 properties were selected for survey from the circa 14,000 properties within the most extreme flood envelope. Among these 1147, the top 100 damage properties from the first sift damages calculations were included.

The property threshold surveys were performed by iO Geomatics in June / July 2015.

The record of threshold levels surveyed for the study area is provided in **Appendix E1.** LiDAR data was used in all non-surveyed properties for the damage assessments.

3.3.2. Defence Level Survey Data

A linear survey was performed along the harbour dock walls at Pollock and York Docks and Albert Quay. Further surveys were performed at Lockview, Ravenhill, Ormeau and Laganbank.

Spot heights were taken every 25m along the survey lengths and any changes in elevation or feature were recorded. The survey results were provided as AutoCAD drawings.

The topographic survey results are provided in **Appendix E2**.

4. Consultation / Stakeholder Engagement

4.1. Stakeholders

A stakeholder list was compiled by Rivers Agency in the tender documents to engage all parties with the project, including statutory bodies, utility providers and business / landowners who could be affected by flooding and / or any flood alleviation works. The list was supplemented by specific contacts made during the study. The list of stakeholders is presented in **Appendix F1.**

4.2. Key Stakeholder Consultation

4.2.1. Key Stakeholder Workshops

Following the completion of the critical infrastructure desktop review and site inspections, meetings with key stakeholders were performed in a series of stakeholder workshops. These workshops were held on 10th and 17th June 2015.

The key stakeholders present at the workshops were:

- Rivers Agency (Strategic Planning, Area & Regional Engineers)
- Belfast Harbour Commissioners (BHC),
- Belfast City Council (Emergency Planning, Connswater Community Greenway liaison),
- Belfast Chamber of Commerce,
- Belfast City Centre Management,
- NIEA Marine Division,
- NI Water,
- NIE,
- Transport NI, and
- Phoenix Gas.

At the workshops the flood risk to the greater Belfast area was presented. The risk to assets, resilience, individual property protection measures and proposals for short, medium and long term flood alleviation options were discussed with the key stakeholders. Comments obtained from the key stakeholders were captured in the communications record; this is provided in **Appendix F2**. The presentations given and flyer issued prior to the workshops are provided in **Appendix F3**.

4.2.2. Key Stakeholder Correspondence

Consultation by letter / email was performed for any consultees not present / available for the stakeholder workshops. The consultation was to the following additional stakeholders:

- Lagan Weir / DSD River Management,
- Department of Justice,
- DRD Roads Service,
- BT,
- NIEA (Built Heritage, Natural Heritage, WMU, Conservation Designation & Protection, Marine Division, Protecting Landscapes),
- RSPB,
- DCAL,
- AFBI NI,
- Belfast Community Planning,
- NIW Environmental Manager,
- DARD Sea Fisheries, and
- Ulster Wildlife.

Any responses received from these consultees is included in the communications record in **Appendix F2**.

4.2.3. DFP Policy & Economics Department Meeting

In addition to the key stakeholder consultation, a meeting between the Project Team and DFP Policy and Economics Department was held on 12th March 2015. The purpose of this meeting was to define the strategic direction of the economic appraisal for the study and agree the approach to dealing with new methodologies required to complete the appraisal. The background to the study and key issues were also discussed.

The outcomes of the meeting were:

- Design life of 100 years is appropriate.
- Design of flood defences to protect city centre to 2115 epoch is appropriate.
- Standard NI Guide to Expenditure Appraisal and Evaluation (NIGEAE) approach to appraisal to determine cost benefit ratios, then if necessary look at Defra approaches such as Outcome Measures to justify the relative levels of Department and potential stakeholder benefits.
- The economic boundary for the study is Northern Ireland, not the wider UK.
- No requirement for particular benefit cost ratio to justify expenditure beyond 1 to 1. Issue of funding the scheme may be a separate issue and might need to be approached once the first benefit cost analysis of preferred options is completed. May require stakeholders to contribute as in English model.
- Project team are to develop papers on any new proposed methodology for information.
- Detailed economic site surveys may be performed for the properties attributing greater than 10% of the total damages to ensure the full extent of the damages is understood and included within the appraisal.

4.3. Summary of Issues Raised by Key Stakeholders

A short summary of some of the items raised by the Key Stakeholders is provided below:

1. Lagan Weir & 5m of banks downstream of the weir will transfer from DSD to Belfast City Council ownership and management in April 2016.
2. BT and NIE have flood emergency plans and equipment in place for a flood event in the city centre. They have been focusing on flood resilience over the last couple of years.
3. Any works in the River Lagan channel would require an EIA / ES and Marine Licence from NIEA.
4. BHC have significant development proposals in City Quays and our proposals need to be sympathetic to the landscaping and limited interaction with the operational areas of the harbour.
5. BHC have their own flood plan and protection measures in place around their site and do not desire flood defences within their operational areas.
6. DSD River Management team operate the Lagan Weir as a tidal barrier on an ad-hoc basis as required in conjunction with Rivers Agency staff at Stranmillis Weir. The operation is not defined within the operating manual and is performed based on operator experience.

5. Hydraulic Assessment

5.1. Hydraulic Model

Flood modelling and analysis was undertaken to inform site and option assessment and is summarised below.

In 2010, Rivers Agency commissioned Aecom to carry out the first stage of the modelling strategy to inform the Belfast FRMP. The impact of tidal inundation along the Belfast frontage from tidal surge events occurring in Belfast Lough was of particular importance to this study. A linked 1D-2D hydraulic model was developed in Infoworks-RS covering the River Lagan from Stranmillis Weir to Lagan Weir and the River Connswater (incorporating the Knock and Loop watercourses). In 2012, this model was updated to include more detailed bank top survey along the River Lagan. In each of the commissions the tidal events were modelled with a baseflow from the fluvial watercourses.

In 2014, JBA were commissioned by Rivers Agency to convert the existing Infoworks-RS model to an Infoworks-ICM model to allow it to be used efficiently internally on their GPU modelling platform. As part of this conversion the existing model schematisation was retained with the exception of the River Lagan and Belfast Lough downstream of Lagan Weir; previously this area was included in the 2D mesh; however, to improve model stability and run times this area was converted to be included in the 1D “in channel” model.

At the inception of the Belfast Tidal Flood Risk Study, it was the intention that this revised model would be used as the base / existing scenario for any options modelling carried out for the study; however, following the site walkover several changes were agreed with Rivers Agency:

- The East Belfast Flood Alleviation Scheme, though not yet fully constructed, would be included in the model.
- Additional information on quay wall heights obtained from the topographic survey would be included in the model.
- The climate change scenarios 2065 and 2115 would be modelled to inform the full time period considered in the economic appraisal.

These changes were made to the model and the revised flood mapping output was used as the base / existing scenario in the assessment.

5.1.1. Model Simulations

Model simulations performed for the assessment of flood risk and review of options included:

Table 5-1 Model Simulations

Model Epoch / Return Period Event	2	10	50	75	100	200	1000	Comment / Purpose
Current Day (2015)	Y	Y	Y	Y	Y	Y	Y	To determine existing flood envelope
2065	Y	Y	Y	Y	Y	Y	Y	Intermediate epoch for economic appraisal and design levels for options
2115	Y	Y	Y	Y	Y	Y	Y	End epoch for economic appraisal

The flooded areas were established using the outputs of the existing hydraulic model and LiDAR data existing in the study area.

It should be noted that the base scenario for the tidal flood mapping in Belfast ignores the Lagan Weir; this prevents interaction with fluvial flows in the River Lagan in terms of flood risk. In reality, the weir can be used ad-hoc as a tidal defence; however, simulating the operation of the weir for the current tidal events increases flood risk predictions in the model due to the increased fluvial storage required upstream of the weir in a tidal event. The model simulation does not take account of drawing down levels in the River Lagan in advance of a tidal event which is what is done in practice to provide greater storage in the impoundment.

5.1.2. Tide Levels

Table 5-2 summarises the maximum tide levels for the range of return periods considered in this study and for the different epochs.

Table 5-2 Maximum Tide Levels for Range of Return Periods

	Present day	2065	2115
Return period (year)	**Max Tide Level (mAOD)**	**Max Tide Level (mAOD)**	**Max Tide Level (mAOD)**
2	2.24	2.52	2.88
10	2.50	2.78	3.14
50	2.93	3.21	3.58
75	3.02	3.30	3.66
100	3.07	3.35	3.71
200	**3.17**	**3.46**	**3.82**
1000	3.30	3.58	3.94

5.1.3. Design Events

The design levels used in the study to assess flood alleviation options were based on the life of the defence type being proposed and, in any case, were no greater than the 1 in 200 year (0.5% AEP) tide level in 2065. To design now for sea level rise beyond 2065 would be unwise given the range of predictions available and the potential for the refinement of the amount of sea level rise in the future. For the purposes of the assessment, it was assumed that any hard engineering defence installed in the short-medium term would be designed to provide the 2065 1 in 200 year (0.5% AEP) SoP.

There is inherent level of uncertainty in flood risk levels, and traditionally a 'freeboard' has been included for the construction of all new defences. This is to allow for the uncertainty in:

- settlement,
- construction tolerance,
- accuracy of forecast extreme water level data,
- wave overtopping,
- boat wash, and
- Defence structural integrity.

It was assumed for the purposes of the options assessment that 100mm freeboard allowance would be added to the tide levels. Climate change uncertainty is considered separately.

Table 5-3 Design Events

1 in 200 year (0.5% AEP)	Tide Level (mAOD)	Comment
Present Day Tide Level (2015)	3.17	Used to assess SoP of existing quays and river banks along River Lagan.
Medium Term Design Level (2065)	3.46	General design level for all flood alleviation works in the short – medium term. Assumes a 50 year design life for defences.
Long Term Design Level (2115)	3.82	Used to assess the need for further flood alleviation works post 2065 and residual damages generated post 2065 if no further works performed.

5.1.4. Current Riverside Levels

An assessment was performed on the surveyed lengths of river bank to determine the height of local bank levels (quayside levels) above ground level

Table 5-4 Bank Levels versus Current & 2065 1 in 200 year (0.5% AEP) Levels

Flood Cell	Location	Approx. Existing Average Bank Levels – Surveyed Lengths	Average Defence Height Increase Required (mm)	
		mOD	Current (3.17mOD)	2065 (3.46mOD)
Harbour / Titanic Quarter	Pollock Dock	2.97	195	485
	Albert Quay	2.69	478	768
	Titanic Quarter – Abercorn Basin to Titanic Slipway	2.94	230	507
	York Dock	2.59	579	869
City Centre	Laganbank	2.68	494	784
Ravenhill		2.89	284	558
Ormeau		2.84	325	615
Lockview, Stranmillis		2.51	660	950

5.2. Model Results

The major tidal flooding mechanism to Belfast City Centre is from overtopping of the quay walls with water flowing south through industrial and commercial areas adjacent to Corporation Street towards the commercial centre of Belfast. Other discrete points along the banks of the River Lagan are also breached in some tidal events and flood properties adjacent to the river banks.

Figure 5-1 illustrates the flood risk from the 1 in 10 year (10% AEP) to 1 in 200 year (0.5% AEP) tidal events, showing the likely areas of inundation in these events for the greater Belfast City Centre area.

Figure 5-2 illustrates the extent of the 1 in 200 year (0.5% AEP) tidal flood events for the 2065 and 2115 epochs for the greater Belfast City Centre area.

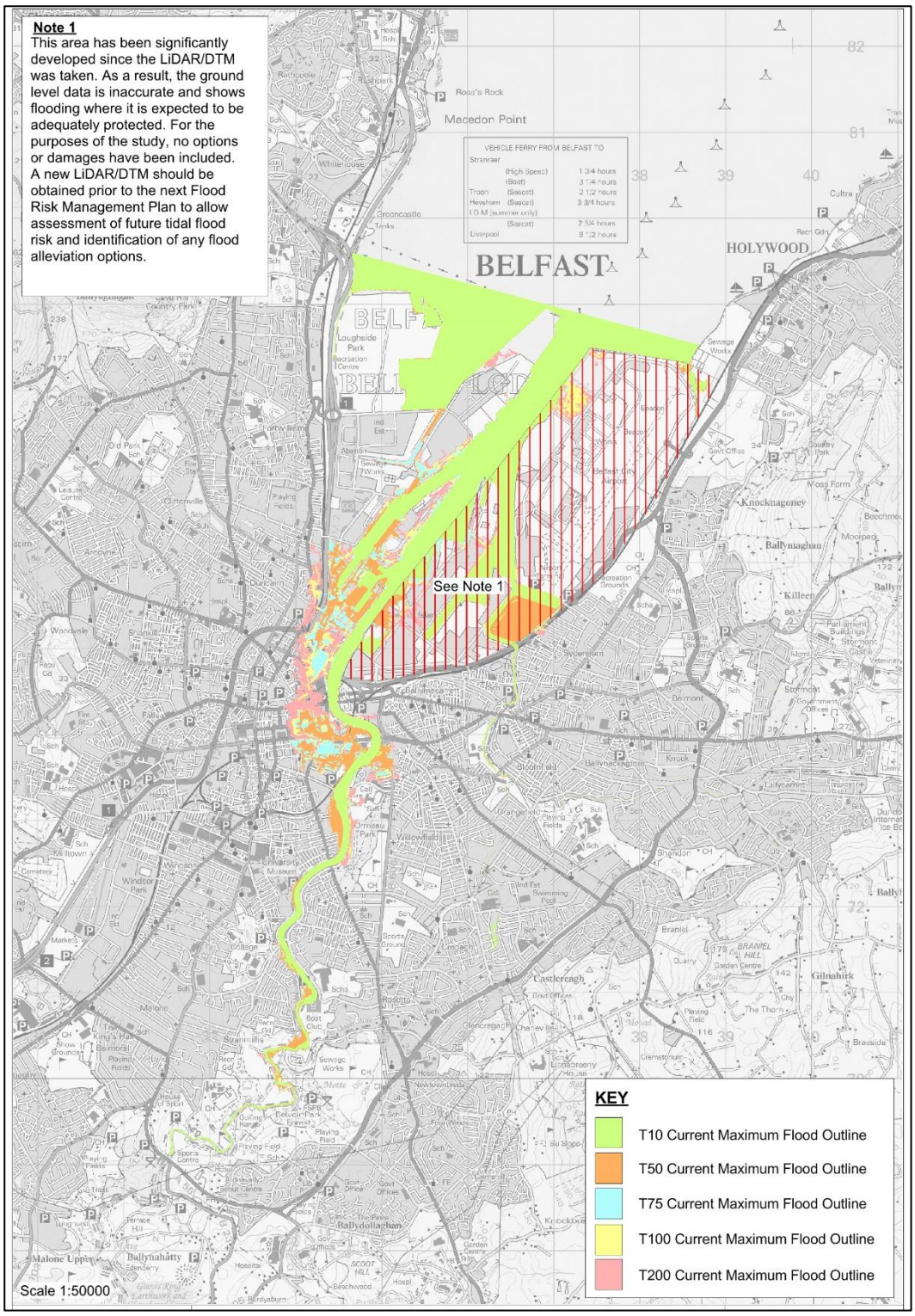

Figure 5-1 Base Flood Outlines Map

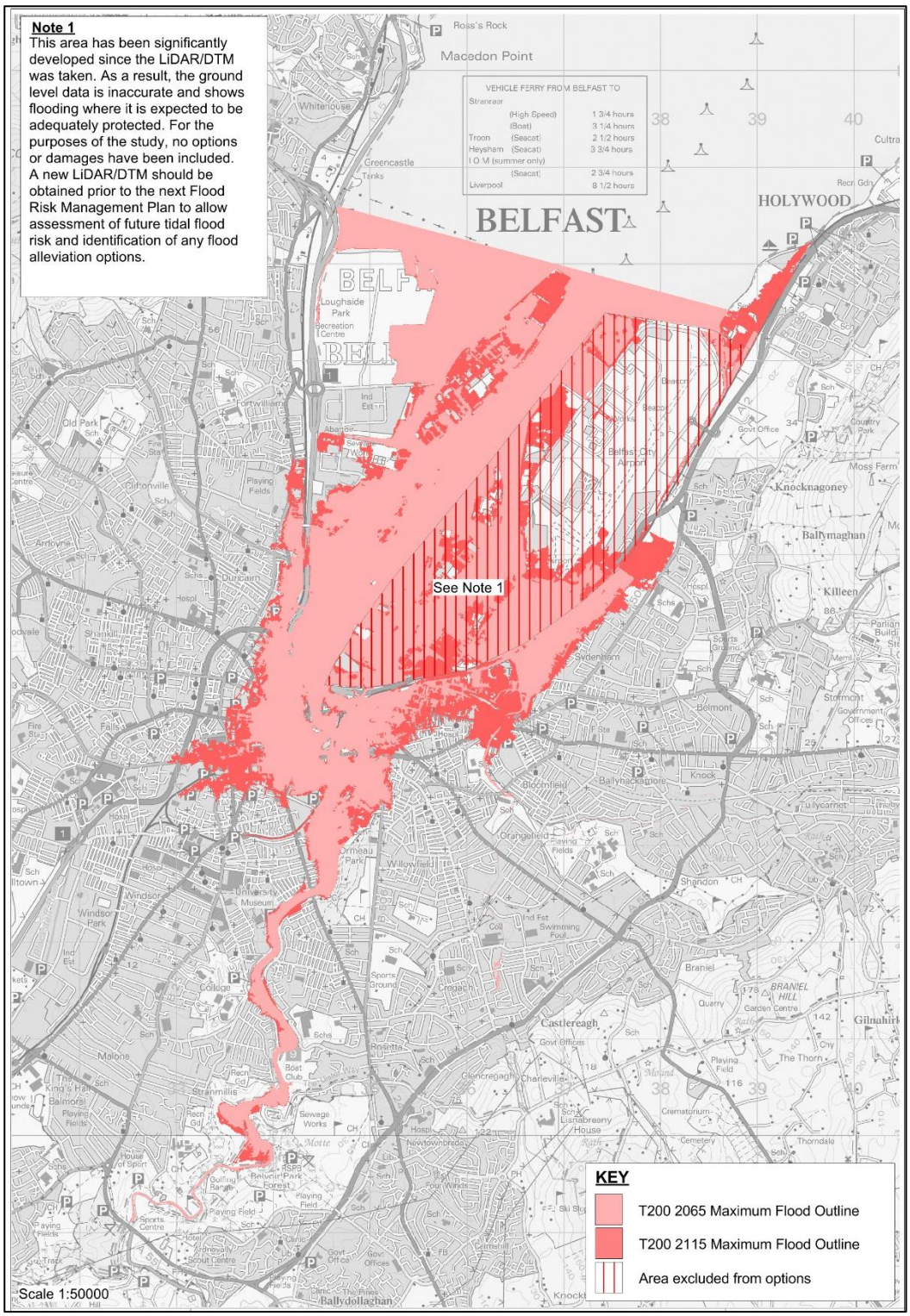

Figure 5-2 2065 & 2115 1 in 200 year (0.5% AEP) Flood Extents

5.3. Flood Cells

The reaches of the River Lagan identified with current and future tidal flood risk from the modelling assessment were divided into flood cells for the purposes of the assessment of flood alleviation options.

The flood cells are listed below and shown in Figure 5-3.

- Flood Cell 1 - Belfast Harbour & City (left bank, including Lagan bank)
- Flood Cell 2 - Titanic Quarter (right bank, downstream of the Lagan Weir)
- Flood Cell 3 - Sydenham / East Belfast (right bank)
- Flood Cell 4 – Ravenhill (right bank)
- Flood Cell 5 - Ormeau Embankment (left bank)
- Flood Cell 6 - Lockview, Stranmillis (left bank)

The flood cells allow the separation of potential flood alleviation works required in each flood risk area and for the undertaking of separate economic appraisals in each cell. This ensures that the justification for investment in any one cell is demonstrated to stand on its own merit and not use the potentially significant flood damages from other cells. This is particularly important for Belfast where Flood Cell 1 – Belfast Harbour & City includes significantly more properties at risk than the other cells combined. However, this being stated, a strategic option which delivers benefit to a number or all of the cells also needs to be considered by combining respective cells.

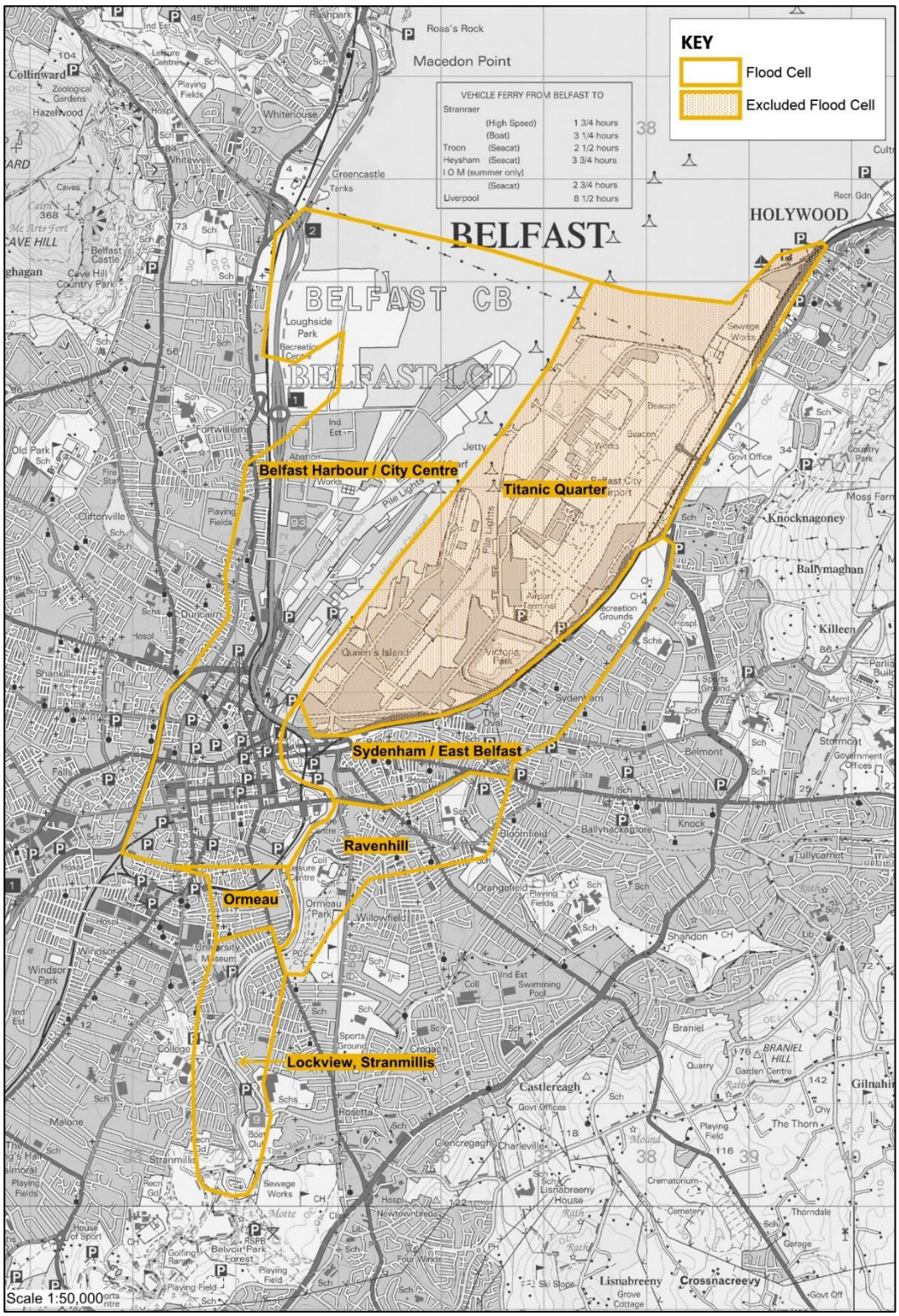

Figure 5-3 Belfast Tidal Flood Cells

5.3.1. Flood Cell 1 - Belfast Harbour & City

A large part of Belfast's commercial city centre is approximately 1m to 2m below the predicted 1 in 200 year (0.5% AEP) still water level of 3.17mOD.

The principal flood mechanism of the commercial centre is via the harbour quaysides; Barnett Dock, Pollock Dock, York Dock and Clarendon Dock. The Belfast Harbour Commissioners (BHC) Port of Belfast Plan Archive Quay Levels Drawing, obtained for this study, provides quay levels for the four quays of 3.09m Ordnance Datum (OD), 2.87m OD, 2.64m OD and 2.87m OD. These are all below the current 1 in 200 year (0.5% AEP) predicted tide level. No specific low spots have been identified from review of the plan drawing; it appears that problems arise from general low ground levels across the harbour area.

Another spill point causing flooding to the city commercial area is at Laganbank; left bank upstream of the Lagan Weir. This quay, adjacent to the Waterfront Hall, is below the current 1 in 200 year (0.5% AEP) level.

The drainage of surface water from the city centre is a gravity network and outfall system. Any tidal flooding within the city centre is, therefore, likely to drain slowly as the drainage network capacity would be overwhelmed. This also raises the likelihood of foul sewage contamination as tidal flooding penetrates and mixes with the foul sewerage network. Flooding of the city centre is likely to cause major disruption for several days or weeks, with increased clean-up and recovery consequences.

Figures 5-4 and 5-5 present the detailed flood extents for the current and climate change epochs for Flood Cell 1.

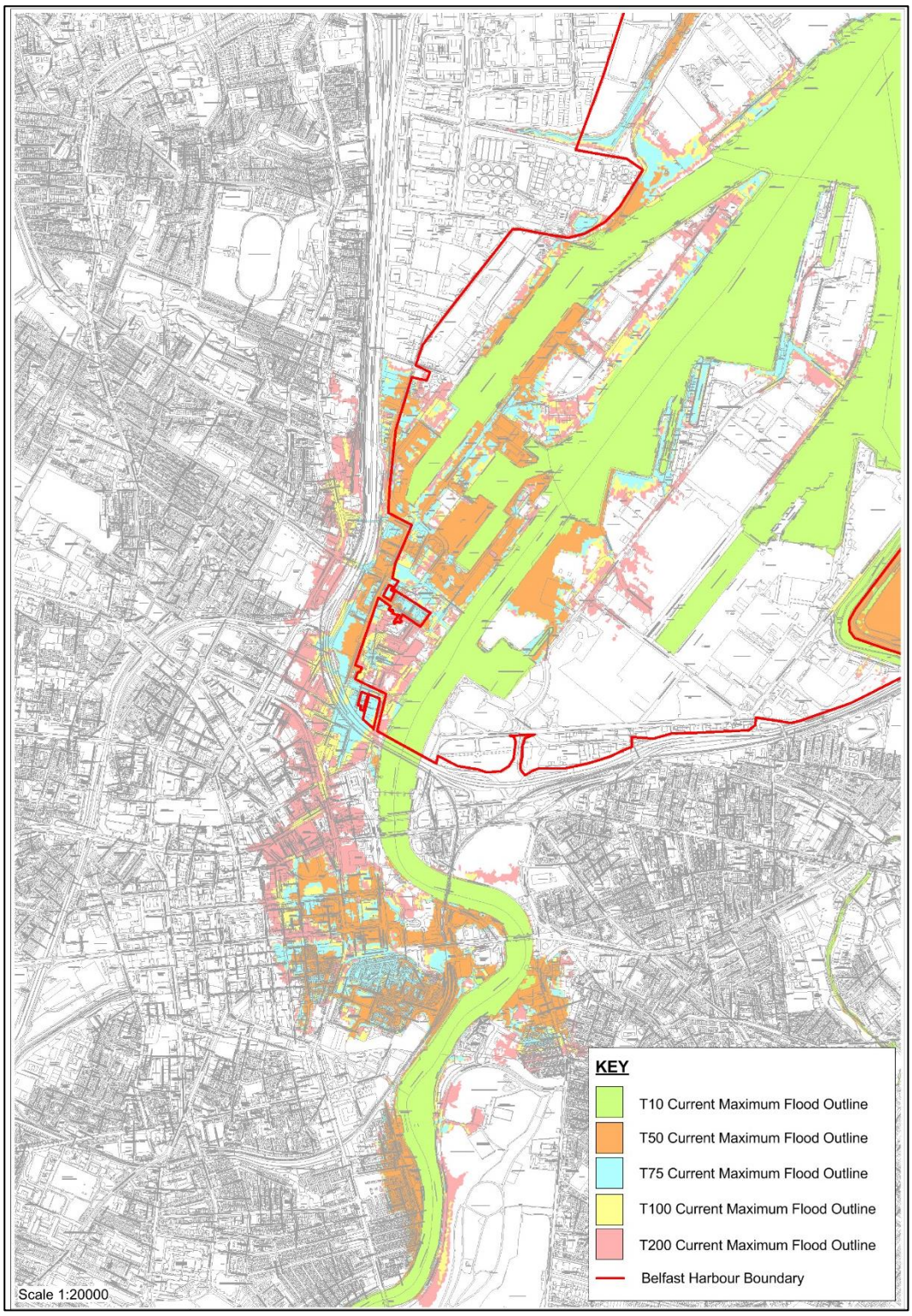

Figure 5-4 Base Map – Belfast Harbour & City

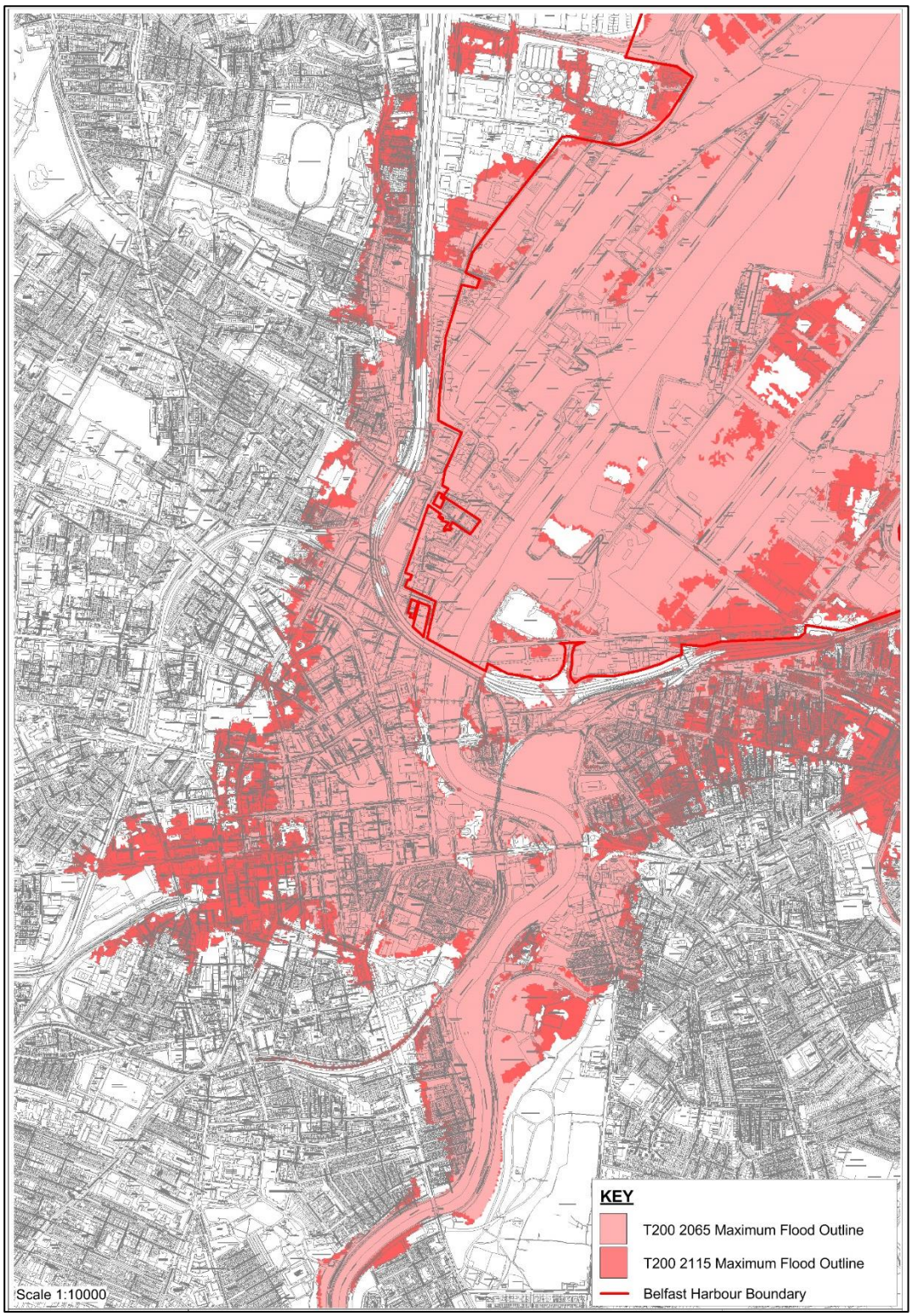

Figure 5-5 Climate Change Map – Belfast Harbour & City

5.3.2. Flood Cell 2 - Titanic Quarter

The flood extent within Titanic Quarter is predicted on LiDAR data obtained from Rivers Agency which is several years old and may not accurately capture the current ground levels across the area.

The Titanic Quarter area is known to have been infilled during redevelopment, therefore, the flood extents predicted from the modelling exercise may be overestimated. The Strategic FRA completed for the Titanic Quarter identified a development level of circa 3.6mOD plus 600mm freeboard which accounts for future sea level rise. This is the level to which future developers will be advised by Rivers Agency for redevelopment.

New DTM data is required for Titanic Quarter to accurately map the flood extent and determine the flood risk in the future. This should be obtained for any subsequent study to inform updates to the FRMP for Belfast. For the purposes of this study, we have excluded the Titanic Quarter flood cell from the economic appraisal and optioneering assessment. The flood risk in this area is low at present; however, some risk remains to the older properties along the river banks.

5.3.3. Flood Cell 3 – Sydenham / East Belfast

The Sydenham / East Belfast flood cell covers the right bank of the River Lagan from Lagan Weir to Albert Bridge and extends as far as the City Airport on the Sydenham Bypass. The right bank of the River Lagan in this flood cell provides the current 1 in 200 year (0.5% AEP) SoP, therefore, no options were assessed for this area in the short-medium term.

The Connswater River is currently protected / being protected from fluvial and tidal flood risk by the construction of the Connswater Greenway Project / East Belfast Flood Alleviation Scheme. This scheme has been added to the tidal model and is shown to provide the 1 in 200 year (0.5% AEP) SoP.

Future sea level rise in 2065 and 2115 epochs have predicted flooding of East Belfast largely arising from overtopping the right bank of the River Lagan (opposite Laganbank) and along the Sydenham Bypass. The right bank at the Howden Sirocco development site is predicted to overtop in a 1 in 200 year (0.5% AEP) event in 2065. The development site has a high brick boundary wall which should provide adequate flood protection in the future, subject to its condition. Low sections of the wall and some new flood defences upstream would be required in the long term; assuming the integrity of the existing wall and the designation of the wall as a defence to prevent its removal. The rail track boundary wall along the bypass is also likely to act as an ad-hoc flood defence in this situation; however, works would be required to provide a continuous defence for future flood protection.

Figures 5-6 and 5-7 present the detailed flood extents for the current and climate change epochs respectively for Flood Cell 3.

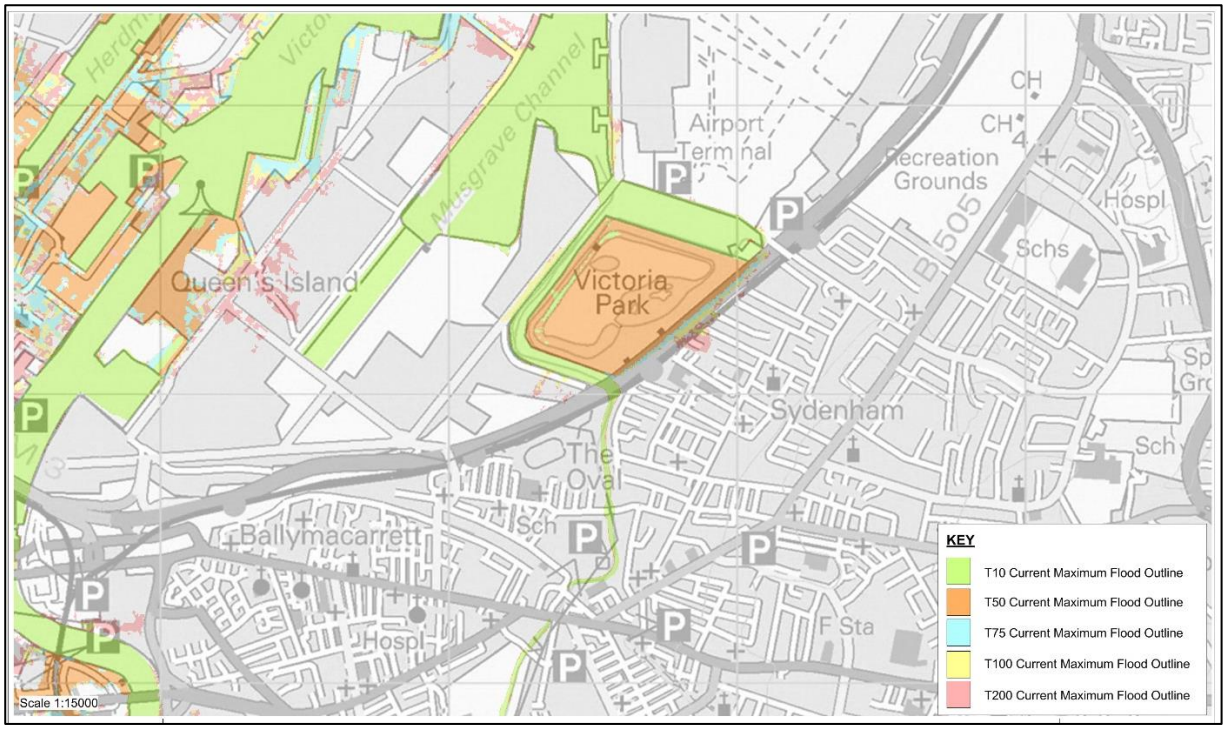

Figure 5-6 Base Map – Sydenham / East Belfast

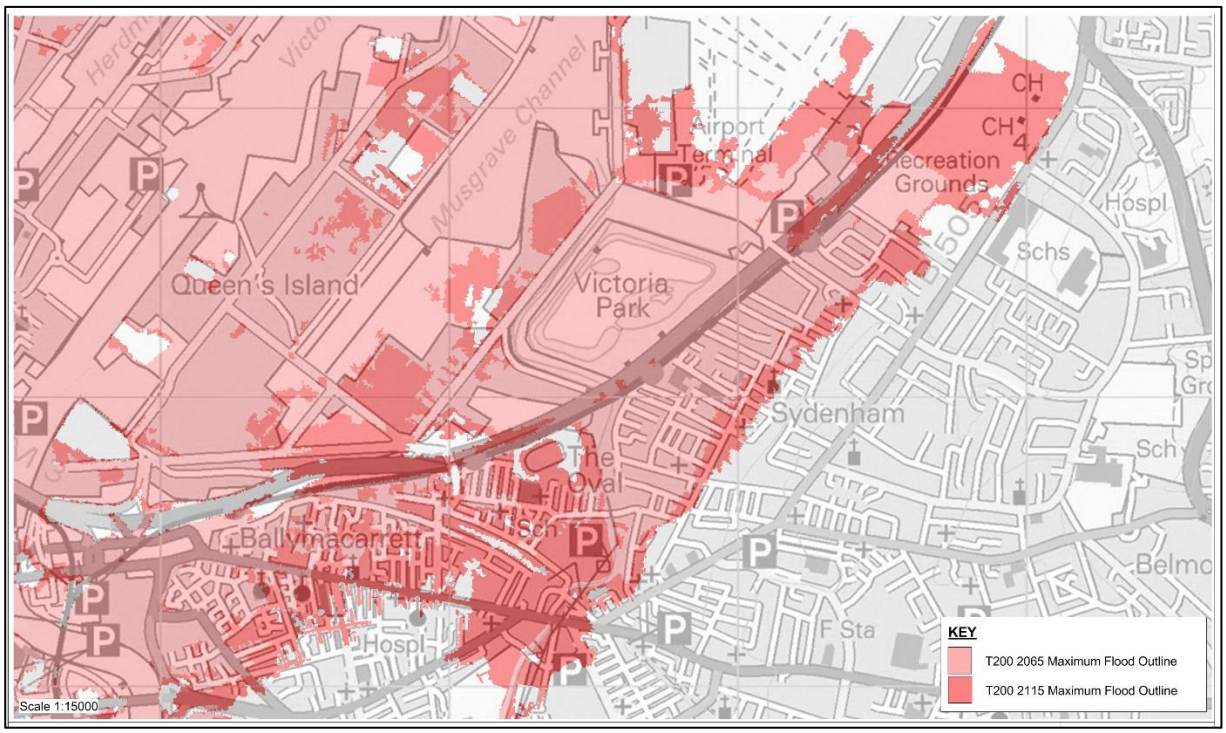

Figure 5-7 Climate Change Map – Sydenham / East Belfast

5.3.4. Flood Cell 4 - Ravenhill

Flood Cell 4 includes the Ravenhill area and the right bank of the Ormeau Embankment. This cell is currently predicted to be at risk of direct overtopping from the tidal river over the riverside walls for a 1 in 10 year AEP event and affects commercial, industrial and residential properties. The majority of the frontage comprises a mixture of buildings and river walls, including some in relatively poor condition. Figures 5-8 and 5-9 present the detailed flood extents for the current and climate change epochs respectively for Flood Cell 4.

The existing right bank of the Ormeau embankment provides the 1 in 200 year (0.5% AEP) SoP. In the future epochs, the right bank is overtopped, no additional properties are flooded; however, the road and lands in Ormeau Park are flooded. The flooding of the right bank of the Ormeau Embankment is presented in Figures 5-10 and 5-11 respectively.

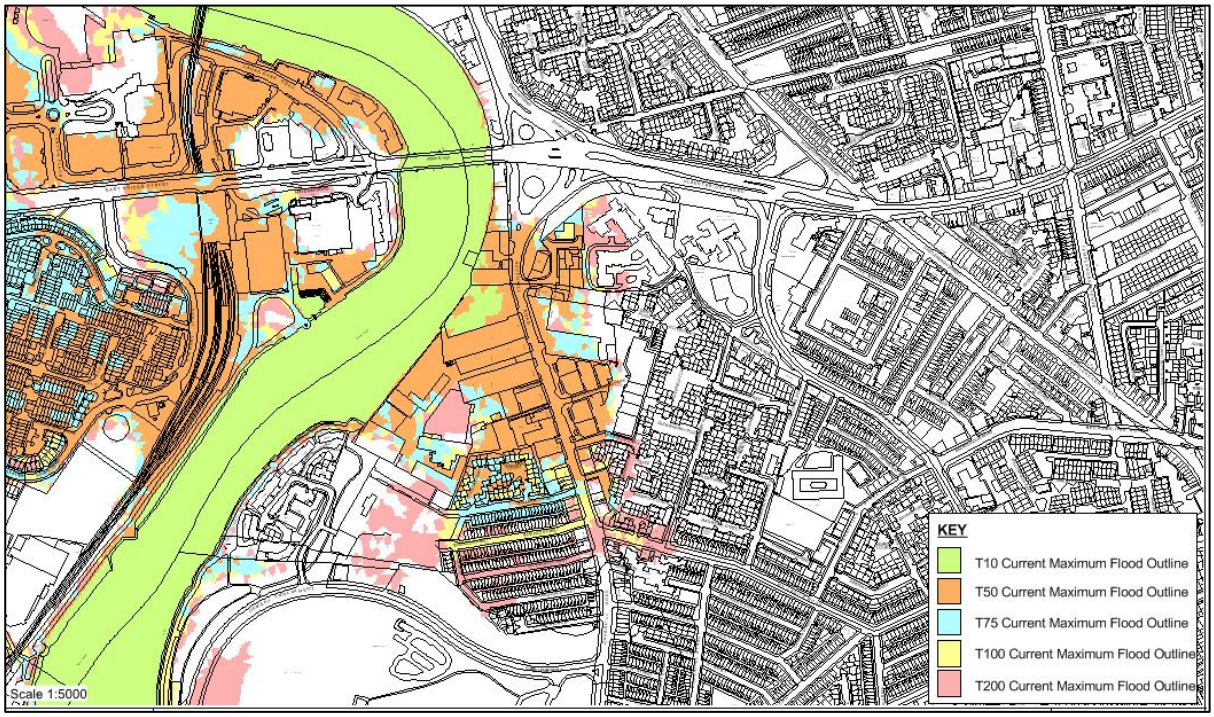

Figure 5-8 Base Map – Ravenhill

Figure 5-9 Climate Change Map – Ravenhill

5.3.5. Flood Cell 5 - Ormeau Embankment

The Ormeau flood cell is currently predicted to be at risk of direct overtopping from the tidal river over the riverside walls beyond a 1 in 25 year AEP event. The majority of the frontage includes a riverside path and river bank in fair to good condition. Flooding in this area will affect predominantly residential properties. In the future epochs the right bank is overtopped, no additional properties are flooded; however, the road and lands in Ormeau Park are flooded.

Figures 5-10 and 5-11 present the detailed flood extents for the current and climate change epochs respectively for Flood Cell 5.

Figure 5-10 Base Map – Ormeau Embankment

Figure 5-11 Climate Change Map – Ormeau Embankment

5.3.6. Flood Cell 6 - Lockview, Stranmillis

Flood risk to residential and commercial properties at Lockview Road, Stranmillis is predicted to commence at the 1 in 10 year AEP event with little change in the flood extent up to the 1 in 200 year (0.5% AEP) event due to the local topography. The right bank has an adequate SoP for current day and is only predicted to flood the road at Annadale Embankment in the future 2065 and 2115 epochs. Note that surface water drainage has been flagged as an issue in this location; any works proposed should take this into account, particularly in regard of public perception to flood risk.

Figures 5-12 and 5-13 present the detailed flood extents for the current and climate change epochs respectively for Flood Cell 6.

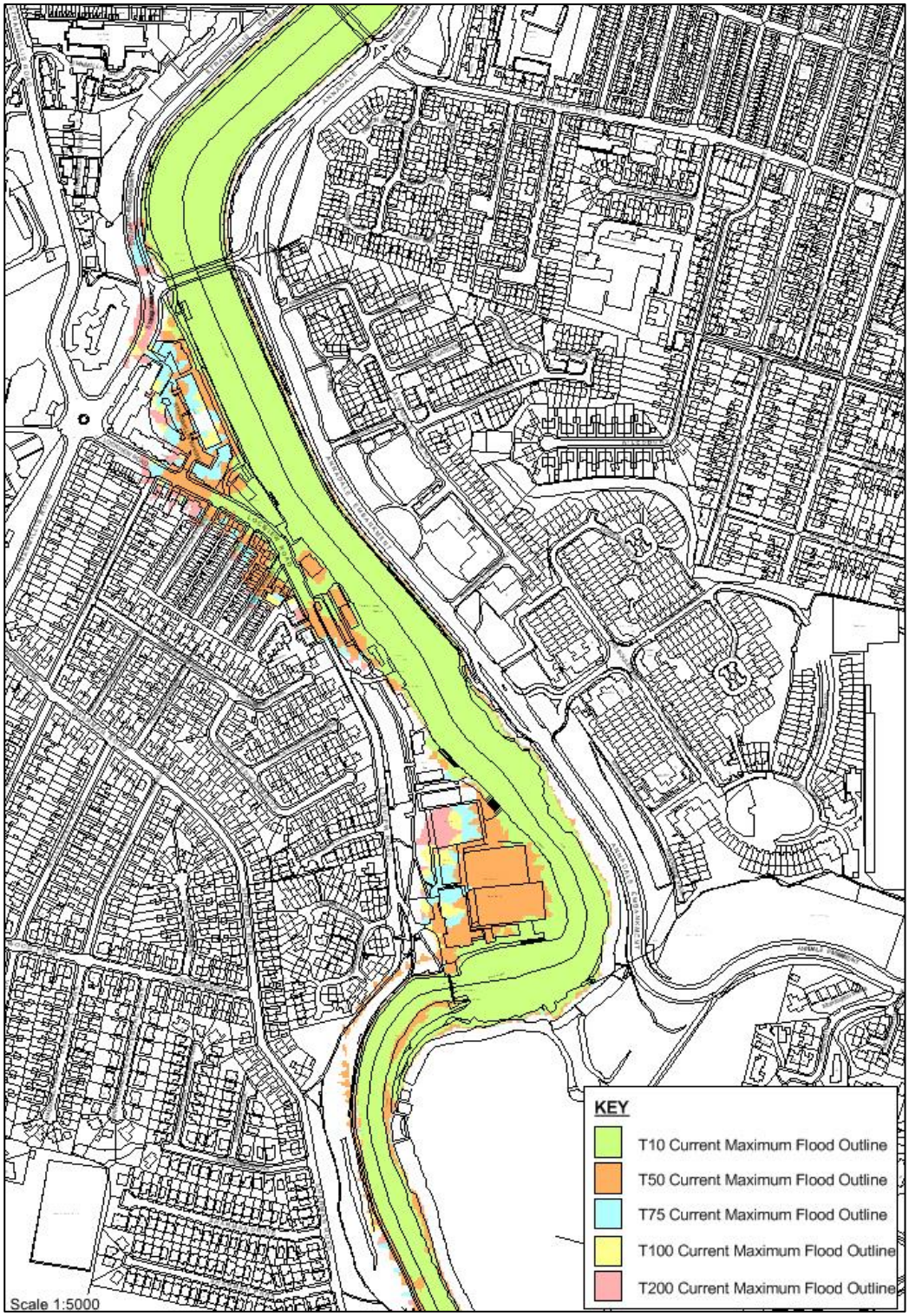

Figure 5-12 Base Map – Lockview, Stranmillis

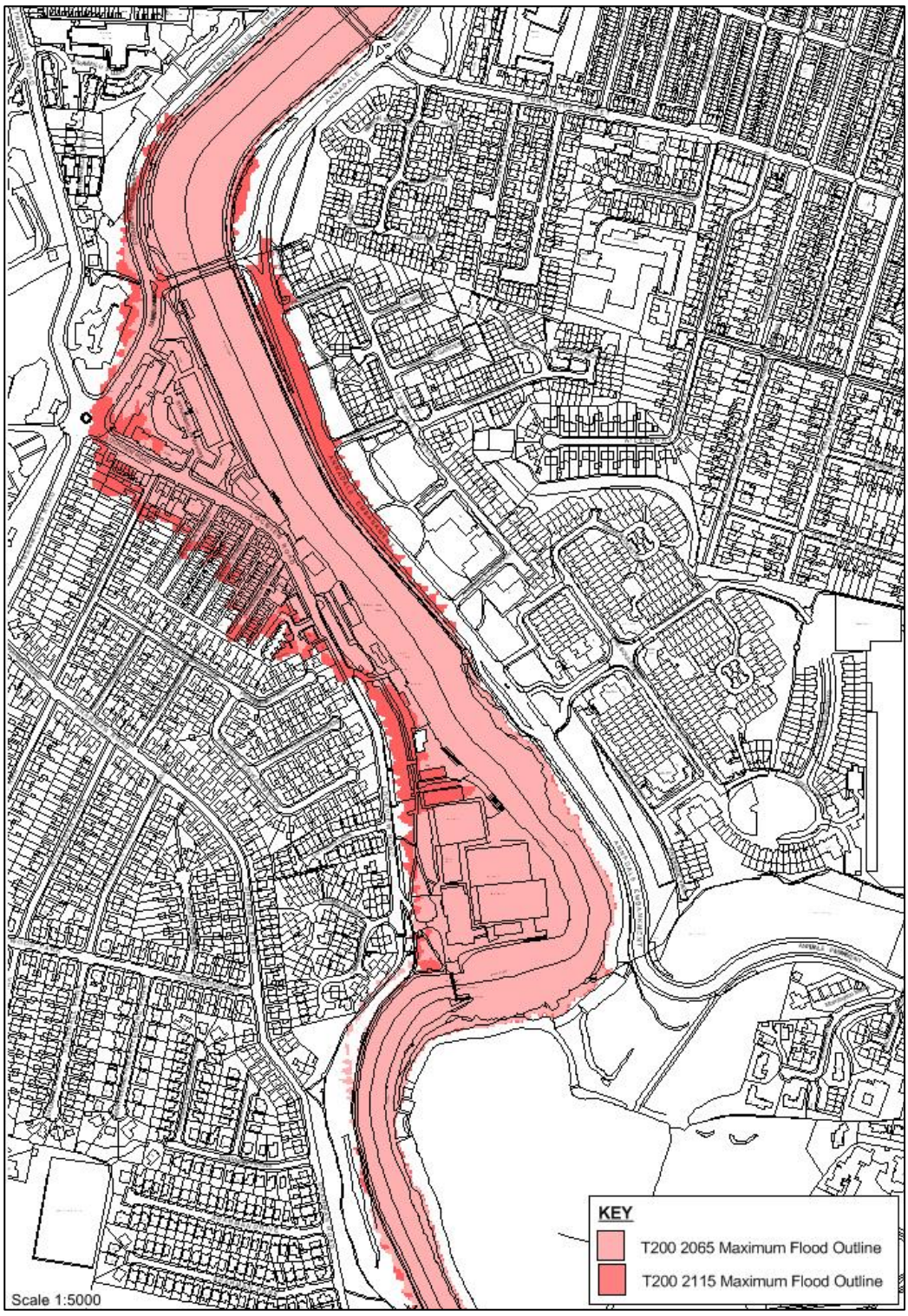

Figure 5-13 Climate Change Map – Lockview, Stranmillis

6. Flood Alleviation Options

The purpose of the study was to review and identify flood alleviation options for the key tidal flood risk areas of Belfast with consideration of future sea level rise and adaptability to meet these future needs.

6.1. Base Case Option - Status Quo

The “Status Quo” base case (Option 0) represents the present situation. Generally this option represents a situation where maintenance would continue at the current level of expenditure and breaches would be repaired following flood events. The risk of flooding would increase over time as the flood defences continue to deteriorate and sea levels rise, increasing the level of damage to property. With future sea level rise, the SoP of existing riverbanks / quays may be reduced to less than 1 in 10 years in the key flood risk areas.

Since there are no specific tidal flood defence assets in Belfast (other than the new scheme recently implemented in East Belfast) there are no current maintenance activities or costs for the Status Quo option for any of the cells. Breach of the harbour quayside walls are not considered applicable due to their primary nature. Their failure would not impact on the flood defence standard as they are the same level as the natural ground level in the harbour. The standard of defence will drop significantly over time though as sea levels rise.

This option will not achieve the objectives of the study and hence is not considered a viable solution. The Status Quo option is included in the economic appraisal as it represents the baseline of flood risk in the economic calculations and benchmarks the assessment of all further flood alleviation options.

6.2. Strategic Flood Alleviation Options

High level strategic options were identified to provide the required SoP (1 in 200 year (0.5% AEP)) across the flood risk areas in Belfast. The options represented flood alleviation approaches from the most comprehensive global solution to the most immediate local protection measures. The options assessed in the study are listed in Table 6-1.

Table 6-1 Strategic Flood Alleviation Options

Option Ref	Option	General Comment
1	New Tidal Barrier at entrance to Belfast Lough	Most expensive solution to tidal flood risk in Belfast. Would resolve all tidal flood risk upstream of barrier but would be significant capital and future cost to operate and maintain.
2	Lagan Weir as Tidal Barrier	Short term option could increase SoP for flood cells upstream of weir by using the existing weir as a formal tidal barrier and raising gate levels in the long term to provide the future SoP upstream.
3	Riverside permanent defences	Combination of permanent constructed flood defence types for each flood cell along or near to line of riverside / quayside
4	Riverside temporary defences	Temporary flood defences installed at each flood cell along pre-established alignment near to line of riverside / quayside for every forecast flood event.
5	Resilience measures & Emergency Plan Updates	PLP and individual property barriers

Each strategic option was assessed in terms of technical, economic and environmental viability. The description of the assessment for each option is presented in the subsequent sections. This assessment forms the basis of the initial shortlisting of options for economic appraisal.

6.2.1. Option 1 – New Tidal Barrier

Option 1 is the most comprehensive global solution to tidal flood risk in Belfast. The optimum location for a new tidal barrier would probably be adjacent to the main ferry terminal, using Dargan Road to tie into high ground to the west. The main barrier across the river at this location would be approximately 400m wide. Such an option would provide a single solution to tidal flood risk to the whole city.

The review of technical, economic and environmental issues for Option 1 is summarised in Table 6-2.

Table 6-2 Option 1 - Technical, Economic and Environmental Assessment

Option Ref	Option	Technical Viability	Economic Impact	Environmental Impact	Shortlisted
1	New Tidal Barrier in Mouth of Belfast Lough	This solution would resolve flood risk in all the locations upstream of the barrier location; however, there would be significant technical challenges in constructing a barrier in an operational port. Complex design and construction.	Most expensive and elaborate solution to resolve tidal flood risk in Belfast. High design and investigation costs. Very high construction costs circa ~£500m. High operating and maintenance costs.	New structure would have significant environmental impact and would require careful planning and temporary works. Would be performed in very heavily designated location and would require NIEA Marine Licence.	No

6.2.2. Option 2 – Lagan Weir as Tidal Barrier

Option 2, using the Lagan Weir as a tidal barrier, could improve the SoP upstream of the Lagan Weir - specifically for Flood Cells 3, 4, 5 and 6 assuming adequate storage in the impoundment was available for incoming fluvial flows in the River Lagan during the barrier closure. The option would not provide improved flood risk management for Flood Cell 1 – Belfast Harbour & City.

The existing top gate level of the Lagan Weir is 3.0mOD which would provide approximately a 1 in 75 year (1.33% AEP) SoP for the upstream River Flood Cells. This SoP would fall to about 1 in 50 year (2% AEP) after 20 years due to forecast sea level rise.

The Lagan Weir was not constructed with the intention of operating as a tidal barrier, and further detailed analysis would be required to confirm the validity of raising the SoP of the Lagan Weir; addressing both the structural integrity of the barrier and gates and the fluvial flow management. The analysis would also need to develop the optimum operating procedure and establish correct trigger levels for a range of tidal / fluvial scenarios. As a precautionary approach, increasing the height of the gates on the existing structure to provide the future 1 in 200 year (0.5% AEP) SoP has not been considered technically viable at this stage.

Since the completion of the hydraulic modelling for this study, a joint probability assessment has been undertaken to consider the risk of fluvial flow coincident with tidal surge events. There is limited storage capacity between Stranmillis Weir and Lagan Weir for managing the fluvial flow during closure of Lagan Weir, which may have the consequence of increased risk rather than reduced risk of flooding for the River cells. The joint probability assessment has indicated that there is a low factor of correlation between fluvial and tidal events, but that it is still sufficiently high to require greater fluvial flows than the baseline flow used in the hydraulic modelling for tidal events in excess of a 1 in 5 to 10 year (20-10%) AEP. There remains a significant risk, therefore, that this option would not be able to be implemented when a tidal surge event warning occurs because of the potential for higher flood risk than if the Lagan Weir were not closed.

The review of technical, economic and environmental issues for Option 2 is summarised in Table 6-3.

Table 6-3 Option 2 – Technical, Economic and Environmental Assessment

Option Ref	Option	Technical Viability	Economic Impact	Environmental Impact	Shortlisted
2	Lagan Weir as Tidal Barrier	This solution improves tidal flood risk upstream of the Lagan Weir to Cell 3-6. It would need to be implemented in conjunction with a downstream option to provide risk management to Cell 1. Joint probability assessment indicates the likely fluvial flow coincident with tidal events > 1 in 5 year will not be manageable in the limited storage capacity between Stranmillis and Lagan Weirs, and hence flood risk could be made worse. Operating the structure as a tidal barrier (in reverse) would need to be validated. Extending the gates to achieve a 1 in 200 year may not be possible without significant alteration to the existing structure. Need for formalised operational guides and manuals by operators.	Potential for significant cost to increase the SoP of the existing weir to the future 1 in 200 year level.	Detailed review of impact on Lagan impoundment as a result of use as tidal barrier may be required; however, impact is likely to be very short-term and be more visual in nature as drawdown of Lagan water levels would be required to provide increased storage volume during high tide / gate up. Unsightly, smelly mud flats may be exposed for a short time.	No – technically too uncertain if achievable without significant cost and fluvial / tidal interaction risk assessment indicates this option could make flood risk worse.

6.2.3. Option 3 – Riverside Permanent Defences

Option 3 represented local flood defences constructed along the riverside in all flood cells identified in the hydraulic model. The flow routes identified in the model and local constraints identified by site inspection guided the selection of appropriate flood defence alignments in each of the flood cells. A range of defence types were required to provide the required SoP in each flood cell.

An assessment of the viability of each of the flood defence types was performed as part of the overall technical, economic and environmental assessment of options. The types of flood defence considered for Option 3 at each of the flood cells and the summary of the results of the assessment of viability is presented in Table 6.4. The detailed assessment of the use of each flood defence type at each flood cell is provided in **Appendix J1**.

Table 6-4 Option 3 – Permanent Defence Types

Defence Type	Details	Used in Option 3	Comment
Raise Quays	Long term approach where quays are raised to suitable level.	No	This would resolve flood risk to city centre but would have no effect upstream of harbour area. Very expensive and complex solution in an operational port. Likely that this would form part of the long term plan in consultation with BHC to raise quays when due for replacement or there is a redevelopment opportunity.
Raise Quay Gates	Any low spots along the defence require raising, including gates in the quay walls.	Yes	This is applicable at Albert Quay where the gate for the Clarendon Dock would not provide the required SoP. Any works to increase the SoP of the gate would need to be done in conjunction with other solutions to remove any spill point in the defence.

Defence Type	Details	Used in Option 3	Comment
Flood Walls	Flood wall defences constructed along river bank where allowable based on landscaping and maintaining access and views to river.	Yes (in selected locations)	Yes – Harbour Area – but all walls would need to be constructed set back from the operational areas of the Harbour and the alignment agreed with BHC within harbour boundary. Yes – Ravenhill - but walls likely to be set back from existing frontage due to poor condition of foundation for upstand walls. Yes – Ormeau - dwarf wall at rear of existing embankment on left bank is simple approach in this flood cell. Yes – Lockview - wall could be constructed along Lockview Road from Stranmillis Wharf to Methody Boat Club.
Flood Banks	Additional new flood banks on River Lagan where space and landscape requires.	No	New flood banks not suitable for any flood cell due to lack of space
Flood Railings	Decorative railing with flood panels at bottom may be manufactured for use in landscape areas.	Yes (in selected locations)	Opportunity to manufacture bespoke decorative railings for quaysides which have flood barrier incorporated in the lower sections. This would complement the existing landscape / public realm. The railings would be permanent but could have access gates incorporated to allow access to required areas. The railings would be appropriate only where the protection required is less than 500mm above existing ground level. If the solid section of barrier is greater than 500mm, glass flood walls or demountable barriers would need to be considered as views would be interrupted.
Alter existing structures	Existing boundary walls and features may be altered / replaced to provide a ‘hidden’ flood defence with flood gates to close gaps.	Yes	Potential to use existing boundary walls etc. to provide flood defence so defence is merged into existing landscape. Would still need gates / temporary barriers at road closure points. Assume that existing walls are robust enough to act as a flood defence in East Belfast and Lockview flood cells.
Raise existing banks / towpaths	Adapting existing structures to achieve higher SoP.	No	Possible to raise existing towpaths / banks at Ormeau and Lockview; however, simple dwarf walls or replacement railings would offer less construction disruption and are likely to be of similar magnitude of cost.
Demountable Barriers	Facilities constructed to allow easy installation of defence in event. Can be temporary or permanently in-situ but removable if necessary.	Yes (in selected locations)	Potential for demountable along harbour frontage and Laganbank Quay in lieu of bespoke flood railings where defence required is greater than 500mm above existing ground level.
Flood Gates	Flood gates may be required at pedestrian and road crossings to ensure a continuous flood defence.	Yes (in selected locations)	Openings in the defence for paths and roads need to be closed. Will assume this is by flood gate.

The overall option assessment on technical merits, and economic and environmental impact is summarised in Table 6.5.

Table 6-5 Option 3 - Technical, Economic and Environmental Assessment

Option Ref	Option	Technical Viability	Economic Impact	Environmental Impact	Shortlisted
3	Riverside Permanent Defences	This solution resolved flood risk in all the locations by construction of local permanent flood defences. These would be structural solutions. Relatively straightforward design and construction. Alignments and site constraints present most technical challenge. Some poor condition structures on the existing river frontage would require detailed assessment at detailed design phase to confirm suitability.	Low – moderate design and investigation costs. Moderate construction costs – maximise use of off-the-shelf products to minimise construction costs. Low to moderate operating and maintenance costs – designed to be passive defences with minimal operation with exception of demountable barriers and flood gates.	New structures would have some environmental impact along the river and would require careful planning and temporary works. Majority of alignments propose defences set back from riverside where possible / necessary so would reduce impact. Most of works through urbanised areas – impact likely on neighbours and trees / vegetation at each of the defence locations.	Yes

6.2.4. Option 4 – Riverside Temporary Barriers

Option 4 represents local temporary barrier flood defences installed along the riverside in all flood cells identified in the hydraulic model. The flow routes identified in the model and local constraints identified by site inspection guided the selection of appropriate alignments for the temporary barriers in each of the flood cells. Where possible, the alignment of the temporary barrier was kept the same as the Option 3 permanent defence alignments to allow direct comparison. The temporary barriers in Option 4 are to provide the 1 in 200 year (0.5% AEP) SoP to allow direct comparison with other options in the economic appraisal. The review of technical, economic and environmental issues for Option 4 is summarised in Table 6-6.

The site walkover of the flood cells in Belfast identified three possible locations identified as having below the current 1 in 200 year (0.5% AEP) SoP where temporary barriers could be used to address flood risk in the short-term. The detailed assessment of the use of temporary barriers for these three areas (City Centre, Ravenhill and Lockview, Stranmillis) is presented in Short-term Flood Defence Options (Temporary Barriers) Report (Ref 5136978/62/DG/004 Rev 3.0 April 2015). A copy of this report is provided in **Appendix H**. The standalone temporary barriers report presents assessment of barriers up to the 1 in 75 year (1.33% AEP) SoP in line with providing an immediate emergency improvement to the SoP in the areas considered.

Table 6-6 Option 4 - Technical, Economic and Environmental Assessment

Option Ref	Option	Technical Viability	Economic Impact	Environmental Impact	Shortlisted
4	Riverside Temporary Defences	Whole defence brought to site and erected in an event. Rigid barrier preferred - Tried and tested barrier system with BS Kitemark for quality. Technical challenges relate to marking out on site the location of any barrier, traffic management and erection protocols for emergency plan.	Low design and investigation costs. Moderate construction costs – maximise use of off-the-shelf products to minimise construction costs; however, rigid defence system still reasonably expensive in the quantities required to protect Belfast. . Moderate to High operating and maintenance costs – annual inspection, cleaning and maintenance costs of stored barrier items. Also minimum of annual practice deployment and event costs.	Barrier alignments proposed were set back from riverside where possible / necessary to reduce impact. Most of works through urbanised areas – impact likely on neighbours and trees / vegetation at each of the defence locations during erection and dismantling. Transportation of barriers to site every year for practice and event deployment may contribute to local environmental impact.	Yes

6.2.5. Option 5 – Resilience Measures / Updated Emergency Arrangements

The detailed assessment of the use of PLP measures for the three areas of Belfast (City Centre, Ravenhill and Lockview, Stranmillis) identified as having below the current 1 in 200 year (0.5% AEP) SoP at the start of the study is presented in Short-term Flood Defence Options (Temporary Barriers) Report (Ref 5136978/62/DG/004 Rev 3.0 April 2015). A copy of this report is provided in **Appendix H**.

Option 5 refers to the use of resilience measures and emergency plans to manage the tidal flood risk in the Belfast flood cells. This represents the most short-term and high risk approach to flood risk management. The review of technical, economic and environmental issues for Option 5 is summarised in Table 6-7.

Table 6-7 Option 5 - Technical, Economic and Environmental Assessment

Option Ref	Option	Technical Viability	Economic Impact	Environmental Impact	Shortlisted
5.1	PLP / Resilience Measures	Last line of defence at individual properties and may be only solution in some instances. Overall project objectives not achieved and flood depths within the city centre may be too deep for PLP measures to accommodate. Tried and tested off-the-shelf products available for any properties that are deemed suitable.	Low cost solution at individual property level; however, circa 8,000 properties at flood risk from 1 in 200 year (0.5% AEP) climate change tidal event in Belfast. Assume £5k / property, then providing PLP to 8,000 properties for such extreme events would cost approx. £40M. This is not viable.	Low environmental impact from construction perspective; however, inundation of large areas of the city centre with flood waters and likely long duration of flooding may cause pollution from stagnation / contamination of flood waters and health issues with local residents.	No

Option Ref	Option	Technical Viability	Economic Impact	Environmental Impact	Shortlisted
5.2	Sandbag Defences	Use of sandbag defences would provide defence for emergencies until a scheme is completed. Emergency Plan can be updated with a preferred defence route from the study but this would not be considered a viable long term solution of managing tidal flood risk in Belfast. Technical challenges are based on availability / filling of vast quantities of sandbags, correct pyramid placement for stability on site under high water levels and the availability of manpower to construct the defences in the short time from flood warning.	Moderate cost solution. Whilst sandbags in vast quantities are likely to be lower cost than permanent or formal temporary barrier approaches, the people costs and emergency plan mobilisation will be moderate and must be considered.	Low impact from construction; however, large quantities of sand required for bags which is a natural resource and the wider environmental impact of mining sand must be considered.	No

Option 5 did not satisfy the project objectives and was not recommended for roll-out across the greater Belfast Area. Resilience measures may be appropriate for small discrete flood locations; however, circa 8,000 properties were predicted to be affected by tidal flood risk to the 2115 1 in 200 year (0.5% AEP) tidal flood event and this would be unviable to protect at a property level or by emergency plans alone.

Emergency Plan Updates – Immediate Option

Whilst Option 5.2 was not suitable as a standalone option, there will be a period of time prior to the implementation of any preferred option when the flood risk remains and requires management. As a result, we provided information from the study to inform updates to the Emergency Plan for Belfast.

The Emergency Plan Update Memo (Ref 5136978/62/DG/016) presented the findings from a review of sandbag defences to provide a 1 in 100 year SoP at Belfast Harbour & City, Ravenhill and Lockview, Stranmillis. These three areas currently have the lowest SoP across the study area. The sandbag alignments follow the same alignments as the purposed temporary barriers / permanent defences in these three locations. Comments on the issues surrounding sandbag defences in terms of numbers of bags required, storage and installation of the defences were provided in the Memo. A copy of the Memo is provided in **Appendix I.**

6.2.6. General Drainage Issues

Drainage issues have been identified at a number of the tidal flood risk areas. In particular, BHC have confirmed that flooding to the harbour area in the January 2014 tidal flood event was not caused by overtopping of the quays at York or Pollock Docks but rather by water flowing back up drainage outfalls and pipework to low lying areas and ponding.

Providing means to over-pump water which collects behind defences or installing flap valves on outfalls in areas of the network capable of being locked for the duration of the high tide is a strategic requirement across the flood cells. This would be performed in conjunction with drainage outfall owners. Any flood defence works to prevent overtopping of the banks in a tidal flood event could be undermined by back drainage flooding. Public perception of flooding sources will not separate surface water flooding from river or tidal flooding so it would be prudent to include this activity in the Mitigation Action Plan and the scope of subsequent detailed design phase.

6.3. Shortlisted Strategic Options

Following the assessment of the strategic options for Belfast tidal flood risk, the following options were taken forward for detailed assessment at each of the flood cells:

- Option 3 – Riverside Permanent Defences
- Option 4 – Riverside Temporary Defences

The preferred overall strategic option for the Mitigation Action Plan must include short (0 to 5 years), medium (5 to 10 years), and long (10 years+) term structural and non-structural measures. The shortlisted options were reviewed to determine which defences were required in the short, medium and long term.

A SoP of 1 in 200 year (0.5% AEP) was used to assess the current quay walls / river banks along the River Lagan from Belfast Harbour to the Stranmillis Weir. If the current SoP was less than 1 in 200 year (0.5% AEP), a short – medium term flood alleviation option was assessed for the area at risk with consideration of future sea level rise in the sizing of the option (up to the 1 in 200 year (0.5% AEP) level in 2065).

If the current river bank / quay wall provided a 1 in 200 year (0.5% AEP) SoP flood alleviation options were developed for construction in the long term to provide further protection for future sea level rise.

6.4. Flood Cell Options

The strategic options were assessed at a flood cell level to determine the exact defence types etc. along the required alignments. Then options for the Belfast Harbour & City Flood Cell were separated for economic appraisal to ensure that the significant flood damages within the commercial city centre flood cell were not used to offset any flood mitigation cost to protect property in other flood cells.

The flood cells are:

- Flood Cell 1 - Belfast Harbour & City
- Flood Cell 2 - Titanic Quarter (area downstream of the Lagan Weir)
- Flood Cell 3 - Sydenham / East Belfast
- Flood Cell 4 – Ravenhill
- Flood Cell 5 - Ormeau Embankment
- Flood Cell 6 - Lockview, Stranmillis

6.4.1. Flood Cell 1 – Belfast Harbour & City

The harbour quays provide below the required current day 1 in 200 year (0.5% AEP) SoP. Options were needed to provide the 1 in 200 year (0.5% AEP) with allowance for sea level rise. The 2065 1 in 200 year (0.5% AEP) design level was used to assess options in the harbour area given the significance of the damage and the opportunity to increase the SoP beyond the current 1 in 200 year (0.5% AEP) level in the short term.

Another spill point to flooding of the city centre is at Laganbank. The quay at Laganbank provides below the required current day 1 in 200 year (0.5% AEP) SoP. Options were needed to provide the 1 in 200 year (0.5% AEP) SoP with allowance for sea level rise. The 2065 1 in 200 year (0.5% AEP) design level was used to assess options in the Laganbank area given the significance of the damage and the opportunity to increase the SoP beyond the current 1 in 200 year (0.5% AEP) level in the short term.

The shortlisted options available to resolve flood risk at the Belfast Harbour & City Flood Risk Area are Option 3 – Riverside Permanent Defences and Option 4 – Riverside Temporary Defences.

Route alignments to tie flood defences to high ground were considered for both Option 3 and Option 4. In identifying the best alignment of the flood defences for Option 3 and 4, the following was taken into consideration:

- Flooding within the Harbour Estate is managed by BHC. Flood defences will only be required to prevent flow paths of flood waters to the city centre and operational areas within the Harbour Estate are to be unhampered by any defence alignment. The harbour boundary is shown in Figures 5-4 and 5-5 for reference. Initial discussions have been held regarding locating a flood defence within the BHC owned boundary to provide improved flood risk to the BHC real estate area and city centre (Route ‘a’). Further discussions would be required to finalise the route and obtain approval from BHC.

- Drawings of the York Street Interchange were requested to allow any flood defences for this area to be accurately tied-in to the proposed scheme. Using these drawings (which are subject to change from on-going public consultation and contractor design) the best estimate of tie-in location was used in the optioneering of Route 'b'. This should be updated once the York Street scheme details are finalised. This alignment is subject to the construction of the York Street scheme to ensure closure of the flow path to the city centre and, therefore, defence works would be constructed after completion of the York Street Interchange.

Following assessment of the various constraints, two alignments were identified:
- Route 'a' – Corry Road / Pollock Road Alignment
- Route 'b' – Belfast Harbour Commissioners Boundary Alignment

6.4.2. Flood Cell 2 – Titanic Quarter

As discussed previously, no options have been proposed for the Titanic Quarter area in the study.

It is expected, given the details available on the recent redevelopment of the site, that there is adequate SoP to the new development areas. To assess tidal flood risk fully across this flood cell, a new DTM will be required which captures the redevelopment in the area.

6.4.3. Flood Cell 3 – Sydenham / East Belfast

The Sydenham / East Belfast flood cell covers the right bank of the River Lagan from Lagan Weir to Albert Bridge and extends as far as City Airport on the Sydenham Bypass. The right bank of the Lagan in this flood cell provides the current 1 in 200 year (0.5% AEP) SoP, therefore, no options were assessed for this area in the short-medium term. In the future epochs, the right bank is predicted to overtop in a number of places causing flooding to areas of East Belfast and Sydenham. Options were considered in the long term in these areas.

The right bank at the Howden Sirocco development site is predicted to overtop in a 2065 1 in 200 year (0.5% AEP) event. The development site has a high brick boundary wall which should provide adequate flood protection in the future, subject to condition. Only gaps in the wall and additional flood defences upstream would be required in this area in the long term.

The shortlisted options available to resolve flood risk at Sydenham / East Belfast are:
- Option 3 – Riverside Permanent Defences
- Option 4 – Riverside Temporary Defences

6.4.4. Flood Cell 4 - Ravenhill

The Ravenhill area does not currently have a 1 in 200 year (0.5% AEP) SoP, therefore, options were assessed to provide the required SoP with consideration of sea level rise.

The shortlisted options available to resolve flood risk at Ravenhill are:
- Option 3 – Riverside Permanent Defences
- Option 4 – Riverside Temporary Defences

A single riverside alignment for Options 3 and 4 was identified at Ravenhill.

6.4.5. Flood Cell 5 - Ormeau Embankment

The left bank of the Ormeau embankment does not currently have a 1 in 200 year (0.5% AEP) SoP, therefore, options were assessed to provide the required SoP with consideration of sea level rise.

The shortlisted options available to resolve flood risk at Ormeau Embankment are:
- Option 3 – Riverside Permanent Defences
- Option 4 – Riverside Temporary Defences

A single riverside alignment for Options 3 and 4 was identified at Ormeau Embankment.

6.4.6. Flood Cell 6 – Lockview, Stranmillis

The left bank of the River Lagan at Lockview does not currently have a 1 in 200 year (0.5% AEP) SoP, therefore, options were assessed to provide the required SoP with consideration of sea level rise.

The shortlisted options available to resolve flood risk at Lockview were:

- Option 3 – Riverside Permanent Defences
- Option 4 – Riverside Temporary Defences

A single riverside alignment for Options 3 and 4 was identified at Lockview, Stranmillis.

6.5. Overall Options

Following review of options at a flood cell level, the options were combined for all flood risk areas to create overall options for Belfast:

- Option 3(a) – Permanent defences throughout the reach including the Route 'a' alignment in the Harbour.
- Option 3(b) – Permanent defences throughout the reach including the Route 'b' alignment in the Harbour.
- Option 4(a) – Temporary defences throughout the reach including the Route 'a' alignment in the Harbour.
- Option 4(b) – Temporary defences throughout the reach including the Route 'b' alignment in the Harbour.

6.6. Shortlisted Options for Economic Appraisal

The economic appraisal assessed the individual options in each of the flood cells to ensure economic viability in each flood cell. The options assessed in the economic appraisal were:

- Flood Cell 1 - Belfast Harbour & City:
  - Option 3 Route 'a' – Riverside Permanent Defences with Corry Road / Pollock Road Alignment
  - Option 3 Route 'b' – Riverside Permanent Defences with edge of BHC Boundary Alignment
  - Option 4 Route 'a' – Riverside Temporary Defences with Corry Road / Pollock Road Alignment
  - Option 4 Route 'b' – Riverside Temporary Defences with edge of BHC Boundary Alignment
- River Flood Cells 3, 4, 5 & 6 – Sydenham, Ravenhill, Ormeau Embankment and Lockview, Stranmillis:
  - Option 3 – Riverside Permanent Defences
  - Option 4 – Riverside Temporary Defences

Option drawings are presented in **Appendix J2**.

6.7. Modelling of Proposed Options

Each of the options was included in the hydraulic model to check that they performed as expected. The options were modelled as single schemes, i.e. they are constructed in one commission.

For detailed design, the models should be re-simulated to include any works already completed and to reflect the final option details.

7. Whole Life Costs

7.1. Whole Life Cost Components

The whole life costs of the shortlisted options were assessed for use in the economic appraisal. Details of cost breakdowns and calculation of the various cost components for each Option is provided in **Appendix K**.

Option costs comprised four main components:

- Capital construction cost,
- Design, management and investigation costs,
- Operation, maintenance, event and training costs, and
- Risk allowance.

Details on the costing of each of these components is provided below.

7.1.1. Capital Construction Costs

The capital construction cost estimates were developed from a combination of supplier quotations, first principle calculations and engineering (CESSM3) price database information factored by the Retail Price Index.

A further 20% allowance for General and Preliminary (site management) costs was also included.

The individual costs and rates used in the development of overall construction costs for the Belfast tidal options are deemed to be robust and reflective of construction costs at the time of writing this report.

7.1.2. Design, Management & Investigation Costs

Cost estimates for the design, management and site investigations to accompany the proposed construction cost of the options were determined based on judgement of an average percentage of these activities of the total outturn cost of the capital works.

Design, and site investigation and survey costs were estimated to be 4% and 2% of the construction cost respectively. Construction management (supervision) was estimated to be 5% of the construction cost.

7.1.3. Operation & Maintenance, Annual Training & Event Costs

Cost estimates for the operation and maintenance of any infrastructure / asset proposed in the options were estimated based on a set rate per linear metre of the type of defence, informed by previous experience.

In the case of the temporary barriers and demountable barriers, a research project has investigated the average value of these activities in relation to the capital cost of the works. This identified a relatively large range from 5% to 15%. Since the proposed options at Belfast would require significant lengths of temporary barriers, the lower bound of the range of cost was used in the assessment due to the efficiencies of scale that could be achieved in a scheme of such a size.

Both temporary and demountable barriers require regular training exercises to ensure their reliability is as high as possible. The cost of training and the use of the barriers during a flood event can be relatively significant and would require permanent resourcing from future budgets. The research indicates that annual event costs range from approximately 6% - 14% of the total capital costs. As above, the lower bound of the range was selected given the scale of the scheme in Belfast.

A similar average was applied to the other assets requiring additional activity during a flood event.

7.1.4. Risk Allowance

Optimism Bias (OB) is an adjustment factor, developed by Treasury, to redress the tendency of project appraisals to be overly optimistic in the estimation of costs. Best estimates of capital and maintenance costs are made and then uplifted by the adjustment factor.

The OB adjustment factor is deemed to be 60% as a base case for strategic flood and coastal defence projects. This factor can be reduced if there is a significant demonstrable risk reduction in cost estimates. With adjustment to risk components, the Optimism Bias applied to Belfast Tidal Flood Risk Study is 38% (0.60 x 63% = 37.8%).

In accordance with the Green Book 2003, this allowance for OB has been applied to the Present Value (PV) Costs including all three elements above (capital construction, design and investigation, and operation and maintenance) as a risk cost factor in the appraisal.

A summary of the costs for each component for each option is provided below. Present Value Costs have also been provided for each option; these costs are calculated over the 100 year appraisal period and includes future works and adaptation of defences in the long term. Note that the PV Costs include Year 50-100 costs which are not shown on the tables. Full details of the breakdown of the PV Costs is provided in **Appendix K**.

7.2. Belfast Harbour & City Costs

Table 7-1 Belfast Harbour & City Options Cost Summary

Option	Design, Management & Survey Cost (£k)	Capital Construction Cost (£k)	Annual Costs (Operation, maintenance, storage, Event / Practice) (£k)	Scheme Cost inc. risk (£k)	Present Value Cost (£k)
Option 3 Route 'a'	833	6,256	24	**9,797**	12,120
Option 3 Route 'b'	565	3,463	11	**5,558**	6,817
Option 4 Route 'a'	45	3,935	329	**5,493**	19,557
Option 4 Route 'b'	45	1,374	129	**1,958**	7,479

7.3. Sydenham / East Belfast Costs

Table 7-2 Sydenham / East Belfast Options Cost Summary

Option	Design, Management & Survey Cost (£k)	Capital Construction Cost (£k)	Annual Costs (Operation, maintenance, storage, Event / Practice) (£k)	Scheme Cost inc. risk (£k)	Present Value Cost (£k)
Option 3	0	0	0	**0**	1,212*
Option 4	0	0	0	**0**	1,599*

*PV costs include future works

7.4. Ravenhill Costs

Table 7-3 Ravenhill Options Cost Summary

Option	Design, Management & Survey Cost (£k)	Capital Construction Cost (£k)	Annual Costs (Operation, maintenance, storage, Event / Practice) (£k)	Scheme Cost inc. risk (£k)	Present Value Cost (£k)
Option 3	72	347	8	**578**	990
Option 4	14	263	23	**381**	2,644

7.5. Ormeau Embankment Costs

Table 7-4 Ormeau Options Cost Summary

Option	Design, Management & Survey Cost (£k)	Capital Construction Cost (£k)	Annual Costs (Operation, maintenance, storage, Event / Practice) (£k)	Scheme Cost inc. risk (£k)	Present Value Cost (£k)
Option 3	108	1,114	1	**1,688**	2,515
Option 4	15	692	71	**976**	5,064

7.6. Lockview, Stranmillis Costs

Table 7-5 Lockview, Stranmillis Options Cost Summary

Option	Design, Management & Survey Cost (£k)	Capital Construction Cost (£k)	Annual Costs (Operation, maintenance, storage, Event / Practice) (£k)	Scheme Cost inc. risk (£k)	Present Value Cost (£k)
Option 3	98	887	3	**1,359**	1,996
Option 4	48	867	69	**1,262**	5,667

7.7. Overall River Cell Cost Summary

Table 7-6 River Cells Options Cost Summary

Option	Design, Management & Survey Cost (£k)	Capital Construction Cost (£k)	Annual Costs (Operation, maintenance, storage, Event / Practice) (£k)	Scheme Cost inc. risk (£k)	Present Value Cost (£k)
Option 3	278	2348	12	**3,625**	6,713
Option 4	77	1822	163	**2,619**	14,974

8. Economic Appraisal

The economic appraisal of the preferred options is presented in a separate report (Belfast Tidal Economic Appraisal Report Ref 5136978/62/DG/09).

A summary of the outcome of the economic appraisal of the options for Belfast Tidal Flood Risk Study is presented below.

The Economic Appraisal Report has been prepared in accordance with the HM Treasury Green Book Appraisal and Evaluation in Central Government, Second Impression 2003 and the associated Northern Ireland Guide.

The following options were appraised in the economic appraisal:

- Belfast Harbour & City:
  - Option 3 Route 'a' – Riverside Permanent Defences with Corry Road / Pollock Road Alignment
  - Option 3 Route 'b' – Riverside Permanent Defences with edge of BHC Boundary Alignment
  - Option 4 Route 'a' – Riverside Temporary Defences with Corry Road / Pollock Road Alignment
  - Option 4 Route 'b' – Riverside Temporary Defences with edge of BHC Boundary Alignment
- Flood Cells 3, 4, 5, 6:
  - Option 3 – Riverside Permanent Defences
  - Option 4 – Riverside Temporary Defences

8.1. Benefit Assessment

The cost of flood damage to property is calculated using a methodology developed by Middlesex University Flood Hazard Research Centre, set out in a book commonly referred to as the "Multi-Coloured Manual" (MCM). The methodology requires the analyst to develop a detailed database of all properties at risk of flooding and to categorise each with codes set out in the manual. The type of property and its floor area is noted as well as the internal floor level for the onset of flooding.

Flood water levels were extracted from the hydraulic model flood mapping output for the various return periods considered under the status quo conditions. These flood levels were used to derive flood depth for each return period at each property subjected to flooding. This data was used to calculate the cumulative flood damages of all properties.

For over-design events for Option 3 and 4 it was assumed that damages remained at the same level – i.e. the depth of flooding for a 1 in 1000 year event for a property remained the same whether the proposed 1 in 200 year (0.5% AEP) SoP defence was present or not. This is a conservative approach and will underestimate the option benefits.

In addition to the direct damage caused by flooding, some indirect damages were included; evacuation costs (temporary accommodation costs, loss of earnings, additional food costs), and emergency service costs. These costs were estimated from guidance provided in the MCM. Research of total emergency costs incurred by local authorities in the UK has determined that emergency costs represent 5.6% of the total economic property losses. This, therefore, represents a multiplier on top of property damages in the appraisal. The total property damages calculated in the appraisal were multiplied by 1.056 to allow for the emergency costs. This figure is applied to all return period events in the appraisal.

Vehicle damages were also determined, based on the recommended MCM factors of 0.28 vehicles per property flooded and £3,100 of loss per vehicle.

A capping figure of the property market value was applied to all of the properties included in the damage assessments. The purpose of capping is to ensure that the total (present value) damage for any one property does not exceed its market value. The capping figure for all residential properties was based on the market value determined from internet searches and consultations on the area. For non-residential properties, a market value per m^2 was used to determine an appropriate market value for that property. No factors have been applied to account for multi-floor buildings since this level of detail is not provided in the available data.

For the temporary defence options a reliability assessment was completed to better understand the risks affecting their successful operation. A range of the most likely risks to affect successful operation were considered and their likelihood estimated. The sum of these independent risks generated a total failure probability. Risks include:

- Warning not issued in time.
- Warning not acted on.
- Barrier failure to erect.
- Barrier failure due to vandalism.
- Barrier failure due to condition.

Assessment of these risks led to a cumulative failure probability of 10.5%. This figure was incorporated into the benefit assessment.

8.2. Net Present Values and Uncertainty

To assess the economic viability of the options, it was necessary to compare the costs and benefits, calculated against those of the baseline option. Under guidance from the NIGEAE, the baseline was the Status Quo option, where the input necessary to maintain services at, or as close as possible to, their current level, is applied. For Belfast there is no existing asset serving a tidal flood risk purpose, and, therefore, there is no cost related to the Status Quo option.

The cumulative costs and benefits of the scheme were discounted over the 100 year appraisal period of the project, at a representative discount rate (3.5% for years 0 – 30, 3.0% for years 31 – 75, and 2.5% for years 76 - 125) to provide a Net Present Value (NPV) of the scheme.

The price date used for all benefits and costs is Q3 2015. This is the last period at which the RPI has been reported (at the time of writing this report) to calculate an uplift value for any costs / benefits developed for this Feasibility Study.

The decision rule was to select the preferred option that maximises NPV whilst providing a flexible and sustainable solution for the future.

8.2.1. Belfast Harbour & City Economic Assessment

Table 8-1 illustrates the economic assessment for Flood Cell 1 – Belfast Harbour & City.

Table 8-1 Belfast Harbour & City Economic Assessment

	Option 0 – Status Quo	Option 3 – Permanent Route 'a'	Option 3 – Permanent Route 'b'	Option 4 – Temporary Route 'a'	Option 4 – Temporary Route 'b'
Costs					
PV Capital Cost (£k)	0	8,143	4,637	4,637	1,636
PV Operation & Maint. (£k)	0	640	304	9,535	3,784
PV Optimism Bias (£k)	0	3,337	1,877	5,385	2,059
Total PV Cost (£k)	**0**	**12,120**	**6,817**	**19,557**	**7,479**
Benefits					
PV Residential Property (£k)	11,958	5,376	5,897	8,642	8,894
PV Non-Res Property (£k)	118,397	56,889	63,094	91,453	95,160
PV Capped Property (£k)	55,811	10,963	15,943	17,623	24,046
PV Evacuation (£k)	1,641	222	308	357	464
PV Emergency Services (£k)	7,261	3,207	3,578	5,155	5,397
PV Vehicle Losses (£k)	1,005	124	164	199	248
Total PV Damages (PVd) (£k)	196,072	76,780	88,986	123,430	134,210
Total PV Benefits (PVb) (£k)		**119,292**	**107,086**	**72,642**	**61,863**
Net Present Value (NPV) (£k)	**0**	**107,172**	**100,269**	**53,086**	**54,384**
Benefit Cost Ratio	**n/a**	**9.8**	**15.7**	**3.7**	**8.3**
Incremental BC Ratio		2.3 (wrt 3B)		0.9 (wrt 4B)	

The option with the highest NPV is Option 3 Route 'a', with a value of £107.2m. This option was selected as the preferred economic option; although, it is noted that Option 3 Route 'b' has a higher Benefit Cost Ratio (BCR) (15.7 cf 9.8).

There are 36 properties at risk from a 1 in 50 year event, not protected by Option 3 Route 'a', located within the Harbour area. A consultation process should be undertaken to discuss the level of risk with these property owners / occupiers and determine whether property level protection (PLP) or changes to their operational procedures can reduce their level of risk.

Uncertainty Assessment

The purpose of the uncertainty assessment was to determine the sensitivity of the NPV for each option to changes in the main cost benefit assumptions, and determine if there was sufficient uncertainty in the assessment to alter the selection of the preferred option.

The particular areas of uncertainty for this assessment include capping values of non-residential property, threshold floor levels, cost of operation and maintenance of temporary and demountable defences, and the rate of climate change sea level rise. These have been tested as below.

- Market values for capping property damages were estimated using a fixed m^2 multiplier rate for different categories of non-residential property. A sensitivity test of the capping rate was undertaken, increasing the value per m^2 by a factor of 2. This led to an increase in NPV for Option 3 Route 'a' to £157m, and Incremental BCR (IBCR) increases to 3.6. The business case is, therefore, strengthened by about 46%. Use of the NAV alternative approach to property valuation would also, therefore, strengthen the business case.
- Threshold flood levels for properties were reduced from 150mm and 50mm for Residential and Non-Residential to 0mm. The NPV for Option 3 Route 'a' increases to £107.7m and BCR to 9.9. Case for option selection is not affected.

- The temporary defence and demountable barriers operation and maintenance costs were factored by 0.5. The NPV for Option 3 Route 'a' increases slightly to £107.5m and the NPVs for Option 4 increase from ~£57m to ~£63m. Therefore, the case for the selection of Option 3 Route 'a' remains.
- Climate change (sea level rise) – the rate of sea level rise reduced to the approximate value for the Lower Bound IPCC rate by taking 2065 sea level as 2115. The NPV for Option 3 Route 'a' reduces to £64.0m and BCR reduces to 6.3. IBCR over Option 3 Route 'b' remains at 2.3. The case for selection of Option 3 Route 'a' remains.

None of the uncertainty tests have amended the selection of the preferred option. The selection of Option 3 Route 'a' was, therefore, considered to be particularly robust.

8.2.2. River Flood Cells Assessment

The assessment for flood cells 3 to 6 (Sydenham, Ravenhill, Ormeau Embankment and Lockview) was combined as a single assessment in Table 8-2 below for brevity and since the analysis for each cell was similar. Separate benefit cost tables for each flood cell are presented in the Economic Appraisal Report.

Table 8-2 River Flood Cells Economic Assessment

	Option 0 –Status Quo	Option 3 – Permanent Defence	Option 4 – Temporary Defence
Costs			
PV Capital Cost (£k)	0	4,455	3,823
PV Operation & Maint. (£k)	0	304	7,028
PV Optimism Bias (£k)	0	1,808	4,123
Total PV Cost (£k)	**0**	**6,567**	**14,974**
Benefits			
PV Residential Property (£k)	20,749	2,968	6,608
PV Non-Res Property (£k)	6,035	1,172	2,608
PV Capped Property (£k)	11,848	0	0
PV Evacuation (£k)	4,293	646	1,439
PV Emergency Services (£k)	1,492	233	519
PV Vehicle Losses (£k)	2,163	164	366
Total PV Damages (PVd) (£k)	46,580	5,184	11,539
Total PV Benefits (PVb) (£k)		**41,396**	**35,040**
Net Present Value (NPV) (£k)	**0**	**34,828**	**20,066**
Benefit Cost Ratio	**n/a**	**6.3**	**2.3**
Incremental BC Ratio		-0.1 (wrt 2)	-0.6 (wrt 3)

The option with the highest NPV is Option 3, with a value of £34.8m. This option was selected as the preferred economic option.

Uncertainty Assessment

The particular areas of uncertainty for this assessment include the same issues raised previously for the Belfast Harbour & City flood cell (capping values of non-residential property, threshold floor levels, cost of operation and maintenance of temporary and demountable defences, and the rate of climate change sea level rise). These have been tested as below.

- Market values for capping property damages were estimated using a fixed m2 multiplier rate for different categories of non-residential property, as detailed in Section 5.4. A sensitivity test increasing capping values used per m2 by a factor of 2 was undertaken. This increased the NPV for Option 3 to £43.2m. The business case is, therefore, strengthened by about 24%.
- Threshold flood levels for properties were reduced from 150mm and 50mm for Residential and Non-Residential to 0mm for both. The case for option selection is not affected.

- The temporary defence and demountable barriers operation and maintenance costs were factored by 0.5. The NPV for Option 4 increases from ~£20m to ~£27m. Therefore, the case for the selection of Option 3 remains.
- Climate change (sea level rise) – rate of sea level rise was reduced to the approximate value for the Lower Bound IPCC rate by taking 2065 sea level as 2115. The NPV for Option 3 reduces to approximately £13m and BCR reduces to 3.0. The case for investment, therefore, remains strong.

None of the uncertainty tests have amended the selection of the preferred option. The selection of Option 3 was, therefore, considered to be robust.

8.3. Non-Monetised Benefit Assessment

To select a preferred scheme, a combined approach of economic, environmental and technical assessment was undertaken. Non-monetary costs and benefits associated with each option were assessed using a qualitative analysis and facilitated further comparison between options to select the preferred option.

The Multi-Criteria Analysis is a technique identified in the NIGEAE Section 2.7. A Weighting and Scoring Method has been adopted to assist in the assessment of the non-monetised issues.

The methodology required to complete the Multi-Criteria Analysis is outlined below:

- Identify risks / performance issues and weight them from Very Significant (5) to Minor (1).
- Define broadly acceptable, tolerable and unacceptable levels of risk/performance for each option.
- Score the levels of risk / performance for each option
- Apply weighting to each score for each respective category and option to determine overall option assessment

Table 8.3 identifies the non-monetised issues which are considered to be key elements to the success of the project but are not captured by the economic assessment.

Table 8-3 Risk / Performance Issues

Issue	Description	Weighting
Traffic Disruption	Flooding of key transport infrastructure can cause significant indirect economic loss as traffic is diverted or delayed. The proposed Option 3 and 4 for Flood Cell 1 (Harbour & City) will also require temporary road closures as some highway crossing points are closed for erection of demountable or temporary barriers.	Significant (4)
Landowner & Approvals	Detailed consultation with key landowners and affected parties has not been undertaken. Option Route ‘a’ and ‘b’ will have different impacts and may be viewed differently by the Belfast Harbour Commissioners as principal landowner.	Moderate (3)
Environmental Designations and Landscape Impacts	Belfast Lough is a Marine protected area (OSPAR), Special Protection Area (SPA) and SSSI. The draft Strategic Environmental Appraisal (SEA) for Belfast Regeneration Strategy 2014 identifies a desire for increased connectivity through the city using waterfront promenades and increased water activity on the River Lagan. Improvements to the waterfront landscape will help achieve these objectives.	Significant (4)
Amenity	The project should provide an opportunity for increased amenity to the public and provide a better quality of life for people.	Moderate (3)

Issue	Description	Weighting
Effects on the local economy	The project should boost the local economy through reduced indirect damages from flooding events not quantified by the assessment. The impact of long duration flooding to the heart of the commercial centre for Northern Ireland as a whole has not been captured. This is further compounded by the potential for foul sewage to mix with flood water causing longer recovery periods for commercial and government organisations.	Very Significant (5)
Operational Liability	Options to reduce flood risk by creating new flood defence assets will leave a residual liability for their operation and maintenance.	Moderate (3)
Adaptability to Future Requirements	Options should provide flexibility to enable adaptation to future requirements as the development of the waterfront continues and / or future climate change sea level rise forecasts are improved.	Moderate (3)

The following criteria were used to score the categories for each option. A scale of 1 to 5 was used to allow greater ability to select scores which are, for example, not broadly acceptable but are more than tolerable.

- Broadly Acceptable: Equal to or greater than 5
- Tolerable: Equal to or greater than 3 but less than 5
- Unacceptable: Equal to or less than 1

The outcome of the Scoring and Weighting for each option is provided in Table 8.4. Detailed allocation of scores for each issue are included in the Economic Appraisal Report (Ref 5136978/62/DG/009).

Table 8-4 Scoring & Weighting Outcome

	Option 0 Status Quo	Option 3(a) Permanent	Option 3(b) Permanent	Option 4(a) Temporary	Option 4(b) Temporary
Total Score (unweighted)	18	27	26	26	25
Weighted Score	50	89	83	84	78

The multi-criteria assessment scores indicate that all Do Something Options have similar non-weighted scores, and all exceed Option 0 Status Quo. Option 3(a) has a slightly higher weighted score (89) than the other options (78 to 84), but the difference is relatively slight and is arguably within the tolerance of scoring and weighting judgement applied. However, the MCA does indicate that there is no major non-monetised benefit impacting the preference of option selection to a significant degree.

8.4. Risk

As part of the economic appraisal of the options the risks to the project and construction of proposed options have been reviewed.

Table 8.5 outlines the risks identified for the project going forward. These risks have been assessed in terms of probability of occurrence, severity, risk owner and countermeasures.

Table 8.5 Belfast Tidal Flood Risk Study Risk Register

Risk No	Risk Type	Raised By	Date Raised	Risk Description	Likelihood	Severity / Impact	Owner	Method of Control/Comments
1	Funding	Consultant	September 2015	Availability of funding to complete the project	Medium	High	Rivers Agency	Tolerate – Work within Rivers Agency current budget projections and works programme.
2	Ground Conditions	Consultant	September 2015	Unknown ground conditions encountered – high water table, running sands, boulders, rock	High	Medium	Designer	Manage – undertake detailed ground investigation before detailed design
3	Existing structures and topography	Consultant	September 2015	Adaptation to existing structures or replacement required	High	Medium	Designer	Manage – undertake detailed site investigation and assessment before detail design
4	Riparian and Landowner consultation	Consultant	September 2015	Consultations and agreements required with third parties, land owners and property owners. Possible delays during negotiations.	Medium	Medium	All	Tolerate – commence negotiations early and continue to address residents' requests as work proceeds.
5	Approvals	Consultant	September 2015	Planning permission and/or other approvals required	Medium	Low	All	Treat – commence discussions with approval bodies as early as possible
6	Unmapped Services	Consultant	September 2015	Potential for unmapped services / utilities to be uncovered during excavations for flood defence works.	Medium	Medium	Contractor	Treat – include trial trenches and service investigations in scope of contractor's works and ensure the latest utility information is provided with the design.
7	Impact on Critical Infrastructure	Consultant	September 2015	Potential for flood defence works to impact on critical infrastructure during construction.	Low	Medium	Designer / Contractor	Manage – continue liaison with utility providers and other critical asset owners throughout design and construction planning phases.

Risk No	Risk Type	Raised By	Date Raised	Risk Description	Likelihood	Severity / Impact	Owner	Method of Control/Comments
8	Poor founding materials	Consultant	September 2015	Sleech, peat and made ground known to exist across the study area which may impact on foundations / temporary works arrangements.	Medium	Medium	Designer / Contractor	Manage - undertake detailed ground investigation before detailed design
9	Contaminated Land	Consultant	September 2015	Tar at Docks area, old landfills and reclaimed lands in vicinity of proposed flood defence works. Need to plan to prevent cross-contamination of Sherwood Sandstone aquifer.	Medium	Medium	Designer / Contractor	Manage - undertake detailed ground investigation / contamination testing before detailed design
10	Unexploded Ordnance (UXOs)	Consultant	September 2015	Historic bombings in Belfast City Centre may increase potential for uncovering UXOs in flood defence works.	Low	High	All	Manage – Perform UXO survey in advance of construction to be aware of the potential in the areas of work and advise the contractor for appropriate methods.

9. Conclusions and Recommendations

9.1. Flood Risk

Belfast is at risk of flooding from a number of sources including tidal, fluvial and surface water. Tidal flood risk is of most concern, with potentially 560 residential and 460 non-residential properties currently at risk from a 1 in 200 year (0.5% AEP) return period.

The most significant flood risk is to the Belfast Harbour & City Flood Cell. An extreme event would cause serious disruption to commerce, the transportation network, and the social fabric of the city. Much of the centre of Belfast area is about 1m to 2m below extreme tide levels. Any significant depth of tidal flooding within the city centre is likely to drain slowly as the drainage network capacity is exceeded. This also raises the likelihood of contamination as tidal flooding overwhelms and mixes with the foul sewerage system. Flooding of the city centre may cause major disruption for several days or weeks, with increased clean-up and recovery consequences.

There are a further four separate flood cells upstream of the Lagan Weir (Sydenham, Ravenhill, Ormeau Embankment and Lockview). These cells include more residential areas. The Titanic Quarter development area on the east side of Belfast is largely above current flood risk concerns due to the implementation of a Strategic Flood Risk Assessment across the area approved by Rivers Agency acting as the competent Flood Risk Authority.

Total numbers of properties at risk are shown in Table 9.1 below. This table illustrates how flood risk increases due to sea level rise and climate change.

Table 9.1 Properties at Risk in All Flood Cells

	Year 2015		Year 2065		Year 2115	
Return period (year)	**Residential**	**Non Residential**	**Residential**	**Non Residential**	**Residential**	**Non Residential**
2	-	3	8	33	293	104
10	6	31	170	67	636	448
50	143	69	818	544	4,214	1,239
75	183	131	1,288	643	5,061	1,431
100	237	176	1,708	685	5,421	1,537
200	**564**	**461**	**2,636**	**770**	**6,050**	**1,858**
1000	1,211	617	3,820	1,090	7,053	2,120

An economic analysis of the total potential damages that would be caused was undertaken using standard flood depth damage methods of analysis. This indicates that for the Status Quo Option, the PV damages (discounted over the next 100 years) for the Belfast Harbour & City flood cell was about £196m, and for the flood cells upstream of the Lagan Weir a further £47m.

9.2. Preferred Flood Alleviation Options

9.2.1. Belfast Harbour & City

A range of options was considered including a new tidal barrier near the ferry terminal, and new permanent or temporary riverside (harbour) flood defence structures. The new tidal barrier option and new defences along the active harbour quaysides were not shortlisted as viable solutions due to their cost and impact on the harbour operations.

Two options were shortlisted to reduce flood risk with two route alignments to tie the new flood defence to high ground. Both routes leave some areas of the harbour unprotected.

- Option 3 – Riverside Permanent Defences; Route ‘a’ and Route ‘b’
- Option 4 – Riverside Temporary Defences; Route ‘a’ and Route ‘b’

The preferred option is Option 3 Route ‘a’, comprising new flood defence walls and structures along the riverside and using Corry Road and Pollock Road as the route alignment to high ground. This option has the highest Net Present Value of £107m and a BCR of 9.8. This option also scored the highest value within the non-monetised multi-criteria assessment.

The alignment for Option 3 Route ‘a’ will require some active flood defence in the form of demountable barriers at road / access crossing points. These active structures will require resources in future to operate and maintain them to ensure they are implemented when required on receipt of a tidal flood warning.

Option 3 Route ‘a’ will not provide flood risk reduction for about 36 properties which will be to the north of the alignment. A consultation process will be required to discuss the level of risk with these property owners / occupiers to determine whether individual property level protection or changes to their operational procedures can reduce their level of risk.

9.2.2. River Flood Cells

Two options were shortlisted to reduce flood risk for the four separate flood cells upstream of the Lagan Weir:

- Option 3 - Permanent Riverside Defences
- Option 4 - Temporary Riverside Defences

The preferred option is Option 3. This option has the strongest business case with a Net Present Value of £34m and a benefit cost ratio of 6.3. It provides a minimum 1 in 200 year (0.5% AEP) standard of defence for the next 100 years.

9.3. Overall Preferred Option

Overall Option 3 is the preferred option for both the Belfast Harbour & City Flood Cell and River Flood Cells, with a preference to follow Route ‘a’ in the Belfast Harbour & City Flood Cell. The overall preferred option is, therefore, Option 3(a).

9.4. Recommendations

The following recommendations are proposed:

- Obtain new DTM / LiDAR data for Titanic Quarter area to allow flood risk to be assessed and options to be developed / confirmed.
- Consultation with Belfast Harbour Commissioners to agree the detailed alignment and finish of the flood defence prior to detailed design.
- Consultation with property owners / occupiers in the harbour area outside defended areas to determine whether individual PLP or changes to their operational procedures can reduce their level of risk.
- Following confirmation of funding, the implementation of Option 3(a) should be progressed, including site investigation, consultation, detail design and planning, followed by construction and commissioning of the new flood defence assets.
- Undertake an assessment of all available drainage network information and then site survey to determine location and condition of all existing culvert outfalls. Assess need and suitability to incorporate flap valve (or similar) to reduce risk of backing up, or requirement for over-pumping if risk of ponding behind existing (or new) river bank / flood walls.

It is recommended that these works are undertaken as high priority as Belfast is vulnerable to significant flood damage and potentially loss of life from moderate probability tidal events.

9.5. Mitigation Action Plan

The conclusions and recommendations arising from the Study were included in the Mitigation Action Plan. The Plan includes the structural and non-structural measures proposed for short, medium and long term tidal flood risk management in Belfast.

A copy of the Plan is provided in **Appendix L**.

9.6. Post-study Consultations

9.6.1. Belfast City Council – Emergency Planning Meeting

The project team met with various staff from a range of departments within Belfast City Council on 10th May 2016 to discuss the coastal flood risk in Belfast and the outcome of the feasibility study modelling and optioneering exercise. Information which was identified at this meeting relevant to the future stages of the study is:

- Works are being progressed by the Council upstream of Stranmillis Weir comprising a new bridge crossing and upgrading of the towpath.
- The council would be keen to have a tow path connection between Stranmillis Weir and the Stranmillis Wharf. If this were to progress the alignment of the proposed flood defence in this area could be reviewed.

9.6.2. Department for Communities (DfC) Meeting

The project team met with DfC representatives, including staff wo operate the Lagan Weir, on 24th May 2016 to discuss the coastal flood risk in Belfast and the outcome of the feasibility study modelling and optioneering exercise. Information which was identified at this meeting relevant to the future stages of the study is:

- The quay walls adjacent to the Lagan Lookout are known to be affected by the tide and remedial works were required during the construction of the basement of the Obel Tower to reduce the vertical movement of the quay walls during high tides.
- There are proposals for a tow path connecting East Bridge Street to the existing tow path at Ravenhill Reach. This may have an impact on the construction of flood defences identified in the Ravenhill flood cell.

9.6.3. Belfast Harbour Commissioners (BHC) Meeting

The project team met with BHC representatives on 31st May 2016 to discuss the coastal flood risk in Belfast Harbour and the outcome of the feasibility study modelling and optioneering exercise. Information which was identified at this meeting relevant to the future stages of the study is:

- BHC require further detailed consultation on any flood defence route alignment through the Harbour Estate.
- BHC would prefer a stepped back defence alignment over a quayside alignment on the Harbour frontage.
- Maintaining access to the operational areas of the Harbour for as long as possible during a flood warning is desirable and BHC need to be included in the emergency planning associated with the closure of flood gates / installation of flood barriers in the Harbour Estate.
- There is historical flooding of the Bombardier buildings along the quay in the Titanic Quarter flood cell. As the study has not assessed this cell given the lack of current ground level data to map the flood extent; it may be necessary to review the Titanic Quarter flood cell flood risk in the next phase of the project.

Appendices

Appendix A. Historical Flood Review

INSERT JBA Hydrological Assessment Annex 2

Appendix B. Desk Study Data

B.1. Site History

B.1.1. Early Prehistoric until 17th Century

Although human occupation is known from around 6000BC near Lough Neagh no Mesolithic remains have been identified in the Belfast area (Manning et al, 1970). By Neolithic times there were flint “factories” on Black Mountain and Squires Hill overlooking the site of the future city. Bronze Age sites are abundant in the Lagan Valley. During later Prehistoric and Roman times little seems to be known but from at least the 5th century and the arrival of Christianity the area appears to have had a settled agricultural civilisation (ibid). There is likely to be keen local interest in any excavations which encounter potential artefact-bearing horizons.

Invasions by the Vikings and later settlement by the Normans and then the Scots in turn each left some features. The Castle was probably constructed in the 13th Century to protect the lowest ford on the River Lagan.

The 16th century saw the “plantation” of Ulster by English colonists who settled around the castle in Belfast as well as further up the fertile Lagan Valley. The forests were cleared in the 16th century for the production of charcoal to help manufacture iron in the numerous iron works along the Lagan Valley (ibid), the ore being imported from Cumbria.

In the early 17th century, Belfast Harbour was an insignificant creek of the River Lagan. The harbour was very small and in private ownership prior to 1637 (Salmond, 1878). It ceased to pay dues to Carrickfergus in 1634 (Millington, 1997). In 1637, an increased drive in trade led to the beginnings of the harbour development; however, it was only in the mid to late 18th century that considerable engineering improvements to the harbour and its port commenced with the establishment of new Harbour Commissioners in 1785. Prior to the development the project area comprised the natural estuarine foreshore mudflats of Belfast Lough as shown by the maps of 1715 and 1860 (approx.).

B.1.2. 18th, 19th and 20th Centuries

The history of development of the Dock Area (north of Whitla Street) is described below.

The following description is taken from Salmond (1878). In the late 18th century Belfast was located on a bend in the River Lagan; at the time a narrow, shallow and winding channel with a tidal influence ebbing out almost entirely just upstream of the town. The channel increased gradually in depth until it reached ‘the Flats’, approximately 2.5 miles downstream, where it had a confluence with the Seal channel near Garmoyle. At this time, the shipping docks of Belfast were largely small tidal docks and recesses only capable of hosting small vessels. Construction of the first dry dock began in 1796.

In 1837 improvements to the channel were begun by deepening and dredging and a new channel for the river was excavated to remove the first river bend near the town. The excavated soil was used to form the embankments and for making up the property called Queen’s Island – a property subsequently developed and used for ship building. This channel was opened in 1841.

Between 1846 and 1849 a second new, straight channel (named the Victoria Channel) was cut through ‘The Flats’ and removed the second bend in the river, ensuring a straight river course from the Town Quays to the mouth of the Seal channel. The excavated material was used to form the Twin Islands and heavy stones were used to pitch the channel faces.

From 1858 onwards, regular dredging and deepening of the channels commenced, gradually easing the navigation route and allowing the hosting of greater sized vessels. Salmond (1878) includes a plan and typical cross sections of quay walls. Further channels were subsequently excavated to straighten the River Lagan downstream of the Victoria Channel and to improve the approaches between the harbour and the Belfast Lough.

Associated with the development of the river and the greater influx of larger vessels, from approximately 1844 considerable expansion and construction of new quays was undertaken on both sides of the river north of Queen’s Bridge. The wharves were generally constructed of timber faces tied back by iron rods and supported with sheet piles and bearing piles in softer materials. These often subsequently required

reinforcement by further footings of piling and masonry rubble. Generally the soft river dredgings were used to fill the land behind the wharves.

Dock construction for shipbuilding and repair continued until at least 1968 when the facility for 1,000,000 t vessels was completed. These works were concentrated in the main shipbuilding areas of Harland and Wolff.

B.2. Regional Geology

B.2.1. General

Sheet 36 of the 1:63360 (1": 1 mile) series of the Geological Survey of Northern Ireland (GSNI) (1966) was supplemented by the special sheet of Geology of Belfast and District (1971) published at the scale of 1:21120 (3": 1 mile). This indicates the regional geology to comprise the following general sequence of strata:

Table B-1 Geological Strata

Era	Period	Formation, lithology
Quaternary	Recent	Estuarine clays, Peat, Beach deposits
	Pleistocene	Upper Boulder Clay, Middle (Malone) Sands, Lower Boulder Clay
Tertiary	Eocene	Antrim Lavas and related dykes
Mesozoic	Cretaceous	Upper Chalk, Hibernian Greensand
	Triassic	Mercia Mudstone Sherwood Sandstone
Palaeozoic	Permian	Marls, Magnesian Limestone, Basal sandstones
	Ordovician / Silurian	Sandstones, siltstones and shales

B.2.2. Structural Geology

Since the Lower Palaeozoic the area has experienced little or no folding. The most important structural lines in the region are ENE-trending (Caledonian age) faults. Two further sets of faults trending North-West and North-East may be recognised from the published geological maps. Probable later re-activation of these faults involved Tertiary strata up to Eocene and Lower Oligocene age and final movements are therefore presumed to be of Tertiary age.

The sequence of movements is as follows:

- Caledonian folding and faulting
- Pre and Intra-Cretaceous faulting.
- Faulting up to Late Oligocene with
  - N-W trend (includes a bifurcating fault under Belfast)
  - E-N-E trend
  - N-E trend
- Minor faulting

Apart from the Caledonian faults that are due to compressive stresses, the more recent are due to tensile stresses which allowed normal faulting. The trends of the main faults are; however, suggested to reflect and be inherited from the Caledonian tectonic framework. Many of the more recently active faults, especially

those trending NW, were later injected by Tertiary basalt and dolerite dykes. A number of dykes have been encountered in various boreholes. These are not restricted to known fault lines.

B.2.3. Geological History

The area experienced sedimentation during the early Palaeozoic and then faulting and folding during the Caledonian orogeny. There may have been further minor disturbance at the end of the Palaeozoic. Subsequent tectonic disturbance has been comparatively minor. Mesozoic strata dip gently NW at approximately 5º.

Faulting during the Tertiary has trends of ENE, NW and NE (Manning et al, 1970). All may reflect earlier structures in the older basement rocks. Near Belfast city centre only the NW-trending series are mapped on the Belfast sheet and none of these appears to have large displacements, nor are any known to have been active since the mid Tertiary.

The Quaternary was mainly dominated by at least two glaciations causing little erosion in the Belfast area but the widespread deposition of two distinct glacial clays.

The retreat of ice in the late glacial period, followed by fluctuating sea levels and isostatic uplift, combined to result in formation of a thin peat bed followed by the deposition of the Estuarine Clay or Sleech during a subsequent period of relative submergence of the city centre area. These deposits infill the much less deeply incised buried channels created by the Lagan and Blackstaff rivers.

B.3. Ground Conditions

B.3.1. General

The published geological maps indicate the surface geology in the harbour area to be Quaternary deposits overlying bedrock, namely:

- Made ground is likely to be encountered as a consequence of the long history of industrial and urban development in the area, particularly associated with development and reclamation of the estuarine margins, backfilling of old excavations, etc.
- Sleech (Estuarine Clays) and peat (Recent) and
- Glacial deposits (Pleistocene), two separate Boulder Clay units (Fluvial Glacial and Glacial Till) separated by the Malone (or ‘Middle’) Sands.

Underlying the Quaternary drift deposits, the bedrock geology along the route generally comprises:

- Sherwood Sandstone and Mercia Mudstone (Lower Triassic) and
- Upper Permian Marls (Upper Permian).

In addition, vertical igneous intrusions (dykes) of variable thickness may be encountered within the bedrock geology.

B.3.2. Pre-Glacial Bedrock Topography

Concealed beneath the thick glacial and post-glacial drift deposits, several deep and steep-sided (or even vertically-sided) valleys have been identified in the surface of the Bunter Sandstone underlying Belfast (Manning et al, 1970). The most prominent bedrock valleys are interpreted to lie:

- SW from central Belfast towards Bog Meadows
- Between Malone Road and River Lagan, oriented north-south
- Trending SE from Belfast Harbour
- Trending east towards Knock.

The bedrock valleys are interpreted to be pre-glacial drainage features (Manning et al, 1970) and were probably cut in response to previous low (glacial) sea levels. They have been subsequently predominantly filled with boulder clay, or sand and gravel in their relatively narrow parts (Gregory, 1983). Some minor modification of the valleys may have occurred by glacial action or sub-glacial erosion (Manning et al, 1970).

The estimated stratigraphic thicknesses are presented below; however, as a result of the pre-existing bedrock valleys, various glaciations and post glacial depositional events, the thickness of each soil formation can be expected to be variable often with some geological units being locally absent. The preferential erosion of the Sherwood Sandstone to form the Lagan Valley floor indicates its low strength compared to the under and overlying strata which outcrop to south and north.

Table B-2 Generalised Strata Thicknesses

Stratum	Typical Thickness of Stratum (m), where found
Made Ground	0.0 - 4.0
Estuarine Alluvium (Sleech)	0.0 - 15.0
Peat	0.0 - 0.9
Sand and Gravel	0.0 - 20.0
Boulder Clays	0.0 - 20.0
Sherwood (Bunter) Sandstone	>100.0
Upper Permian Marls	>10.0
Intrusive Dykes	0.1 - 6.0

B.3.3. Strata Descriptions and assumed geotechnical properties

The strata descriptions summarised below are based on geological references, memoirs and borehole information obtained from the Geological Survey of Northern Ireland (GSNI). Geotechnical properties listed below are those assumed from the general literature.

B.3.3.1. Made Ground (Recent)

The Made Ground is not recorded in the published geological maps but it is expected in most of the urban areas as shown by most borehole logs. It can be expected to vary widely from hardcore to old refuse and excavation spoil, often of alluvium or Sleech, which was used to raise the ground level relatively locally within the old city area. Nearer the sea the Made Ground is expected to be hydraulic fill, Sleech from adjacent dredging (Salmond 1878) and refuse used to create the reclaimed areas in which the docks were excavated. It is known that much of that reclamation occurred after 1715.

The Duncrue Industrial Estate is built on an old landfill site which is still undergoing consolidation and settlement and in which decomposition is still occurring, Methane emissions from both this refuse and possibly also from the underlying Sleech are still being monitored and the buildings are known to be experiencing consolidation settlement.

B.3.3.2. Alluvium (including Sleech)

The River Lagan deposits alluvium in the form of brown sandy silt and reddish clay along its length during times of flooding. This material passes laterally (or vertically) into the Estuarine Clay or Sleech which is a very soft or soft to locally firm, lightly over-consolidated, grey organic clay or silt. It may be sandy or contain sandy partings and its organic content varies. Characteristically it is very variable, both vertically and laterally. The maximum thickness is of the order of 15-17m but rapid lateral thickness variations are common. A local thickness of 25m (to the underlying sands) was noted by Darling 1994 near the Duncrue works though nearby the Sleech only extended to approximately 7m depth.

The dissolved sulphate content may be high (0.2 - 0.4g/l) requiring sulphate-resisting cement, but the few pH values available are 8.0-8.5 which is very alkaline (benign to concrete). Boreholes in the Sleech have encountered methane.

B.3.3.3. Peat

Underlying the Estuarine Clays there is often a bed of peat typically 0.3m thick (occasionally up to 0.9m thick) which blanketed most of the old topography at the end of the Pleistocene. It is most commonly preserved beneath the thicker sections of Sleech. Peat is characteristically highly compressible and may evolve methane.

B.3.3.4. Boulder Clay

There are known to be two boulder clays in the district historically referred to as the Upper and Lower Boulder Clay and now identified as the Fluvial Glacial Clay and Glacial Till respectively.

The Fluvial Glacial Clay is firm to stiff, brown to reddish-brown, fissured, plastic clay with a low stone content. It may include some laminated clay and it may have partings and lenses of fine sand. It is known to reach 8m thickness and may be best developed on the North side of the City (At Pollock Dock more than 25m thickness was encountered (Glover, 1999); however, this layer may thin further to the SW.). The top of the boulder clay may be softened. It is often overlain by a layer of loose sands or silty sands and clays which may be transitional to the alluvium as the ice retreated.

The Glacial Till is most typically a stiff to very stiff, partly fissured, silty, slightly gravelly, red-brown clay with low compressibility. It contains numerous cobbles and boulders especially towards the base. Little data has been found on actual clast dimensions so size ranges of cobbles (0.06 - 0.2m) and boulders (bigger than 0.2m) must be assumed to match the criteria in British Standard 5930.

Recent work undertaken on the Belfast Sewers project would indicate that the occurrence of cobbles and boulders is far greater than in anticipated in current published material. On this project boulders in excess of 1m and up to 2m were encountered.

There are commonly lenses and layers of sands and silts and the distinction between the glacial clays and the intervening Malone sands and gravels is not a simple or single feature.

The Glacial Till may reach nearly 30m thickness. It is heavily over consolidated with numerous cobbles and boulders. Clean bands of gravel and cobbles can be found at the base of the unit which contain boulders.

B.3.3.5. Sand and Gravel

The Middle (Malone) Sands and Gravels are medium dense stratified red-brown, silty fine to medium sands with some gravel and occasional lenses of laminated clay. Cobble and boulder sized material can be found in the Malone Sand layer. Permeability can be variable with higher values attributable to buried river channels. Typically, uncemented, permeable deposits such as these sands can ‘blow’ or run into excavations under adverse seepage conditions.

B.3.3.6. Intrusive Dykes

From the available borehole logs and field observations the dykes are described as pale grey, fine to medium grained macro-crystalline, completely fractured, completely to highly weathered weak dolerite at the top becoming dark grey, fine to medium grained macro-crystalline, jointed, moderately to slightly weathered strong dolerite with depth. Dolerite was sometimes encountered interbedded with the sandstone suggesting the presence of either sandstone relics inside a dyke or thin sills. Their thickness is variable between 0.5 and 6.0m. They are quite numerous in the Sherwood Sandstone, mostly trending W30N.

B.3.3.7. Sherwood Sandstone

These rocks are moderately weak, weakly bedded, red-brown to yellow, fine to medium grained, friable sandstones with minor marl lenses and layers. The grains are mainly composed by quartz and feldspar and cemented by iron oxides. The uppermost 5m of the sandstone are from highly to moderately weathered with most cementation destroyed. There are bands of green and grey arenite.

The marl lenses have the effect of limiting groundwater inflows and may reduce weathering penetration below rockhead.

B.4. Hydrology and Hydrogeology

B.4.1. Hydrology

Tides, Flooding and Flood Prevention

The tidal range at Belfast Docks is 3.9m with a mean High Water Springs of +1.36mMSL at Kilroot Power Station (Carwell and Roberts, 1982). The city centre has been subject to occasional flooding in the past.

Millington (1997) notes that the highest water level recorded (at the outlet of the Blackstaff relief culvert) was +2.5m and was due to a tidal surge, not a river flood.

The Lagan Weir was constructed in 1993 to retain some water in the channel upstream during the lower part of the tidal cycle. The construction of the weir was partly to improve water quality in the river and partly to protect the city from flooding (ibid).

McConnel Lock and Weir, at River Terrace, constructed in the early 20th Century, has been abandoned and partly dismantled.

B.4.2. Hydrogeology

The main aquifer beneath Belfast comprises the Sherwood Sandstone. The sandstone aquifer is confined by the glacial clays or the alluvium. It may still have sub-artesian pressures which were witnessed in the past (Manning et al, 1970). Manning et al reported that work by Hartley (1935) indicated a minimum of 900m^3/hour should be available from the sandstones. Yield from the sandstone is strongly influenced by the presence of faults, numerous dykes, mainly those trending NW, and marl horizons.

Saline groundwater intrusion into the sandstone is only reported in reclaimed areas, including one at Whitla Street (Manning et al, 1970).

B.5. Ground Contamination

B.5.1. General

This section summarises the potential risks and hazards due to ground contamination within the harbour area.

Potential contamination to be encountered:

- Tars are present at shallow depth near the docks (locally to old gas works site); and
- There were substantial tip sites in the dock area once the area was already developed as well as part of the whole earlier reclamation process.

Particular care must be taken during excavation to avoid cross-contamination between different geological formations and aquifers. This is especially important for the Sherwood Sandstone, the main aquifer in the area. This formation can be in hydraulic continuity with the overburden drift deposits especially where the glacial clays are absent. In such cases the Sherwood Sandstone is particularly vulnerable to contamination.

B.6. Unexploded Munitions

Belfast was subjected to aerial bombing raids during World War II. Three particularly large scale raids occurred 7 - 8 April 1941, 15 - 16 April 1941 and 4 - 5 May 1941 (Barton 1999). Considerable damage was inflicted over the strategic areas of the harbour and docklands, particularly the Harland and Wolff shipyards, and aircraft factories in the east of the city. Damage was also sustained in other business and residential areas. A UXO risk assessment may need to be undertaken for works in or adjacent to the docks area.

Appendix C. Environmental Constraints

C.1. Constraints Report

INSERT CONSTRAINTS REPORT

C.2. Environmental Scoping Exercise (EA12 Form)

INSERT EA 12 FORM

Appendix D. Site Inspections

D.1. Walkover Survey 1

INSERT WALKOVER SURVEY NOTES

D.2. Options Walkover Survey

INSERT OPTIONS WO NOTES

D.3. Boat Survey

INSERT BOAT TRIP NOTES

Appendix E. Topo Survey

E.1. Threshold Survey Data

X	Y	Z	Note
334193.8	373620.8	3.712	Threshold level
334192.7	373617.4	3.332	Entrance level
334202.9	373662.4	3.449	Threshold level
334200.7	373662.9	2.928	Entrance level
334138.7	373588.8	3.442	Threshold level
334158.7	373652.4	3.049	Threshold level
334032.9	373479.8	3.928	Threshold level
334069.5	373479	3.889	Threshold level
334096.3	373542.2	3.956	Threshold level
334083.1	373546.6	3.962	Threshold level
334083.1	373546.6	3.963	Threshold level
334040.6	373617.1	2.94	Threshold level
334036.6	373644.1	2.867	Threshold level
334035.5	373656.9	2.87	Threshold level
334034.5	373667.3	2.884	Threshold level
334033.6	373673.1	2.864	Threshold level
333947.6	373660.2	5.139	Threshold level
333855.1	373701.7	3.392	Threshold level
333859.3	373664.2	3.493	Threshold level
333798.9	373642.9	3.956	Threshold level
333798.8	373642.8	3.646	Entrance level
333757.9	373722.3	3.514	Threshold level
333725.6	373587.3	3.68	Threshold level
333697.2	373454.8	3.868	Threshold level
333699.9	373462.8	3.828	Threshold level
333699.9	373462.8	3.826	Threshold level
333701.2	373466.8	3.681	Threshold level
333706.1	373477.8	3.662	Threshold level
333627.6	373650	3.032	Threshold level
334157.7	373699.3	2.699	Threshold level
334155.6	373700.4	2.055	Entrance level
334140.9	373727.1	1.783	Threshold level
334142.2	373726.5	1.622	Entrance level
334132.1	373691.9	2.358	Threshold level
334131.2	373688.8	2.35	Threshold level
334104.4	373756.3	1.754	Threshold level
334153.2	373756.3	1.78	Threshold level
334148.2	373774	1.839	Threshold level
334170	373772.6	1.911	Threshold level
334170.2	373769.4	1.57	Entrance level
334178	373755.4	2.202	Threshold level
334177.8	373756	1.756	Entrance level
334066.6	373757	4.007	Threshold level
334102.1	373709.5	1.644	Threshold level
334083.4	373700.4	1.75	Threshold level
334083.4	373700.4	1.752	Threshold level
334078.3	373748.2	2.077	Threshold level
334078.1	373748.6	1.734	Entrance level

X	Y	Z	Note
334100.5	373801.6	1.794	Threshold level
334148.7	373806.5	1.854	Threshold level
334148.9	373806.7	1.483	Entrance level
334125.2	373816.9	1.778	Threshold level
334130.5	373817.6	1.294	Entrance level
334090.7	373827.3	1.922	Threshold level
334089.1	373827.5	1.51	Entrance level
334221.2	373705.1	2.832	Threshold level
334217.1	373708.6	2.307	Entrance level
334198.5	373788.3	2.219	Threshold level
334209	373846.5	2.513	Threshold level
334210.9	373845.8	2.165	Entrance level
334081	373923.5	1.902	Threshold level
334080.9	373923.5	1.688	Entrance level
334077.4	373957.2	2.305	Threshold level
334069.9	373900.5	1.664	Threshold level
334011.4	373952.9	2.701	Entrance level
333918.9	373940.7	3.564	Threshold level
333904.3	373939.3	3.538	Threshold level
333830.8	373930.7	3.688	Threshold level
334015.2	373948.4	4.177	Threshold level
333935	373826.2	3.358	Threshold level
333726.2	373920.8	3.533	Threshold level
333880.9	373959.6	3.991	Threshold level
333885.5	373993.4	4.975	Threshold level
333887.4	373992.1	4.203	Entrance level
333832.9	374029.8	4.919	Threshold level
333832.5	374034.3	4.054	Entrance level
333853.1	374100.7	3.088	Threshold level
333806.9	374145.2	3.245	Threshold level
333799.7	374214	3.354	Threshold level
333794.8	374259.8	3.271	Threshold level
333683	374061	3.56	Threshold level
333683	374061.1	3.56	Threshold level
333662.4	374058.6	3.683	Threshold level
333662.8	374059	3.647	Threshold level
333637.5	374056.3	3.837	Threshold level
333650.4	374081.4	3.587	Threshold level
333550.6	374071.6	3.904	Threshold level
333550.6	374071.8	3.898	Threshold level
333635.3	374055.8	3.809	Threshold level
334325.8	373594.5	2.716	Threshold level
334359.3	373586.9	3.112	Threshold level
334392.1	373579.2	2.95	Threshold level
334434.2	373563.2	2.945	Threshold level
334417.9	373605.1	2.458	Threshold level
334392.5	373613.8	2.566	Threshold level
334362.4	373626.8	2.5	Threshold level
334474.3	373574.1	2.931	Threshold level
334423.5	373587.5	2.652	Threshold level
334470.1	373593	2.829	Threshold level

X	Y	Z	Note
334484.3	373625	2.739	Threshold level
334484.5	373625.7	2.329	Entrance level
334493.9	373645.4	2.448	Threshold level
334493.5	373644.4	2.319	Entrance level
334368.4	373677.9	2.341	Threshold level
334384.9	373670.2	2.581	Threshold level
334436.1	373656.4	2.538	Threshold level
334445.7	373656.3	2.475	Threshold level
334439.6	373645.3	2.467	Threshold level
334412.7	373632.3	2.53	Threshold level
334393.3	373648	2.571	Threshold level
334393.7	373650	2.287	Entrance level
334368.4	373655.4	2.622	Threshold level
334371.2	373659.9	1.948	Entrance level
334389.2	373715.4	2.407	Threshold level
334375.7	373734.7	2.533	Threshold level
334401	373783.3	2.739	Threshold level
334436.6	373803.1	2.516	Threshold level
334447.4	373780.2	2.584	Threshold level
334471	373781.2	2.523	Threshold level
334457.1	373776.5	2.594	Threshold level
334378.9	373788.7	2.587	Threshold level
334352.9	373769.9	2.514	Threshold level
334334.8	373784.5	2.567	Threshold level
334314.1	373757	2.57	Threshold level
334286.7	373776.6	2.605	Threshold level
334259.8	373778.5	2.56	Threshold level
334307.9	373789.8	2.507	Threshold level
334370.1	373817.3	2.563	Threshold level
334380.7	373838.7	2.551	Threshold level
334379.5	373828.1	2.072	Entrance level
334389.4	373816.6	2.625	Threshold level
334436.6	373849	2.312	Threshold level
334437.1	373851.6	1.997	Entrance level
334448.7	373820.2	2.373	Threshold level
334471	373824.1	2.209	Threshold level
334503.7	373803.7	2.418	Threshold level
334608.1	373797.6	3.229	Threshold level
334552	373807.8	2.843	Threshold level
334522.9	373840.8	2.465	Threshold level
334470.7	373870.4	2.465	Threshold level
334385.7	373864.6	2.548	Threshold level
334315.9	373827.7	2.628	Threshold level
334285.5	373832.4	2.547	Threshold level
334256.4	377041.7	3.19	Threshold level
334255.3	377040.1	2.891	Entrance level
334299.4	377037.9	2.84	Threshold level
334293.6	377037	2.946	Threshold level
334293.8	377039.8	2.541	Entrance level
334242	376965.1	3.239	Threshold level

X	Y	Z	Note
334317	377004.4	3.068	Threshold level
334316.9	377004.8	2.887	Entrance level
334275.2	376968.8	3.125	Threshold level
334275.3	376968.3	2.876	Entrance level
334322	376975.7	2.738	Entrance level
334321.5	376976.2	3.074	Threshold level
334301.2	376963.6	3.105	Threshold level
334301.5	376964	2.798	Entrance level
334240	376911.2	3.11	Threshold level
334516.2	376339.5	3.661	Threshold level
334522.7	376332	3.681	Threshold level
334690.2	376542.1	3.127	Threshold level
334707.4	376545.9	3.127	Threshold level
334699.6	376537.9	3.109	Threshold level
334284.7	374587.7	6.194	Threshold level
334268.5	374573.2	2.958	Threshold level
334267.4	374502.9	3.015	Threshold level
334344.7	374344.8	4.476	Threshold level
334348.8	374326.2	4.417	Threshold level
334354.2	374275.2	3.482	Threshold level
334355.2	374264	3.154	Threshold level
334342.8	374378.8	3.972	Threshold level
334341	374393.9	3.511	Threshold level
334340.4	374398.1	3.255	Threshold level
334495.1	373957.1	2.013	Threshold level
334492.3	373976.2	2.07	Threshold level
334489.7	373982.1	2.736	Entrance level
334509.9	373984.6	3.915	Entrance level
334518.1	373983.7	5.062	Threshold level
334526	373989.4	4.736	Entrance level
335019.3	374973	4.379	Threshold level
335015.4	374974.2	4.363	Threshold level
335004.9	374976.7	4.369	Threshold level
334976.7	374968.2	4.377	Threshold level
334970.7	374957.5	4.355	Threshold level
334948.3	374933.5	4.353	Threshold level
334938.5	374927.1	4.355	Threshold level
334923.3	374920.5	4.353	Threshold level
334860.9	374870.8	4.149	Threshold level
334861	374870.8	4.154	Threshold level
334800.3	374936.7	4.154	Threshold level
334987.4	374917.5	4.391	Threshold level
334984.1	374920.5	4.384	Threshold level
334977.8	374927.2	4.389	Threshold level
334964.3	374926.6	4.382	Threshold level

X	Y	Z	Note
334970.2	374921.4	4.407	Threshold level
334970.2	374921	4.388	Threshold level
334977.1	374914.1	4.386	Threshold level
334980.2	374910.4	4.368	Threshold level
335031.6	374962.9	5.72	Threshold level
335033.4	374957.1	4.007	Entrance level
335002.5	374912	5.735	Threshold level
335002.7	374908.3	4.015	Entrance level
334989.4	374895	4.054	Entrance level
334985.4	374895	5.712	Threshold level
334961.3	374875.7	4.049	Entrance level
334957.8	374877.2	5.716	Threshold level
334941.4	374866.1	3.897	Threshold level
334817.4	374782.8	4.155	Threshold level
334765.8	374807.3	4.128	Threshold level
334741.1	374816.9	4.113	Threshold level
334689.7	374843	4.129	Threshold level
334977.8	374741.4	3.115	Threshold level
335137.2	374777	2.814	Threshold level
335492.6	374798.7	3.707	Threshold level
335469.1	374796.9	3.666	Threshold level
335470.4	374801.5	3.202	Entrance level
336241.1	375337.2	3.803	Threshold level
336241.7	375330.9	2.949	Entrance level
336130	375133.4	3.823	Threshold level
336128	375138.1	3.362	Entrance level
336766.5	375853.3	3.908	Threshold level
335028.9	374895	4.553	Threshold level
335046.3	374923.1	4.099	Threshold level
333599.9	374289.1	3.53	Threshold level
333613.7	374288.3	3.551	Threshold level
333671.5	374285.6	3.357	Threshold level
333679	374285	3.507	Threshold level
333731.8	374229.4	3.276	Threshold level
333680.6	374170.6	3.58	Threshold level
333658.9	374159.2	3.555	Threshold level
333670.1	374169.6	3.562	Threshold level
333689.9	374171.6	3.542	Threshold level
333699	374172.6	3.55	Threshold level
333704.7	374173.1	3.561	Threshold level
333715.5	374175.6	3.59	Threshold level
333803	374358.8	3.157	Threshold level
333785.6	374420.5	3.431	Threshold level
333763.1	374500	3.868	Threshold level
333744.6	374564.9	3.83	Threshold level

X	Y	Z	Note
333737.9	374587.4	3.782	Threshold level
333767.2	374397.2	3.361	Threshold level
333902.8	374310.7	2.38	Threshold level
333946.2	374284.2	2.383	Threshold level
333946.2	374284.2	2.382	Threshold level
333967.1	374265.7	2.228	Threshold level
333946.7	374360	2.418	Threshold level
333946.1	374358.6	2.438	Entrance level
333941.6	374356.7	2.596	Threshold level
333911.6	374231.9	2.72	Threshold level
333926.2	374233.2	2.369	Threshold level
333872	374236.3	3.143	Threshold level
333853.4	374236.2	2.961	Threshold level
333857.7	374234.8	2.78	Threshold level
333918.1	374462.4	3.283	Threshold level
333919.9	374463	3.102	Entrance level
333866.9	374528.2	3.263	Threshold level
333858.9	374533.3	3.349	Threshold level
333961.3	374520.7	3.147	Threshold level
333959.4	374524.1	2.991	Threshold level
333954.2	374532.2	2.978	Threshold level
333908.3	374606	3.109	Threshold level
333890.4	374635.1	3.142	Threshold level
333961.9	374567.6	3.301	Threshold level
333978.3	374577.4	3.293	Threshold level
334011	374596.9	3.135	Threshold level
333994.1	374584.2	3.067	Threshold level
333876	374682.1	5.035	Threshold level
333866.7	374690.4	4.717	Threshold level
333861.3	374686.6	3.564	Entrance level
333808.3	374647.2	3.554	Threshold level
333823.2	374717.7	3.692	Threshold level
333817.1	374727.8	3.841	Threshold level
333813.3	374732.5	4.03	Threshold level
333537.4	373794	3.661	Threshold level
333537.4	373794	3.663	Threshold level
333521.4	373960.4	3.72	Threshold level
333537.1	373803.2	3.621	Threshold level
333557.8	373900.6	3.075	Threshold level
333403.4	373626.3	3.602	Threshold level
333405	373619.1	3.603	Threshold level
333399.3	373616	3.601	Threshold level
333398	373618.7	3.585	Threshold level
333394.8	373601.4	3.573	Threshold level
333400.8	373623	3.378	Entrance level

X	Y	Z	Note
333397	373609.3	3.365	Entrance level
333380.3	373656.7	3.974	Threshold level
333381.5	373649.1	3.237	Entrance level
333286.2	373599.1	3.573	Threshold level
333363.8	373622.7	3.555	Threshold level
333362.5	373623.4	3.336	Entrance level
333346.3	373617	3.598	Threshold level
333346.7	373617.9	3.378	Entrance level
333354.6	373669.2	3.992	Threshold level
333437	373525.8	3.174	Threshold level
333434.3	373496.5	3.341	Threshold level
333420	373539.6	3.375	Threshold level
333416.9	373596.4	3.572	Threshold level
333418	373599.9	2.993	Entrance level
333381.2	373684.2	5.975	Threshold level
333323.3	373843.2	3.729	Threshold level
333572.3	373903.6	3.162	Threshold level
333478.6	373963.7	3.722	Threshold level
333463.8	373962.6	3.739	Threshold level
333655.2	373834.2	3.231	Threshold level
333656.7	373824.5	3.245	Threshold level
333655	373839.1	3.506	Threshold level
333783.9	373822.4	3.758	Threshold level
333769.7	373820.6	3.664	Threshold level
333769.7	373820.6	3.591	Threshold level
333998.9	375242.4	3.442	Threshold level
333994.4	375251	3.508	Threshold level
333996.4	375249.8	3.06	Entrance level
333979.1	375275	3.392	Threshold level
333977.5	375271.6	3.124	Entrance level
333959.4	375294.2	3.582	Threshold level
333963.3	375292	3.153	Entrance level
333936	375253	3.516	Threshold level
333916.3	375237.1	3.69	Threshold level
333914.1	375273.3	3.879	Threshold level
333885.7	375255.3	3.898	Threshold level
333888.4	375251.3	3.755	Entrance level
333897.9	375250.8	3.88	Threshold level
333895.1	375252.1	3.496	Entrance level
333893.9	375302.7	3.9	Threshold level
333894.5	375305.5	3.572	Entrance level
333904.5	375317.9	3.966	Threshold level
333900.6	375319.9	3.649	Entrance level
333805	375097.1	4.021	Threshold level
333806.4	375098	3.728	Entrance level

X	Y	Z	Note
333823	375101.3	3.989	Threshold level
333822.1	375100	3.76	Entrance level
333888.6	375074.3	3.569	Threshold level
333891.9	375075.7	3.369	Entrance level
333891.9	375075.7	3.369	Entrance level
333891.4	375086.2	3.522	Threshold level
333908.9	375118.1	3.82	Threshold level
333927.5	375115.8	3.686	Threshold level
333926	375113.2	3.359	Entrance level
333902.8	375052.5	3.393	Threshold level
333898.6	375053	3.211	Entrance level
333929	375037.8	3.52	Threshold level
333926.7	375037.8	3.16	Entrance level
333930	375027.1	3.19	Threshold level
333935.4	375024.1	3.077	Threshold level
333880.9	375044.8	3.836	Threshold level
333882.3	375046.8	3.608	Entrance level
333924.6	374954.1	3.317	Threshold level
333751.4	374860.1	4.072	Threshold level
334146	375721.7	3.456	Threshold level
334142.9	375722.5	3.102	Entrance level
334118	375723.3	3.471	Threshold level
334120.4	375721	3.136	Entrance level
334099.5	375713.4	3.539	Threshold level
334097.4	375710.3	3.149	Entrance level
334081.4	375698.3	3.562	Threshold level
334083.6	375704.1	3.041	Entrance level
334096.3	375691.4	3.024	Entrance level
334100.8	375691.6	3.253	Threshold level
334097.1	375692.4	3.018	Entrance level
334055.4	375641	3.482	Threshold level
334056.4	375640.3	3.189	Entrance level
334069.7	375636.1	3.181	Entrance level
334070.1	375635.6	3.476	Threshold level
334071.1	375669.9	3.822	Threshold level
334088.5	375667.6	3.212	Entrance level
334092.6	375666.1	3.255	Threshold level
334099.2	375637.5	3.078	Threshold level
334102	375642.2	2.903	Entrance level
334102	375642.2	2.902	Entrance level
334127.2	375633.9	3.073	Threshold level
334128	375636.2	2.776	Threshold level
334128	375636.1	2.79	Threshold level
334115.2	375609.9	3.123	Threshold level
334076.8	375743.4	3.482	Threshold level

X	Y	Z	Note
334080.3	375773.8	3.452	Threshold level
334111.2	375784.9	3.261	Threshold level
334125.4	375767.2	3.682	Threshold level
334078.2	375798	3.473	Entrance level
334086.6	375797.8	3.798	Threshold level
334086.4	375841.1	3.785	Threshold level
334080.9	375841.3	3.651	Entrance level
334086.8	375860.2	3.796	Threshold level
334086.4	375856.3	3.573	Entrance level
334086.5	375884.4	3.633	Threshold level
334082.2	375883.9	3.708	Entrance level
334088.1	375906.1	3.657	Threshold level
334082.9	375903.7	3.609	Entrance level
334070.8	375880.1	4.162	Threshold level
334073.5	375879.8	3.746	Entrance level
334109.3	375860.8	3.822	Threshold level
334108.8	375855.5	3.107	Entrance level
334108.8	375831.1	3.519	Threshold level
334109	375839.6	3.302	Threshold level
334172.9	376261.5	1.583	Threshold level
334173.4	376264.2	1.613	Threshold level
334100.6	376246.4	3.668	Threshold level
334101.4	376247.8	3.064	Entrance level
334105.9	376182.7	3.312	Threshold level
334106.8	376184	2.916	Entrance level
334083.5	376206.3	4.108	Threshold level
334082.8	376204.5	3.619	Entrance level
334103.5	376141.7	3.291	Threshold level
334104.3	376143.2	2.73	Entrance level
334065.4	376171	3.852	Threshold level
334064.3	376169.4	3.51	Entrance level
334025.8	376055.7	3.438	Threshold level
334025.6	376059	3.382	Threshold level
334030.1	376072.8	3.66	Threshold level
334030.7	376073.4	3.497	Entrance level
334086.2	376053.3	3.568	Threshold level
334087	376054.8	3.356	Entrance level
334115.6	376042	3.635	Threshold level
334116	376043.9	3.45	Entrance level
334122	376050.2	3.383	Threshold level
334134.3	376045.5	3.34	Threshold level
334134.3	376045.5	3.34	Threshold level
334087.9	376064.9	3.614	Threshold level
334087.8	376062.9	3.376	Entrance level
334030.4	376088.9	3.718	Threshold level

X	Y	Z	Note
334030.3	376087.8	3.544	Entrance level
333994.9	376044.2	4.02	Threshold level
333995.9	376047.3	3.439	Entrance level
333964.4	376071.8	3.808	Threshold level
334029.4	376047.6	3.54	Threshold level
334088	376023.8	3.643	Threshold level
334087.6	376022.6	3.52	Entrance level
334140.9	376023.7	3.93	Threshold level
334133.9	376056.8	3.3	Threshold level
334131.6	376079.4	3.134	Threshold level
334130.1	376099.7	3.014	Threshold level
334128.2	376126.9	2.721	Threshold level
334205.4	376483.6	3.268	Threshold level
334203.2	376484.5	2.944	Entrance level
334199.1	376453.9	3.065	Threshold level
334195.9	376428.7	2.909	Threshold level
334219.7	376399.6	3.011	Threshold level
334287.9	376390.4	3.07	Threshold level
334291.2	376378.3	3.153	Threshold level
334291.4	376378.3	3.156	Threshold level
334212.9	376386.7	3.156	Threshold level
334180.6	376383.2	2.793	Threshold level
334165	376314.5	2.792	Threshold level
334155.1	376275.5	2.734	Threshold level
334133.2	376281.9	2.985	Threshold level
334141	376316.2	3.021	Threshold level
334154.5	376366.6	2.621	Threshold level
334155.9	376370.3	2.637	Threshold level
334210.6	376348.4	2.599	Threshold level
334205.8	376352.4	2.156	Entrance level
334242.6	376357.7	2.757	Threshold level
334292.8	376420.3	2.787	Threshold level
334299.2	376436.1	2.873	Threshold level
334297.5	376436.4	2.503	Entrance level
334286.6	376442.3	2.929	Threshold level
334287.6	376444.5	2.542	Entrance level
334289.2	376478.8	2.808	Threshold level
334289.8	376479.5	2.632	Entrance level
334301.9	376491.7	2.814	Threshold level
334299.5	376492.4	2.618	Entrance level
334284.1	376499.3	2.809	Threshold level
334306.7	376584.6	3.303	Threshold level
334282.9	376554.7	3.088	Threshold level
334281.6	376528	3.107	Threshold level
334231.1	376509.1	3.172	Threshold level

X	Y	Z	Note
334241.8	376527.4	3.323	Threshold level
334287.9	376574.7	3.533	Threshold level
334233.3	376636.8	3.662	Threshold level
334216.6	376637	3.436	Threshold level
334292.5	376628.1	3.668	Threshold level
334289.6	376605.9	3.692	Threshold level
334296.4	376665.1	3.258	Threshold level
334309.1	376662.6	3.21	Threshold level
334310.8	376713.7	3.079	Threshold level
334313.5	376778.2	3.194	Threshold level
334313.6	376778.2	3.193	Threshold level
334201.8	376680.7	3.138	Threshold level
334221.4	376693.6	2.812	Threshold level
334286.7	376686.1	2.949	Threshold level
334280.7	376687.3	2.981	Threshold level
334292.7	376693.1	2.967	Threshold level
334293.1	376701.5	2.932	Threshold level
334287.8	376708.6	2.944	Threshold level
334293.3	376701.4	2.916	Threshold level
334273.4	376711.9	2.781	Threshold level
334224.3	376718.2	2.565	Threshold level
334239.1	376726.5	2.523	Threshold level
334282.6	376722.4	3.018	Threshold level
334288.7	376721.3	3.05	Threshold level
334294.3	376728.2	3.033	Threshold level
334294.6	376736.6	3.042	Threshold level
334289.3	376743.6	3.051	Threshold level
334241.7	376750.8	2.606	Threshold level
334217	376763.9	2.761	Threshold level
334255.7	376758.8	2.756	Threshold level
334265.9	376757.7	2.779	Threshold level
334289.9	376755.8	3.064	Threshold level
334295.7	376762.7	3.029	Threshold level
334296	376771.1	3.016	Threshold level
334290.4	376778	3.04	Threshold level
334274.6	376780.9	2.874	Threshold level
334223	376786.9	2.64	Threshold level
334184.6	376790	2.624	Threshold level
334199.1	376840.2	3.332	Threshold level
334196.7	376839.4	2.629	Entrance level
334186.4	376721.4	2.757	Threshold level
334183	376666.4	3.118	Threshold level
334186.5	376627.4	3.429	Threshold level
334191.1	376593.6	3.616	Threshold level
334200	376562.8	3.737	Threshold level

X	Y	Z	Note
334207.3	376521.4	3.405	Threshold level
334207.5	376496.5	3.242	Threshold level
334228	376581.6	3.855	Threshold level
334259	376484.4	3.219	Threshold level
336609.3	374378.9	2.969	Threshold level
336608.7	374374.6	3.246	Threshold level
336599.8	374356.8	3.342	Threshold level
336638.2	374304.1	4.035	Threshold level
336649.8	374433.5	3.707	Threshold level
336649.9	374434.4	3.739	Threshold level
336649	374434.7	3.344	Entrance level
336653.4	374443.2	3.767	Threshold level
336653.9	374448.2	3.739	Threshold level
336653.1	374453.7	3.296	Entrance level
336654.9	374456.2	3.735	Threshold level
336653.5	374464.8	3.744	Threshold level
336653.6	374466.1	3.743	Threshold level
336651.1	374464.4	3.264	Entrance level
336653.2	374453.8	3.289	Entrance level
336274.1	374292.5	2.826	Threshold level
336235.2	374648.7	3.287	Threshold level
336243.1	374701.3	3.357	Threshold level
336307.5	374638.3	3.23	Threshold level
336314.4	374691.2	3.33	Threshold level
336270.6	374597.1	3.68	Threshold level
336261.9	374605	3.655	Threshold level
336318.7	374545.7	3.171	Threshold level
336212.7	374502.6	3.133	Threshold level
336118.2	374545.9	3.711	Threshold level
336120.4	374550.2	3.045	Entrance level
336162.9	374528.2	3.772	Threshold level
336161.9	374531.2	3.244	Entrance level
336096.2	374746.7	3.793	Threshold level
336114.5	374753	3.817	Threshold level
335886	374593.9	2.989	Threshold level
335939	374575.8	2.739	Threshold level
335950.2	374520.1	2.923	Threshold level
335968.9	374522.5	2.968	Threshold level
335842.2	374641.3	3.089	Threshold level
335851.4	374648.3	2.7	Entrance level
335910.4	374673.3	2.869	Threshold level
335899.7	374667	2.866	Threshold level
335883.5	374667.2	2.923	Threshold level
336084.7	374609.6	3.174	Threshold level
336022.3	374619.8	3.13	Threshold level
336090.9	374610.3	3.172	Threshold level
336090.8	374610.2	3.005	Entrance level
336218	374443.7	2.779	Threshold level
336207.3	374447.9	2.859	Threshold level
336309.9	374318.5	2.994	Threshold level

X	Y	Z	Note
336311.8	374323.9	2.999	Threshold level
336311.3	374324.4	2.801	Entrance level
336313.8	374329.2	2.983	Threshold level
336313.6	374329.8	2.814	Entrance level
336315.7	374334.5	2.992	Threshold level
336315.6	374334.7	2.816	Entrance level
336304.2	374326.7	2.96	Threshold level
336292	374365.2	2.926	Threshold level
336490.9	374427.4	3.397	Threshold level
336499.9	374439.5	3.399	Threshold level
336509.6	374452	3.394	Threshold level
336519	374464.1	3.4	Threshold level
336517.9	374484.2	3.41	Threshold level
336509	374496.5	3.404	Threshold level
336497.6	374505.1	3.396	Threshold level
336524	374502.1	3.41	Threshold level
336471.5	374423.1	3.42	Threshold level
336457	374428.8	3.425	Threshold level
336406.8	374502.2	3.7	Threshold level
336409.9	374509.3	3.689	Threshold level
336409.8	374512.5	3.423	Entrance level
336093.4	374657.2	3.198	Threshold level
336167.7	374647.6	3.117	Threshold level
336218.9	374625.9	3.702	Threshold level
336223.6	374624.1	3.66	Threshold level
336226.2	374625.3	3.18	Entrance level
336236.5	374623	3.642	Threshold level
336237.9	374623.6	3.262	Entrance level
336234.7	374617.6	3.642	Threshold level
336236.8	374615.3	3.27	Entrance level
336270.9	374634.9	3.464	Threshold level
336216.4	374249.3	2.842	Threshold level
336196.9	374271.3	2.954	Threshold level
336194.2	374271.8	2.954	Threshold level
336188.7	374272.7	2.99	Threshold level
336176.5	374275.2	3.054	Threshold level
336159.4	374278.3	3.201	Threshold level
336143.5	374281.2	3.307	Threshold level
336262.1	374258.9	2.35	Threshold level
336268.8	374257.6	2.304	Threshold level
336401.7	374263.6	2.932	Threshold level
336435.8	374206.2	3.349	Threshold level
336446.1	374183.2	3.38	Threshold level
336448.9	374224.9	3.388	Threshold level
336439.8	374226.8	3.401	Threshold level
336413	374232.2	3.401	Threshold level
336385.1	374237.6	3.506	Threshold level
336380.3	374238.1	3.506	Threshold level
336375.7	374239.1	3.501	Threshold level
336367.3	374240.5	3.518	Threshold level
336060	374142.7	3.476	Threshold level

X	Y	Z	Note
336064.6	374144.9	3.357	Threshold level
336074.2	374129.1	3.334	Threshold level
336068	374126	3.271	Threshold level
336059.3	374121.1	3.38	Threshold level
336057.8	374120.5	3.564	Threshold level
336050.5	374116.7	3.728	Threshold level
335574.4	374537.8	3.215	Threshold level
335569.7	374594.1	3.116	Threshold level
335539.7	374503.6	3.321	Threshold level
335504.7	374518.5	3.38	Threshold level
335601.7	374497.2	3.181	Threshold level
335659.6	374488.3	3.16	Threshold level
335657.9	374490.1	2.997	Entrance level
335649.2	374472.2	3.125	Threshold level
335648.5	374472.8	2.965	Entrance level
335688.2	374478	3.083	Threshold level
335688.2	374478.1	2.926	Entrance level
335694.2	374438.7	3.25	Threshold level
335679.1	374458.1	3.048	Threshold level
335679	374457	2.86	Entrance level
335706.1	374455.6	3.237	Threshold level
335702.9	374454.7	3.042	Entrance level
335623.9	374618.2	3.166	Threshold level
335625.6	374617.9	2.918	Entrance level
335634.2	374530.7	3.456	Threshold level
335642.6	374538.4	2.758	Entrance level
335780.4	374590.1	2.859	Threshold level
335781.6	374594.2	2.87	Threshold level
335780.9	374594	2.657	Entrance level
335758.4	374542.3	3	Threshold level
335758.9	374543.5	2.786	Entrance level
335768.4	374536.2	3.004	Threshold level
335768.7	374536.1	2.731	Entrance level
335766.1	374454	2.907	Threshold level
335766.7	374453.7	2.61	Entrance level
335781.5	374471.4	3.337	Threshold level
335763.9	374433.6	3.255	Threshold level
335766.8	374434.6	2.927	Entrance level
335734.6	374513.1	3.107	Threshold level
335735.3	374513.2	2.937	Entrance level
335736.2	374388.4	3.591	Threshold level
335736.2	374390.4	3.123	Entrance level
335740	374371.4	3.763	Threshold level
335731.8	374371.9	3.565	Entrance level
335830.1	374566.2	3.005	Threshold level
335831.3	374565.7	2.624	Entrance level
335862.8	374503.4	3.2	Threshold level
335839.7	374512.3	3.198	Threshold level
335850	374568	2.955	Threshold level
335849.4	374568.3	2.675	Entrance level
335892.6	374447	3.642	Threshold level

X	Y	Z	Note
335899.5	374444.5	2.924	Entrance level
335969.7	374397.7	3.922	Threshold level
335969.1	374397.7	3.592	Entrance level
335750.9	374593	2.507	Threshold level
335492	374568.6	3.984	Threshold level
335476.3	374568.8	3.988	Threshold level
335458	374561.7	4.031	Threshold level
335461.2	374576	4.023	Threshold level
335464.3	374590.1	4.013	Threshold level
335467.3	374604.6	4.016	Threshold level
335466.2	374613.5	4.026	Threshold level
335494.4	374612.1	4.043	Threshold level
335443.9	374507.3	3.349	Threshold level
335428.6	374577.6	2.961	Threshold level
335356.4	374498.1	3.015	Threshold level
335355.8	374498.2	2.801	Entrance level
335380.1	374482.1	3.132	Threshold level
335329.7	374448.3	3.187	Threshold level
335330.5	374448.5	2.787	Entrance level
335291.9	374533.9	2.755	Threshold level
335292.7	374533.8	2.574	Entrance level
335595.5	374347.6	3.625	Threshold level
335599.8	374324.5	3.773	Threshold level
335600.2	374324.9	3.612	Entrance level
335539.4	374378.3	3.434	Threshold level
335529.7	374380	3.413	Threshold level
335461.7	374393	3.198	Threshold level
335452.3	374386.4	3.233	Threshold level
335407.8	374368.5	3.396	Threshold level
335407.4	374370.7	3.394	Threshold level
335376.3	374340.7	3.846	Threshold level
335374.9	374346.9	3.383	Entrance level
335192.6	374072.7	3.244	Threshold level
335186.6	374001.8	3.473	Threshold level
335186.2	374001.8	3.218	Entrance level
335215.5	374029.9	3.356	Threshold level
335230.5	374034.7	3.594	Threshold level
335230.1	374034.1	3.427	Entrance level
335157.4	374012.7	3.393	Threshold level
335159.1	374012.9	3.14	Entrance level
335162.9	373970.9	3.38	Threshold level
335162.2	373970.8	3.23	Entrance level
335214.1	374117.6	3.113	Threshold level
335272.6	374047.4	3.473	Threshold level
335298.9	374018.2	3.651	Threshold level
335131.8	374146.6	3.649	Threshold level
335132.6	374146.3	3.445	Entrance level
335079.3	374134.5	3.539	Threshold level
335080.2	374134.3	3.383	Entrance level
335047.8	374097.3	3.194	Threshold level
335046	374094.8	2.67	Entrance level

X	Y	Z	Note
335058.2	374064.3	3.09	Entrance level
335058	374064.6	2.933	Entrance level
335019.2	374083.2	3.312	Threshold level
335018.7	374083.2	3.099	Entrance level
335394.8	374071.3	3.713	Threshold level
335404.5	374167.7	3.695	Threshold level
335404.6	374167	3.583	Entrance level
335359.5	374094.1	3.646	Threshold level
335360.2	374095	3.498	Entrance level
335328	374139.1	3.412	Threshold level
335318.6	374149	3.389	Threshold level
335317.4	374151.6	3.325	Threshold level
335317.9	374148.7	3.173	Entrance level
335249.5	374123.8	3.726	Threshold level
335263.5	374131.5	3.598	Threshold level
335373.1	374263.2	4.085	Threshold level
335371.8	374268.5	3.703	Entrance level
335325.2	374223	3.868	Threshold level
335325.9	374223.4	3.421	Entrance level
335379.9	374249.1	3.951	Threshold level
335380.6	374249.2	3.573	Entrance level
335385.2	374256.8	4.152	Threshold level
335385.3	374256.3	3.752	Entrance level
335040.8	374290.9	3.863	Threshold level
335043.3	374288.9	3.167	Entrance level
335048.8	374296.7	3.339	Threshold level
335049.1	374296	3.045	Entrance level
335076.1	374296.2	2.911	Threshold level
335069.5	374267.7	2.914	Threshold level
335128	374306.9	3.027	Threshold level
335065.3	374376.2	3.356	Threshold level
335099.2	374374.6	3.275	Threshold level
335100.7	374374.9	2.861	Entrance level
335126.7	374425	3.352	Threshold level
335127.2	374424.3	2.733	Entrance level
335153.9	374387.9	3.177	Threshold level
335153.5	374386.6	2.751	Entrance level
335209.3	374379.4	3.27	Threshold level
335209.2	374378.6	2.988	Entrance level
335206.7	374351.8	3.424	Threshold level
335206.4	374352.2	3.056	Entrance level
335186.4	374354	3.296	Threshold level
335186.8	374353.8	2.995	Entrance level
335252.3	374371.8	3.544	Threshold level
335252	374371.3	3.149	Entrance level
335289	374266.3	2.96	Entrance level
335288.7	374266.5	3.325	Threshold level
335246.6	374322.6	3.484	Threshold level
335247.4	374321.7	3.056	Entrance level
335254.9	374311.3	3.015	Entrance level
335254.5	374311.1	3.251	Threshold level

X	Y	Z	Note
335254.8	374311.7	3.012	Entrance level
335279.1	374417.5	3.482	Threshold level
335279.5	374417.6	3.185	Entrance level
335270.7	374419.3	3.204	Entrance level
335270.5	374419.1	3.49	Threshold level
335188.7	374272.9	3.579	Threshold level
335189.5	374272.2	3.179	Entrance level
335211	374232.3	3.482	Threshold level
335211.3	374231.9	3.225	Entrance level
335232.7	374190.4	3.614	Threshold level
335232.9	374190	3.437	Entrance level
337597.9	375482	3.444	Threshold level
337595.4	375460.2	3.439	Threshold level
337438.9	375528.2	3.013	Threshold level
337437.3	375538.8	2.044	Entrance level
337371.6	375583.2	2.732	Threshold level
337339.5	375447.8	2.93	Threshold level
337341.1	375447.6	2.535	Entrance level
337181.3	375472.5	2.224	Threshold level
337370.2	375344.2	3.409	Threshold level
337372.1	375344.2	3.196	Entrance level
337123.4	375342.3	2.567	Threshold level
337093.7	375349.8	2.597	Threshold level
337205.7	375284.7	2.803	Threshold level
337217.2	375279.9	2.834	Threshold level
337099.8	375278.2	3.016	Threshold level
337153.7	375158.8	3.148	Threshold level
337153.6	375158.7	3.108	Threshold level
337145.8	375131.8	3.53	Threshold level
337144.3	375120.1	3.53	Threshold level
337009.9	375156.9	2.585	Threshold level
337067.1	375157	3.124	Threshold level
336969.4	375244.3	2.772	Threshold level
336971.9	375248.2	1.884	Entrance level
336891	375204.9	1.315	Threshold level
336854.7	375205.5	1.421	Threshold level
336867.6	375175.5	1.323	Threshold level
336879.9	375107.6	1.864	Entrance level
336884	375106.3	2.64	Threshold level
336886	375110	2.714	Threshold level
336881.9	375112.2	1.76	Entrance level
336915.2	375091.2	2.599	Threshold level
336981.6	374937.4	3.406	Threshold level
336974.6	374923.8	3.393	Threshold level
337029.2	375043.1	3.372	Threshold level
336914.1	374861.4	3.273	Threshold level
336942.5	374801.4	3.517	Threshold level
336958.1	374848.9	3.596	Threshold level
336743.9	374722.1	1.851	Threshold level
336751.6	374720.2	1.841	Threshold level
336733	374736.9	1.805	Threshold level

X	Y	Z	Note
336727.1	374799.2	2.105	Threshold level
336723.7	374790.1	2.063	Threshold level
336721.2	374781.6	2.057	Threshold level
336702.7	374772.7	1.447	Threshold level
336600.8	374772.8	1.576	Threshold level
336785.4	374656.5	2.911	Entrance level
336786	374656.9	3.232	Threshold level
336881.9	374705.7	3.989	Threshold level
336789.4	374607.2	3.389	Threshold level
336657.2	374555.6	2.7	Threshold level
336635.1	374595.5	1.88	Threshold level
336625.3	374585.9	2.083	Threshold level
336680	374629.2	2.353	Threshold level
336652.9	374998.5	1.275	Threshold level
336766.1	374954.7	1.658	Threshold level
336704.4	375069.9	0.841	Threshold level
336610.3	374954.4	1.567	Threshold level
336629.9	374877.6	1.375	Threshold level
335043.1	373564.1	3.402	Threshold level
335028	373562	3.362	Threshold level
335074.1	373547.1	3.044	Threshold level
334970.8	373529.9	3.121	Threshold level
335005.5	373593.7	3.347	Threshold level
334966.9	373570.2	3.295	Threshold level
334983.2	373555.9	3.306	Threshold level
334957	373488.6	3.167	Threshold level
334995.5	373416.8	2.987	Threshold level
335206.6	373458.2	3.467	Threshold level
335230	373536.3	4.098	Threshold level
335210.3	373552.4	3.725	Threshold level
335163.7	373546.9	3.635	Threshold level
335198.5	373525.2	3.783	Threshold level
335233.9	373611.9	4.088	Threshold level
335232.8	373476.2	4.037	Threshold level
335238.5	373490.4	4.331	Threshold level
335221.5	373596.3	4.189	Threshold level
335182.9	373632.6	3.863	Threshold level
335200.5	373645.1	3.676	Threshold level
335149.4	373582.2	3.55	Threshold level
335184.1	373585.6	3.777	Threshold level
335183.1	373602	3.722	Threshold level
335158.7	373607.1	3.566	Threshold level
335225.3	373787	4.241	Threshold level
335203.2	373769.9	3.956	Threshold level
335185	373760.5	3.983	Threshold level
335201.6	373723.8	4.226	Threshold level
335223.6	373756.9	4.318	Threshold level
335165.2	373779	3.782	Threshold level
335014.4	373859.1	2.797	Threshold level
334708.7	373517.3	4.846	Threshold level
334711	373528.2	4.822	Threshold level

X	Y	Z	Note
334761.5	373586.2	3.588	Threshold level
334758.8	373586.3	3.495	Threshold level
334766.5	373593.5	3.506	Threshold level
334768.3	373595.4	6.089	Threshold level
334778.7	373604.8	3.5	Threshold level
334810.6	373620.7	3.375	Threshold level
334802	373617.8	3.369	Threshold level
334778.8	373541.8	4.217	Threshold level
334759.6	373549.5	4.203	Threshold level
334771.9	373527.9	4.216	Threshold level
335022.5	373538	2.916	Threshold level
334964	373551.2	3.316	Threshold level
334966.1	373502	3.184	Threshold level
335007.2	373418.5	3.009	Threshold level
335227.3	373453.1	3.959	Threshold level
335175.8	373560.3	3.571	Threshold level
335013.7	373881	2.845	Threshold level
334709.7	373518.6	3.832	Threshold level
334718.6	373536.7	3.519	Threshold level
334779.3	373605.6	3.521	Threshold level
334798	373574.8	3.771	Threshold level
334801	373596.1	3.787	Threshold level
334740.6	373510.4	4.268	Threshold level
335002.9	373507.9	3.21	Threshold level
334987.9	373428.8	3.26	Threshold level
335230.1	373522	4.411	Threshold level
335087.6	373805.5	2.649	Threshold level
334709.3	373521.2	4.829	Threshold level
334724.2	373544.5	3.462	Threshold level
334780.1	373606.6	6.113	Threshold level
334796.6	373575.2	3.772	Threshold level
334802.3	373595.7	3.739	Threshold level
334744.6	373487.4	4.278	Threshold level
335001	373495.7	3.193	Threshold level
334987.9	373428.8	3.261	Threshold level
335037.3	373735.6	2.44	Threshold level
334720.9	373541.9	6.002	Threshold level
334793.4	373615.3	4.253	Threshold level
334796.1	373578.3	3.765	Threshold level
335049.2	373503.3	3.25	Threshold level
335052	373439.2	3.368	Threshold level
335039.9	373728.7	2.413	Threshold level
334731.8	373555.2	6.012	Threshold level
334800.3	373618.6	4.278	Threshold level
334795.3	373578.5	3.758	Threshold level
335089.2	373511.9	3.297	Threshold level
335103	373447.4	3.685	Threshold level
335047.1	373703	2.231	Threshold level
334737.8	373560.8	3.491	Threshold level
334804.1	373618.9	4.265	Threshold level
334789.3	373577.7	3.744	Threshold level

X	Y	Z	Note
335089.2	373511.9	3.297	Threshold level
335101.9	373436.6	3.563	Threshold level
334740.6	373568	6.006	Threshold level
334811.6	373620.8	4.255	Threshold level
334788.2	373578.1	3.78	Threshold level
335088.3	373523.9	3.292	Threshold level
335053.5	373428.7	3.276	Threshold level
334744.2	373572.5	3.451	Threshold level
334814.3	373620.9	3.361	Threshold level
335088.3	373523.9	3.291	Threshold level
335090.1	373367.6	4.381	Threshold level
335042.1	373716.5	2.557	Threshold level
334756.1	373586.3	6.101	Threshold level
334815.6	373620.6	3.382	Threshold level
335035.1	373513.1	3.28	Threshold level
335053	373365	3.763	Threshold level
335042.1	373716.5	2.554	Threshold level
335018.5	373374.6	3.997	Threshold level
335092.3	373864.4	3.044	Threshold level
335035.1	373512.3	2.959	Threshold level
335021.4	373393.6	3.416	Threshold level
335144	373645.4	3.568	Threshold level
335095.5	373485.7	3.396	Threshold level
335054.4	373402.6	3.623	Threshold level
335158.6	373695.3	3.575	Threshold level
335046.4	373475.6	3.224	Threshold level
335060.1	373393.3	3.638	Threshold level
335155.1	373712.2	3.56	Threshold level
334990.3	373466.6	3.264	Threshold level
335090.5	373398.4	3.784	Threshold level
335101.6	373688.1	2.417	Threshold level
334961.4	373462.2	3.252	Threshold level
335225.7	373372.2	3.94	Threshold level
335109.3	373666.1	2.674	Threshold level
334970.4	373453	3.326	Threshold level
335224.5	373359.9	4.09	Threshold level
334971.4	373702.3	2.731	Threshold level
335039.7	373463.9	3.23	Threshold level
335225.7	373373.6	3.964	Threshold level
334961.6	373692.1	2.859	Threshold level
335095.5	373474.7	3.275	Threshold level
335203.7	373342.1	4.232	Threshold level
334944.3	373694.5	2.612	Threshold level
335163.7	373377.3	4.007	Threshold level
334987.9	373700.3	2.8	Threshold level
335181.4	373385.7	3.792	Threshold level
334707.1	373506.5	4.049	Threshold level
335162.6	373415	3.906	Threshold level
335167.8	373427.3	3.844	Threshold level
334706.9	373509.5	4.874	Threshold level
335229.2	373411.7	4.146	Threshold level

X	Y	Z	Note
334707.1	373510.5	4.041	Threshold level
335218.5	373400.8	4.092	Threshold level
335141.7	373444.8	3.894	Threshold level
335142.9	373516.7	3.385	Threshold level
335042.4	373564.1	2.923	Entrance level
335072.4	373550	2.761	Entrance level
335022.5	373540.2	2.653	Entrance level
334962.8	373537.4	2.882	Entrance level
334964.7	373551.2	2.974	Entrance level
334967.3	373569.3	2.948	Entrance level
334982.5	373556.1	2.908	Entrance level
335094	373476.4	3.086	Entrance level
335142.8	373516.1	3.003	Entrance level
335230.1	373523.3	3.715	Entrance level
335229.9	373535.5	3.849	Entrance level
335175.7	373558.5	3.276	Entrance level
335163.7	373547.4	3.303	Entrance level
335199.5	373525.4	3.419	Entrance level
335234.9	373612	3.845	Entrance level
335232.9	373476.6	3.874	Entrance level
335237.3	373490.1	3.978	Entrance level
335222.9	373595.6	3.865	Entrance level
335183.5	373632.7	3.525	Entrance level
335199.8	373647.3	3.842	Entrance level
335151.7	373582.8	3.141	Entrance level
335183.5	373585.7	3.243	Entrance level
335180.5	373599.4	3.433	Entrance level
335159.2	373607.4	3.227	Entrance level
335226.9	373786.8	3.923	Entrance level
335204.3	373768.5	3.6	Entrance level
335185.5	373760.8	3.59	Entrance level
335202.2	373724.9	3.858	Entrance level
335221.8	373756.9	4.049	Entrance level
335167.7	373778	3.374	Entrance level
334708.7	373509.5	3.894	Entrance level
334710.3	373524	3.723	Entrance level
334761.9	373582.3	3.742	Entrance level
334771.3	373592.7	3.904	Entrance level
334811.3	373619.4	3.239	Entrance level
334798.7	373616.3	3.384	Entrance level
334788.9	373577.1	3.627	Entrance level
334801.8	373596.3	3.627	Entrance level
335042.4	373564.1	2.922	Entrance level
334970.6	373533.1	2.94	Entrance level
334802.2	373616.9	3.343	Entrance level
335028.5	373561.9	2.934	Entrance level
334520.1	373003.8	2.808	Threshold level
334473.7	372667.2	3.662	Threshold level
334483.8	372660.9	3.667	Threshold level
334515.7	372683.5	3.654	Threshold level
334484.9	372717.4	3.404	Threshold level

X	Y	Z	Note
334519.9	372736.1	2.645	Threshold level
334515.6	372753	2.892	Threshold level
334521.3	372795.6	2.889	Threshold level
334442.8	372789.2	3.864	Threshold level
334479.1	372799.5	3.353	Threshold level
334523.8	372811.8	2.593	Threshold level
334521.8	372839.2	2.698	Threshold level
334446.5	372832.1	3.836	Threshold level
334528.1	372864	2.608	Threshold level
334335.2	373023.7	3.995	Threshold level
334445.8	373041.6	2.497	Threshold level
334441.7	373068.3	2.46	Threshold level
334425	373081.1	2.94	Threshold level
334419.4	373080.6	2.841	Threshold level
334377.1	373074.6	3.667	Threshold level
334337.4	373068.9	4.318	Threshold level
334401.4	373103	3.325	Threshold level
334396.2	373124.5	3.138	Threshold level
334440.6	373104.3	2.632	Threshold level
334456.2	373111.9	2.665	Threshold level
334364.2	373205.9	3.964	Threshold level
334444.5	373149.5	2.402	Threshold level
334458.8	372646.8	4.107	Threshold level
334474.2	372666.5	3.326	Threshold level
334485.9	372640.1	3.621	Threshold level
334513.8	372709.6	2.715	Threshold level
334461.6	372739.5	3.897	Threshold level
334483.4	372786	3.298	Threshold level
334493.6	372831.6	3.332	Threshold level
334473.3	372840	3.512	Threshold level
334526.6	372874	2.436	Threshold level
334335.2	373023.7	3.993	Threshold level
334439.3	373083.7	2.642	Threshold level
334364.5	373105.2	3.469	Threshold level
334387.2	373211.7	3.846	Threshold level
334448.5	373203.6	2.664	Threshold level
334510.5	372677.3	3.614	Threshold level
334460.5	372694.9	3.916	Threshold level
334448.4	372748.8	4.046	Threshold level
334454.5	372778.2	3.757	Threshold level
334460.9	372822.7	3.789	Threshold level
334499.2	372848.1	3.103	Threshold level
334526.6	372874	2.436	Threshold level
334398.9	373034.1	3.274	Threshold level
334346.8	373162.4	4.094	Threshold level
334383.3	373199.6	3.612	Threshold level
334448.2	373206.1	2.947	Threshold level
334453.7	372708.8	4.118	Threshold level
334489.8	372760.4	3.397	Threshold level
334422.1	372771.2	3.944	Threshold level
334436.7	372815.9	4.132	Threshold level

X	Y	Z	Note
334518.4	372899.9	2.486	Threshold level
334411.7	373036.8	3.231	Threshold level
334346.6	373188.2	4.049	Threshold level
334391.8	373165	3.681	Threshold level
334518	372768.5	2.896	Threshold level
334421.6	372770.8	4.203	Threshold level
334507.2	372933.6	2.581	Threshold level
334430	373040.4	2.984	Threshold level
334398.1	373139.6	3.378	Threshold level
334418.5	372782.2	4.199	Threshold level
334496.9	372965.6	2.599	Threshold level
334489.7	372988.2	2.34	Threshold level
334478.4	373022.3	2.332	Threshold level
334458.4	373018.7	2.385	Threshold level
334449.4	373017.2	2.612	Threshold level
334404.4	373009.7	3.072	Threshold level
334367.8	373003.7	3.548	Threshold level
334332.2	372997.9	4.005	Threshold level
334340.1	373024.3	4.009	Threshold level
334362.9	373028.4	3.775	Threshold level
334510	372676	3.22	Entrance level
334481.6	372662.7	3.288	Entrance level
334516.8	372683.8	3.336	Entrance level
334454.2	372708.5	3.948	Entrance level
334520.1	372736.1	2.613	Entrance level
334518.3	372768.6	2.789	Entrance level
334419.7	372780.1	3.865	Entrance level
334444.3	372786.9	3.552	Entrance level
334480.5	372797	3.116	Entrance level
334521.5	372841.7	2.54	Entrance level
334436.8	372818.1	3.814	Entrance level
334500.4	372845.2	2.907	Entrance level
334364.2	373026.5	3.459	Entrance level
334430.3	373036.7	2.733	Entrance level
334444.6	373042.1	2.266	Entrance level
334439.3	373083.5	2.043	Entrance level
334426.4	373081.1	2.359	Entrance level
334419	373082.8	2.579	Entrance level
334378	373075.9	3.357	Entrance level
334336.6	373070.6	3.978	Entrance level
334398.1	373102.2	2.763	Entrance level
334392.8	373123.8	2.884	Entrance level
334443.1	373102.4	2.039	Entrance level
334352.5	373185.3	3.692	Entrance level
334396.6	373139	3.193	Entrance level
334440	373067.8	1.875	Entrance level
334264	376019.6	2.722	Entrance level
334159.8	375679.3	2.621	Entrance level
334180.9	375671.6	2.488	Entrance level
334186.8	375611.5	2.801	Entrance level
334153	375622.6	2.622	Entrance level

X	Y	Z	Note
334173.6	375633.6	2.663	Entrance level
334286.8	375654.2	2.181	Entrance level
334213.3	375571.2	2.628	Entrance level
334056	375369	3.451	Entrance level
334084.6	375448.6	3.561	Entrance level
334035.7	375500.6	3.325	Entrance level
334136.2	375459.7	2.725	Entrance level
334026.9	375241.3	2.753	Entrance level
334028.6	374972.7	2.405	Entrance level
333987.7	374995.5	2.705	Entrance level
334098.8	374963.4	2.607	Entrance level
333968	374881.3	2.989	Entrance level
334006.1	374719.4	2.541	Entrance level
333948.8	374760.2	3.172	Entrance level
333959	374755.1	3.044	Entrance level
334000.8	374658.9	2.902	Entrance level
334106.8	374628.9	2.397	Entrance level
334058.3	374634.6	2.648	Entrance level
334189.1	375626.7	2.814	Entrance level
334007	374686	2.831	Entrance level
334191.9	375652	2.737	Entrance level
334424.3	376005	2.447	Threshold level
334186.9	375774.6	2.386	Threshold level
334179.5	375668.8	2.789	Threshold level
334198.9	375685.2	2.459	Threshold level
334157.4	375620.9	3.081	Threshold level
334159.5	375646.8	3.24	Threshold level
334177.1	375638.7	2.801	Threshold level
334211.8	375573.4	2.877	Threshold level
334098.1	375326.3	2.753	Threshold level
334079.1	375445.4	3.678	Threshold level
334029.7	375497.6	3.673	Threshold level
334138.9	375458.6	2.788	Threshold level
334151.5	375318.5	2.789	Threshold level
333983	375053.7	2.949	Threshold level
334010.8	374992.7	2.656	Threshold level
333976.7	374972.5	2.849	Threshold level
334172.9	374840.4	2.374	Threshold level
334004.8	374721.5	2.672	Threshold level
333949.7	374763.4	3.121	Threshold level
333958.6	374758.4	3.175	Threshold level
334008.8	374685.6	2.909	Threshold level
334001.6	374682.1	2.847	Threshold level
334058	374636.3	2.71	Threshold level
334176	374583.7	3.167	Threshold level
334437.8	376004.8	1.878	Threshold level
334143.4	375771.9	3.005	Threshold level
334197.2	375652.5	2.853	Threshold level
334150.1	375624.3	2.98	Threshold level
334144.2	375677.1	3.085	Threshold level
334066.8	375348	3.67	Threshold level

X	Y	Z	Note
334033.2	375261.5	3.214	Threshold level
334027.4	374971.7	2.713	Threshold level
333986.9	374994.2	2.89	Threshold level
334092	374935.9	2.548	Threshold level
334180	374811.1	2.444	Threshold level
333938.3	374667.8	3.22	Threshold level
334110.7	374627.3	2.563	Threshold level
334145.4	374538.3	2.477	Threshold level
334484.1	376145.8	2.154	Threshold level
334159.4	375774.2	2.932	Threshold level
334195.5	375624.1	2.768	Threshold level
334137.3	375695	3.083	Threshold level
334049.5	375360.3	3.645	Threshold level
334025.1	375242.9	3.117	Threshold level
334101.9	374960.1	2.901	Threshold level
334032.2	374900.6	2.744	Threshold level
333925.6	374659.6	3.363	Threshold level
334110.7	374627.3	2.559	Threshold level
334492.5	376174.6	2.081	Threshold level
334179.4	375812.6	2.674	Threshold level
334188.6	375610.8	3.019	Threshold level
334139.6	375652.1	2.982	Threshold level
334091.2	374871.6	2.561	Threshold level
333903.6	374646.1	3.416	Threshold level
334492.4	376174.7	2.007	Threshold level
334210.5	375797.6	2.74	Threshold level
334287.3	375658.3	3.009	Threshold level
334004.3	374829.7	2.838	Threshold level
333999.2	374659	3.003	Threshold level
334267	376113.2	1.827	Threshold level
334158.7	375676.4	2.799	Threshold level
333968	374881.3	3.709	Threshold level
334264.8	376011	3.032	Threshold level
334265.9	376021	3.341	Threshold level
334241.4	374556.3	2.498	Entrance level
334217.3	374570.1	2.604	Entrance level
334127.5	374472.5	2.27	Entrance level
334110.8	374462.9	2.319	Entrance level
334185.8	374377.9	2.329	Entrance level
334194.5	374431.4	2.24	Entrance level
334049.2	374520.2	2.407	Entrance level
334083.4	374486.1	2.201	Entrance level
334025.5	374580.1	2.915	Entrance level
333940.3	374442.4	2.721	Entrance level
333970.2	374392.1	2.315	Entrance level
334175.2	373859	1.192	Entrance level
334172.3	373828.6	1.171	Entrance level
334117.3	373856.7	1.003	Entrance level
334092.6	373867.7	1.213	Entrance level
333978.5	373966.5	2.829	Entrance level
334056.4	374086.2	0.926	Entrance level

X	Y	Z	Note
334221.2	374099.4	1.287	Entrance level
334237.7	374086.8	1.19	Entrance level
333928.7	374086.1	2.574	Entrance level
333993.9	374026.2	1.556	Entrance level
333981.6	374154.7	1.517	Entrance level
333984.3	374406.5	2.366	Entrance level
334092.4	373855.2	1.076	Entrance level
334113.4	373869.8	1.103	Entrance level
333959.9	373964.6	2.988	Entrance level
334251.3	373972.5	1.439	Entrance level
334237.7	374086.8	1.193	Entrance level
333972.4	374179.9	1.774	Entrance level
334225.8	374035.8	1.141	Entrance level
334221.6	374685.9	2.108	Threshold level
334333.7	374651.4	3.415	Threshold level
334226.7	374577.4	3.029	Threshold level
334200.6	374567.7	2.692	Threshold level
334109.8	374464	2.676	Threshold level
334073.6	374439.8	2.161	Threshold level
334198.5	374430	2.502	Threshold level
334193.8	374450.9	2.595	Threshold level
334085.6	374486.8	2.469	Threshold level
334073	374508.1	2.579	Threshold level
334046.7	374532.4	2.706	Threshold level
333966.5	374388	2.573	Threshold level
333990.6	374410.5	2.717	Threshold level
334171.1	373828.2	1.443	Threshold level
334117.4	373855.7	1.491	Threshold level
334092.4	373853.3	1.475	Threshold level
334113.8	373870.6	1.496	Threshold level
333959.5	373965.9	3.667	Threshold level
334059.8	374027.7	1.203	Threshold level
334266.4	373998.3	1.29	Threshold level
334224.7	374036.4	1.777	Threshold level
334215.8	374099.4	1.377	Threshold level
334237.5	374094.6	1.583	Threshold level
333944.5	374087.6	2.279	Threshold level
333994.4	374046.7	1.719	Threshold level
333968.2	374179.1	1.851	Threshold level
334346.8	374670.3	3.379	Threshold level
334216.7	374572.1	2.77	Threshold level
334185.4	374563.4	2.303	Threshold level
334149.3	374485.7	2.328	Threshold level
334059.5	374403.2	2.369	Threshold level
334210.9	374480.5	2.602	Threshold level
334026.6	374581.1	3.051	Threshold level
334035.6	374508.5	2.723	Threshold level
334174.7	373857.7	1.46	Threshold level
334027.6	373861.3	1.565	Threshold level
334083.8	373958.1	2.267	Threshold level
334058.4	374040.1	1.258	Threshold level

X	Y	Z	Note
334251.9	373971.3	1.931	Threshold level
334218.9	374064.7	1.336	Threshold level
334163.3	374110.6	1.617	Threshold level
334042.1	374096.1	1.439	Threshold level
333984.1	374154.8	1.63	Threshold level
334348.1	374678.7	3.381	Threshold level
334127.4	374473.2	2.432	Threshold level
334110.5	374434.1	2.267	Threshold level
334050.1	374518	2.73	Threshold level
333935.9	374439.5	2.979	Threshold level
334092.7	373868.4	1.497	Threshold level
334099.9	373959.9	2.258	Threshold level
334054.4	374085.9	1.258	Threshold level
334198.8	374113.7	1.252	Threshold level
333996.7	374025	1.721	Threshold level
334022.1	374211.5	1.979	Threshold level
334357.3	374697.1	3.374	Threshold level
334192.1	374350.7	2.602	Threshold level
334172	373966.3	2.013	Threshold level
334198.8	374113.7	1.252	Threshold level
333985.1	374267.6	1.966	Threshold level
334350.6	374707.9	3.397	Threshold level
334218.3	373989.1	1.283	Threshold level
334196.3	374134.1	1.566	Threshold level
333947	374302.3	2.301	Threshold level
334333.5	374631.6	3.374	Threshold level
334185.4	374377.5	2.642	Threshold level
334208.2	373987.7	1.392	Threshold level
334161.2	374130.6	1.599	Threshold level
333934.3	374315.7	2.397	Threshold level
334260.6	374644.8	2.67	Threshold level
334191.6	373986.6	1.702	Threshold level
334152.4	374129.8	1.592	Threshold level
334025.4	374269.2	1.72	Threshold level
334237.6	374636.8	2.65	Threshold level
334064.1	373990.3	1.735	Threshold level
334149	374129.4	1.591	Threshold level
334014.9	374264.6	1.824	Threshold level
334232.7	374549.8	2.941	Threshold level
333978.9	373967.6	3.344	Threshold level
334144	374129.1	1.591	Threshold level
334134.2	374127.9	1.575	Threshold level
334125.2	374126.9	1.642	Threshold level
334116.6	374125.8	1.68	Threshold level
334105.2	374125	1.518	Threshold level
334080.3	374122.9	1.368	Threshold level
334066.5	374122.2	1.297	Threshold level
334050.4	374137.9	0.954	Threshold level
333935.9	374108.6	2.018	Threshold level
333928.7	374086.1	3.267	Threshold level
334281.2	374364.6	1.989	Entrance level

X	Y	Z	Note
334387.9	374150	1.298	Entrance level
334679.3	373963.3	1.033	Entrance level
334615	374017.5	1.104	Entrance level
334710.1	374052.5	1.895	Entrance level
334787.7	373998	2.487	Entrance level
334463.7	373701.7	1.984	Entrance level
334518.8	373680.4	2.213	Entrance level
334297.5	374436	2.19	Threshold level
334202.2	374260.4	1.998	Threshold level
334393.4	374173.2	1.372	Threshold level
334349	374173.4	1.665	Threshold level
334608.2	374061.3	0.218	Threshold level
334616.4	373963	0.824	Threshold level
334707.6	374048	3.525	Threshold level
334859.8	373992.1	2.087	Threshold level
334841.3	374011.8	2.028	Threshold level
334474.2	373705	2.427	Threshold level
334505.7	373671.4	2.455	Threshold level
334234.7	374359.2	2.615	Threshold level
334202.9	374254.7	1.978	Threshold level
334389.4	374192.5	1.222	Threshold level
334299.8	373902.9	1.796	Threshold level
334601.6	374030.2	1.263	Threshold level
334587.5	373950.2	0.649	Threshold level
334788	373996.5	2.953	Threshold level
334859.8	373992.1	2.087	Threshold level
334812.5	373965.2	3.917	Threshold level
334443.3	373695.4	2.411	Threshold level
334282.6	374363	2.449	Threshold level
334183	374327.5	2.307	Threshold level
334678.9	373964.2	1.009	Threshold level
334779.5	374049.1	2.73	Threshold level
334870.4	373926.2	5.887	Threshold level
334453.6	373727	2.681	Threshold level
334137.6	374312.6	2.459	Threshold level
334711.3	374047.6	1.63	Threshold level
334841.7	373910.6	3.21	Threshold level
334410.9	373740.7	2.26	Threshold level
334146.2	374330.9	2.303	Threshold level
334614.3	373752.1	2.669	Threshold level
334387.8	373747.6	2.643	Threshold level
334158.1	374333.2	2.281	Threshold level
334603.5	373772.7	3.058	Threshold level
334376	373736	2.554	Threshold level
334188.5	374363.9	2.615	Threshold level
334584.7	373757.6	2.571	Threshold level
334476.3	373720.6	2.261	Threshold level
334234.1	374202.1	1.608	Threshold level
334602	373705.7	2.55	Threshold level
334498.2	373760.6	2.606	Threshold level
334233.7	374206.1	1.809	Threshold level

X	Y	Z	Note
334603.7	373698.9	2.601	Threshold level
334504.2	373767.3	2.656	Threshold level
334455.8	374093.5	1.984	Threshold level
334539.5	373690	2.456	Threshold level
334567.6	373741.7	2.747	Threshold level
334410.3	374091.9	1.38	Threshold level
334520.4	373707.6	2.439	Threshold level
334521	373664.5	2.856	Threshold level
334410.8	374038.9	1.157	Threshold level
334535.3	373744.2	2.646	Threshold level
334388.6	374149.8	1.571	Threshold level
334434.4	373141	1.992	Entrance level
334432.7	373147.6	2.099	Entrance level
334404	373264.9	2.816	Entrance level
334450.7	372954.9	2.564	Entrance level
334464.7	372912.7	2.62	Entrance level
334472.2	372918.7	2.596	Entrance level
334452.2	372974.4	2.73	Entrance level
334445.7	372976	2.762	Entrance level
334436.1	372974.9	2.795	Entrance level
334359.2	372962.4	3.7	Entrance level
334346.3	372960.4	3.833	Entrance level
334333.6	372942.9	4.031	Entrance level
334337.4	372930.1	4.239	Entrance level
334272.2	372547.5	3.923	Entrance level
334250.4	372513.9	3.819	Entrance level
334103	372375.8	3.176	Entrance level
334068.9	372345.4	3.649	Entrance level
334065.7	372344.1	3.704	Entrance level
334287.2	372346.5	3.283	Entrance level
334270.6	372295.7	4.619	Entrance level
334238.2	372280.1	4.358	Entrance level
334443.9	372944.4	2.418	Entrance level
334472.6	372951.8	2.436	Entrance level
334430.8	372974.1	2.836	Entrance level
334063.1	372338.8	3.74	Entrance level
334288.2	372320	4.363	Entrance level
334473	372953.9	2.416	Entrance level
334432.6	373140.5	2.627	Threshold level
334431	373147.4	2.733	Threshold level
334418.7	373196.5	2.813	Threshold level
334458	373166.4	2.642	Threshold level
334446	372942	2.511	Threshold level
334478.3	372919.8	2.536	Threshold level
334473	372948.4	2.532	Threshold level
334458.8	372980.1	2.5	Threshold level
334448.5	372986.6	2.474	Threshold level
334426.1	372981.6	2.806	Threshold level
334357.9	372969.8	3.727	Threshold level
334347.9	372968.8	4.001	Threshold level
334343	372944	4.328	Threshold level

X	Y	Z	Note
334344.1	372931.8	4.446	Threshold level
334255.7	372515	4.161	Threshold level
334301.8	372390.8	4.112	Threshold level
334068.4	372346.5	4.141	Threshold level
334065.3	372344.5	4.105	Threshold level
334062.4	372338.8	4.132	Threshold level
334285.3	372318.3	4.763	Threshold level
334268.2	372300.3	4.571	Threshold level
334236.4	372285.1	4.489	Threshold level
334401.5	373265	3.423	Threshold level
334438	372951.5	2.76	Threshold level
334458.2	372911.9	2.601	Threshold level
334472.2	372956.2	2.489	Threshold level
334489	372898.6	2.593	Threshold level
334369.1	372887	4.239	Threshold level
334288.6	372351.5	3.43	Threshold level
334494.7	372880.8	2.49	Threshold level
334367.6	372866.8	3.877	Threshold level
334279	372371.8	3.799	Threshold level
334475.9	372875.6	2.561	Threshold level
334336.2	372609	4.172	Threshold level
334113	372386.9	2.555	Threshold level
334284.5	372362.5	3.945	Threshold level
334466	372897.2	2.623	Threshold level
334343.3	372612.5	4.377	Threshold level
334107.6	372384.6	2.558	Threshold level
334438.6	372864.2	2.99	Threshold level
334363.2	372597.8	5.462	Threshold level
334102.1	372382.1	2.564	Threshold level
334426.5	372855.7	3.172	Threshold level
334369.1	372576.5	5.446	Threshold level
334097.4	372379.9	2.557	Threshold level
334411	372882.3	3.253	Threshold level
334350.5	372549.3	4.794	Threshold level
334092.2	372377.5	2.528	Threshold level
334369.6	372842.6	3.808	Threshold level
334365.5	372564.1	4.813	Threshold level
334401.5	372898.1	3.257	Threshold level
334281.4	372537.8	3.809	Threshold level
334423	372886.1	3.089	Threshold level
334276.2	372549.3	4.121	Threshold level
334416.9	372934.9	3.246	Threshold level
334411.1	372952.5	3.512	Threshold level
334389	372948.9	3.636	Threshold level
334392	372975.4	3.533	Threshold level
334388.3	372926.3	3.447	Threshold level
334363.8	372920.1	4.399	Threshold level
333885.5	371364.8	2.535	Entrance level
333854.2	371347.6	3.619	Entrance level
333845.5	371336.8	3.587	Entrance level
333838.5	371323.7	3.955	Entrance level

X	Y	Z	Note
333832.7	371316.6	4.087	Entrance level
333829.8	371328.9	3.892	Entrance level
333839.8	371345.8	3.534	Entrance level
333845.6	371353.1	3.33	Entrance level
333850.4	371363.7	3.111	Entrance level
333852.1	371380	2.833	Entrance level
333820.3	371395.3	3.135	Entrance level
333797.9	371373.9	3.609	Entrance level
333789	371362	3.942	Entrance level
333782.8	371373.4	3.852	Entrance level
333788.3	371382.5	3.622	Entrance level
333796.4	371405.3	3.323	Entrance level
333760.6	371430.5	3.558	Entrance level
333920.1	371340.6	2.239	Entrance level
333943.5	371295.3	2.409	Entrance level
333919.8	371227.2	3.94	Entrance level
333922.9	371232.3	3.995	Entrance level
333927.6	371238.5	3.973	Entrance level
333932.3	371245.4	3.967	Entrance level
333951.4	371242.9	3.458	Entrance level
333942.5	371269.2	3.78	Entrance level
333966.3	371225.9	3.997	Entrance level
333877	371369.9	2.6	Entrance level
333937	371275.6	3.752	Entrance level
333876.1	371369.1	3.098	Threshold level
333862.4	371357.3	3.42	Threshold level
333847.3	371336.8	3.88	Threshold level
333839.5	371322.8	4.384	Threshold level
333834.7	371315.7	4.515	Threshold level
333827.7	371329.2	4.363	Threshold level
333838.6	371346.2	3.937	Threshold level
333843.1	371355.3	3.885	Threshold level
333837.3	371365.7	3.49	Threshold level
333852.3	371379.3	3.444	Threshold level
333834.6	371387.4	3.223	Threshold level
333798.3	371373.5	4.038	Threshold level
333791.9	371360.5	4.334	Threshold level
333779.7	371374.6	4.089	Threshold level
333785.9	371385	4.106	Threshold level
333795.9	371405.1	3.653	Threshold level
333760.6	371428.3	3.783	Threshold level
333918.4	371339.4	3.019	Threshold level
333941.3	371294.5	2.966	Threshold level
333918.1	371226.9	4.327	Threshold level
333922.3	371232.6	4.294	Threshold level
333926.8	371239	4.316	Threshold level
333931.4	371245.7	4.313	Threshold level
333938.1	371248.2	3.801	Threshold level
333943.2	371269.3	3.928	Threshold level
333937.9	371275.9	3.903	Threshold level
333884.5	371362.6	3.255	Threshold level

X	Y	Z	Note
333854.3	371347.6	3.867	Threshold level
333849.6	371364.1	3.43	Threshold level
333819.6	371394.6	3.365	Threshold level
333953.1	371243.6	3.779	Threshold level
333974.3	371239	3.826	Threshold level
333964.7	371226.1	4.699	Threshold level
334276.7	374952.9	1.892	Entrance level
334320.3	374966.5	2.077	Entrance level
334391.5	375133.5	2.336	Entrance level
334328.7	375005.7	2.551	Entrance level
334546.1	375144.2	2.861	Entrance level
334520.7	375284.3	2.058	Entrance level
334461	375277.3	1.79	Entrance level
334483.4	375259.2	1.739	Entrance level
334538.2	375218.3	1.475	Entrance level
334566.1	375535.5	2.303	Entrance level
334535.3	375447.3	2.399	Entrance level
334430.6	375603.5	2.212	Entrance level
334384.2	375135.8	2.31	Entrance level
334358	375027.8	2.586	Entrance level
334527.3	375226.1	1.446	Entrance level
334378.3	375141.5	2.266	Entrance level
334493.2	375251	1.589	Entrance level
334474.1	375264.5	1.573	Entrance level
334465.7	375270.6	1.586	Entrance level
334292.7	374945.8	1.998	Threshold level
334272.2	374954.2	1.897	Threshold level
334379.3	375141.8	2.618	Threshold level
334328.6	375005.4	2.696	Threshold level
334359.8	375026.5	3.454	Threshold level
334532.9	375170.6	3.379	Threshold level
334526.6	375278.8	1.96	Threshold level
334467.2	375273	1.824	Threshold level
334494.4	375252.1	1.694	Threshold level
334451.9	375245.7	2.782	Threshold level
334534.3	375438.1	2.8	Threshold level
334441.6	375595.1	2.312	Threshold level
333858.3	371468.9	4.608	Threshold level
334290.1	374946.4	2.016	Threshold level
334293.9	374929.4	1.306	Threshold level
334385	375137.1	2.664	Threshold level
334550.1	375145	3.345	Threshold level
334685.6	375252.4	3.405	Threshold level
334537.1	375272.4	1.871	Threshold level
334475.5	375266.7	1.733	Threshold level
334507.4	375243.3	1.681	Threshold level
334321.6	375218.4	1.943	Threshold level
334531	375433.7	2.829	Threshold level
334430.3	375602.8	2.291	Threshold level
333865.5	371451.6	4.613	Threshold level
334284.3	374948.5	2.01	Threshold level

X	Y	Z	Note
334323.7	374973.9	3.742	Threshold level
334391.8	375134.2	2.632	Threshold level
334668.8	375236.6	3.051	Threshold level
334542.9	375267.4	1.852	Threshold level
334484.7	375260.4	1.822	Threshold level
334529.1	375228	1.711	Threshold level
334327.5	375291.1	2.054	Threshold level
333972.5	371308.1	3.019	Threshold level
334276.3	374952.1	2.222	Threshold level
334466.9	375321.2	1.885	Threshold level
334557.4	375258	1.796	Threshold level
334540.6	375219.4	1.633	Threshold level
334063.1	371124.3	4.201	Threshold level
334471	375318.2	1.907	Threshold level
334569.1	375250.5	1.802	Threshold level
334549.1	375212.6	1.716	Threshold level
334346.3	375295.6	2.16	Threshold level
334070.1	371084.2	3.999	Threshold level
334475.1	375315.3	1.882	Threshold level
334524.9	375314.4	3.3	Threshold level
334574.5	375533	2.587	Threshold level
334087.7	370995.1	3.358	Threshold level
334479.6	375312.1	1.894	Threshold level
334511	375313	3.272	Threshold level
334089.1	370984.5	3.36	Threshold level
334484.1	375309.6	1.862	Threshold level
334409.4	375373.4	2.139	Threshold level
334486	375308.7	1.842	Threshold level
334446.4	375355.6	1.955	Threshold level
334069.7	371115.6	3.659	Threshold level
334491.5	375304.8	1.827	Threshold level
334503.3	375337.6	3.31	Threshold level
334513.4	375289	1.887	Threshold level
334403.1	375370.7	2.016	Threshold level
334520.7	375283.3	2.463	Threshold level
334399.7	375363.8	1.85	Threshold level
334397.6	375359.7	1.832	Threshold level
334393.6	375351.4	1.872	Threshold level
334391.4	375346.9	2.143	Threshold level
334389.1	375342.2	2.033	Threshold level
334448.3	375329.9	1.806	Threshold level
334446.1	375325.5	1.844	Threshold level
334443.8	375320.9	1.847	Threshold level
334441.4	375316.1	1.84	Threshold level
334439.1	375311.4	1.853	Threshold level
334437	375307	1.848	Threshold level
334434.9	375302.9	1.839	Threshold level
334453.6	375285	1.871	Threshold level
334461.8	375278.4	1.85	Threshold level
335043.4	374985.4	4.157	Entrance level
335042.8	375009.5	4.261	Entrance level

X	Y	Z	Note
335040.7	375032.1	4.274	Entrance level
335036.1	375048.7	4.293	Entrance level
334983.9	375026.2	4.364	Threshold level
334852	374008.1	2.481	Threshold level
334985.5	375001	4.346	Threshold level
334999.5	374988.5	4.347	Threshold level
335007.1	374986.5	4.361	Threshold level
335017.3	374983.8	4.359	Threshold level
335021.6	374983.3	4.356	Threshold level
335025.9	374982.4	4.425	Threshold level
335022.1	375048.3	4.312	Threshold level
335018	375047	4.329	Threshold level
335013.5	375045.6	4.336	Threshold level
335006.5	375042.5	4.361	Threshold level
335003.7	375042.1	4.338	Threshold level
334996.5	375039.2	4.29	Threshold level
335033.7	375045.3	6.006	Threshold level
335034.2	375043.5	6.002	Threshold level
335035.7	375037.4	5.997	Threshold level
335036	375035.5	5.998	Threshold level
335037.2	375029.3	6.009	Threshold level
335037.4	375027.6	6.012	Threshold level
335038.3	375021.2	5.995	Threshold level
335038.4	375017.6	6.001	Threshold level
335038.9	375013	5.983	Threshold level
335038.9	375011.3	5.985	Threshold level
335038.8	375004.8	6.007	Threshold level
335038.8	375002.9	5.987	Threshold level
335039	374996.5	5.978	Threshold level
335039	374994.5	5.98	Threshold level
335039.4	374988.4	5.954	Threshold level
335039	374986.2	5.989	Threshold level
333925.3	371330.5	2.313	Entrance level
333916.7	371311.8	2.613	Entrance level
333915.3	371312.7	2.914	Threshold level
333910.9	371305.6	2.945	Threshold level
333923.6	371329.1	2.962	Threshold level
333902.8	371292.4	3.131	Threshold level
333894.2	371279.1	3.458	Threshold level
333882.4	371261.2	4.135	Threshold level
333879.7	371256.7	4.005	Threshold level
333886.3	371243.2	4.053	Threshold level
333892.7	371253.3	3.942	Threshold level
333898.8	371263	3.652	Threshold level
333905.3	371272.5	3.507	Threshold level
333911.4	371282.1	3.334	Threshold level
333924.4	371301.3	2.789	Threshold level
333927.9	371304.3	2.737	Threshold level
333948.8	371320	3.163	Threshold level
333893.8	371356.7	3.166	Threshold level
333884	371339.4	3.502	Threshold level

X	Y	Z	Note
333877.5	371328.3	3.692	Threshold level
333871.2	371318.4	4.06	Threshold level
333866.9	371311.8	4.097	Threshold level
333860.8	371302	4.306	Threshold level
333869.6	371289.8	4.429	Threshold level
333875.3	371300.7	3.971	Threshold level
333880.7	371311.3	3.836	Threshold level
333887	371321.2	3.537	Threshold level
333896	371331.3	3.334	Threshold level
333902	371341	3.083	Threshold level

E.2. Topographic Survey Data

INSERT CD OF SURVEY DRAWINGS

Appendix F. Stakeholder Consultation

F.1. Stakeholder List

INSERT STAKEHOLDER CONTACTS

F.2. Stakeholder Communication Record

INSERT COMMS REGISTER

F.3. Stakeholder Workshops

F.3.1. Workshop Leaflet

INSERT LEAFLET

F.3.2. Options Review Workshop

INSERT PRESENTATION

F.3.3. Stakeholders Workshop

INSERT PRESENTATION

F.3.4. BHC Workshop

INSERT PRESENTATION

Appendix G. Flood Mapping

G.1. Base Flood Map

INSERT MAP

G.2. Climate Change Flood Maps

INSERT MAP

INSERT MAP

Appendix H. Temporary Barriers Report

Appendix I. Emergency Plan Update Memo

Appendix J. Flood Alleviation Options

J.1. Flood Defence Type Assessment

Technical Viability Assessment

The long list flood defence types were assessed for each of the flood cells initially in terms of technical viability. Once the technically viable defence types for each flood cell were filtered further assessment of environmental and economic impact of the overall defence was performed to identify the short list of options.

Table J.1 presents the results of the long list assessment of the available options at each of the flood locations.

The relevant cells have been colour-coded red, amber and green to indicate the viability of the defence type at each of the flood cells to resolve flooding. Red implies the defence type is not a viable solution at the flood cell, amber is viable but likely to have technical issues or be less viable than other types and green is a more easily achieved defence type at the flood cell which will provide the required SoP.

Table J-1 Long List Defence Type Assessment

Defence Type	General Comment	Technical Viability				
		Harbour & City	Sydenham / East Belfast	Ravenhill	Ormeau	Lockview
Raise Quays	Long term approach where quays are raised to suitable level as development continues in Harbour.	Yes – would resolve flood risk to city centre but no effect upstream of harbour area. Very expensive and complex solution in an operational port.	Yes – would resolve some flood risk to East Belfast in long term.	Yes – but access to perform works is difficult and likely that entire sections of quay would require replacement for poor condition.	N/A	N/A
Raise Quay Gates	Any low spots along the defence will require raising, including gates in the quay walls.	Yes - would need to be done in conjunction with other solutions to remove spill point in defence.	N/A	N/A	N/A	N/A
Flood Walls	Flood wall defences constructed along river bank where allowable based on landscaping and maintaining access and views to river.	Yes – but all walls would need to be constructed set back from the operational areas of the Harbour and line agreed with BHC within harbour boundary.	N/A	Yes – but walls likely to be set back from existing frontage due to poor condition of foundation for upstand walls.	Yes – dwarf wall / kerb at rear of existing embankment on left bank would increase SoP.	Yes – wall could be constructed along Lockview Road / rear of boat club but access could be restricted.
Flood Banks	Additional new flood banks on River Lagan where space and landscape requires.	No – not suitable to construct flood banks.	No – raising existing flood banks may be suitable to increase SoP at Victoria Park in the future but no new flood bank.	No – not suitable to construct flood banks.	No – existing structure could be altered but no new flood bank would be suitable in this location.	Yes – could use flood banks to protect a length of Lockview at Belfast Boat Club.

Defence Type	General Comment	Technical Viability				
		Harbour & City	Sydenham / East Belfast	Ravenhill	Ormeau	Lockview
Flood Railings	Decorative railing with flood panels at bottom may be manufactured for use in landscape areas.	Yes – bespoke landscape appropriate flood railings could be used.	Yes – railings could be used along Sydenham Bypass / Victoria Park to contain tidal flood.	No – unlikely that railings would be suitable for the Ravenhill area given the poor condition of the existing frontage and need to create a suitable set back location.	Yes – could set back flood railings at rear of towpath; however, significant length of defence required and this may not be most economic.	Yes – bespoke landscape appropriate flood railings could be used along towpath at Stranmillis Wharf in conjunction with other works.
Raise existing banks / towpaths	Adapting existing structures to achieve higher SoP.	N/A	Yes – possible to raise banks to increase SoP.	N/A	Yes – possible to raise towpath to increase SoP.	Yes – possible to raise towpath and rear access driver at Boat club to increase SoP
Alter existing structures & provide flood gates at openings	Existing boundary walls and features may be altered / replaced to provide a 'hidden' flood defence with flood gates to close gaps.	Possible – potential to use existing boundary walls etc. to provide flood defence with gates / temporary barriers at road closure points; however, ability of existing structures to act as flood defences is unknown so assume not suitable and significant lengths of new wall would be required.	Yes – potential to use existing boundary walls etc. to provide flood defence so defence is merged into existing landscape.	No – existing features unsuitable for flood defence, additional works required.	Yes – existing towpath could be raised and SoP increased.	Yes – potential to use existing boundary walls etc. to provide flood defence. Would still need gates / temporary barriers at road closure points. Assume that existing walls are robust enough to act as a flood defence.

Defence Type	General Comment	Technical Viability				
		Harbour & City	Sydenham / East Belfast	Ravenhill	Ormeau	Lockview
Demountable Barriers	Facilities installed to allow easy installation of defence in event.	Yes – potential for demountable along harbour frontage and set back from operational areas – would still need gates / temporary barriers at road closure points.	Yes – potential to use demountable barriers along Sydenham Bypass to contain flood waters in Victoria Park.	Yes – potential to use demountable barriers set back from existing river wall. Foundation would require consideration.	Possible – other methods would be more suitable to provide flood defence. Significant length of demountable barrier would be required.	Yes - Demountable barrier may be constructed along river; however, likely to be more appropriate permanent solutions.
Temporary Barriers	Whole defence brought to site and erected in an event.	Yes – temporary barrier route defined in separate report.	Possible – potential to use temporary barriers along Sydenham Bypass to contain flood waters in Victoria Park.	Yes – temporary barrier route defined in separate report. Difficult installation along proposed route.	Possible – other methods would be more suitable to provide flood defence. Significant length of temporary barrier would be required.	Yes – temporary barrier route defined in separate report.
PLP / Resilience Measures	Last line of defence at individual properties and may be only solution in some instances.	Yes – within harbour boundary PLP may be appropriate for high consequence properties.	Possible – flood risk is in medium to long term with sea level rise – may be able to supplement other solutions with PLP.	Yes – PLP may be only solution for properties on river frontage.	Possible – existing embankment and towpath protecting properties – PLP not appropriate due to depth of flooding in an overtopping event.	Yes – PLP may be appropriate for boat club buildings rather than linear defence.

J.2. Overall Options Drawings

J.2.1. Option 3(a)

INSERT DRAWING

J.2.2. Option 3(b)

INSERT DRAWING

J.2.3. Option 4(a)

INSERT DRAWING

J.2.4. Option 4 (b)

INSERT DRAWING

J.2.5. Option 3

INSERT DRAWING

J.2.6. Option 4

INSERT DRAWING

Appendix K. Costs

Cost Summary	Construction Cost (£/m)	O&M Cost (£/m)	Other Annual/Event Costs (£/m)	Comment
1m High Flood Wall with Rail	£1,000.00	£1.00	£-	Construction cost based on first principles calcs and CESMM3 uplifted. Small allowance for annual inspection. Passive so no event or other annual costs.
0.6m High Flood Wall with Rail	£850.00	£1.00	£-	Construction cost based on first principles calcs and CESMM3 uplifted. Small allowance for annual inspection. Passive so no event or other annual costs.
1m High Glass Flood Wall with Rail	£1,900.00	£1.00	£-	Construction cost based on Flood Control International Quotation with moderate installation difficulties and limited bends. Small allowance for annual inspection. Passive so no event or other annual costs.
Flood Gates (1.1m high)	£2,686.21	£37.00	£25.00	Construction cost based on Flood Control International Quotation with moderate installation difficulties. Allowance for annual inspection and maintenance to match Temp Barriers. Allowance for closure of gates in an event and annually as part of practice drills.
Demountable (1m high)	£900.00	£37.00	£44.40	Construction cost based on Flood Control International Quotation with moderate installation difficulties. Allowance for annual inspection and maintenance of fittings. Allowance for annual maintenance and inspection to match Temp Barriers.
Temporary Barriers (1m high)	£740.00	£37.00	£44.40	Construction cost as per research presented on past projects in standalone Temporary Barrier report. Uplifted to 2015 by RPI. % of 5% and 6% of capital cost for operations and maintenance and event costs respectively based on the same research of past projects.

Cost Summary	Construction Cost (£/m)	O&M Cost (£/m)	Other Annual/Event Costs (£/m)	Comment
Lock Gate Alterations	£1,000.00	£2.50	£-	Allowance for construction of barrier on top of existing lock gate. Small allowance for annual inspection. Passive so no event or other annual costs.
Amending existing walls	£250.00	£5.00	£-	Allowance for amending existing walls to act as flood defences. Allowance for annual inspection. Passive so no event or other annual costs.
Flood wall extension	£250.00	£2.50	£-	Assume barrier installed on top of existing flood walls. Allowance for amending to increase SoP. Small allowance for annual inspection. Passive so no event or other annual costs.

Harbour / City Centre Flood Cell

3a - Permanent Riverside Defences (Harbour Route)

Year	Construction Cost (£)	Construction Cost plus 25% General & Prelims Cost & Supervision (£)
2018	£ 4,028,904	£ 5,036,129
2065	£ 4,310,104	£ 5,387,629
Total Construction Costs	£ 8,339,007	£ 10,423,759
Annual Costs 2018-2065	£ 22,075	
Annual Costs 2065-2115	£ 22,223	

Option 3 a - Medium Term Costs

Type	Cell	Approx Length m	Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Amend Existing Wall	Belfast Harbour / City Centre	165	£ 250.00	£ 41,250.00		£ 5.00	£ 825.00	£ -	£ -	£ 825.00
Flood Gate	Belfast Harbour / City Centre	33.1	£ 2,686.21	£ 88,913.55		£ 37.00	£ 1,224.70	£ 25.00	£ 827.50	£ 2,052.20
Flood Wall H	Belfast Harbour / City Centre	1113	£ 1,000.00	£ 1,113,000.00		£ 1.00	£ 1,113.00	£ -	£ -	£ 1,113.00
Demountable Barrier	Belfast Harbour / City Centre	205.1	£ 900.00	£ 184,590.00		£ 37.00	£ 7,588.70	£ 44.40	£ 9,106.44	£ 16,695.14
Glass Flood Wall	Belfast Harbour / City Centre	1363.5	£ 1,900.00	£ 2,590,650.00		£ 1.00	£ 1,363.50	£ -	£ -	£ 1,363.50
Lock Gate Alterations	Belfast Harbour / City Centre	10.5	£ 1,000.00	£ 10,500.00		£ 2.50	£ 26.25	£ -	£ -	£ 26.25
		2890.2		**£ 4,028,903.55**			**£ 12,141.15**		**£ 9,933.94**	**£ 22,075.09**

Option 3 a - Additional Future Costs

Type	Cell	Approx Length m	Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Glass Flood Wall	Belfast Harbour / City Centre	148	£ 1,900.00	£ 281,200.00		£ 1.00	£ 148.00	£ -	£ -	£ 148.00
		148		**£ 281,200.00**	**£ 4,310,103.55**		**£ 148.00**		**£ -**	**£ 148.00**

3b - Permanent Riverside Defences (M2 Route)

Year	Construction Cost (£)	Construction Cost plus 25% General & Prelims Cost & Supervision (£)
2018	£ 1,786,947	£ 2,233,683
2065	£ 2,068,147	£ 2,585,183
Total Construction Costs	£ 3,855,093	£ 4,818,867
Annual Costs 2018-2065	£ 9,590	
Annual Costs 2065-2115	£ 9,738	

Option 3 b - Medium Term Costs

Type	Cell	Approx Length m	Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Amend Existing Wall	Belfast Harbour / City Centre	123	£ 250.00	£ 30,750.00		£ 5.00	£ 615.00	£ -	£ -	£ 615.00
Flood Gate	Belfast Harbour / City Centre	19.1	£ 2,686.21	£ 51,306.61		£ 37.00	£ 706.70	£ 25.00	£ 477.50	£ 1,184.20
Flood Wall H	Belfast Harbour / City Centre	254.15	£ 1,000.00	£ 254,150.00		£ 1.00	£ 254.15	£ -	£ -	£ 254.15
Demountable Barrier	Belfast Harbour / City Centre	83.7	£ 900.00	£ 75,330.00		£ 37.00	£ 3,096.90	£ 44.40	£ 3,716.28	£ 6,813.18
Glass Flood Wall	Belfast Harbour / City Centre	723.9	£ 1,900.00	£ 1,375,410.00		£ 1.00	£ 723.90	£ -	£ -	£ 723.90
		1203.85		**£ 1,786,946.61**			**£ 5,396.65**		**£ 4,193.78**	**£ 9,590.43**

Option 3 b - Additional Future Costs

Type	Cell	Approx Length m	Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Glass Flood Wall	Belfast Harbour / City Centre	148	£ 1,900.00	£ 281,200.00		£ 1.00	£ 148.00	£ -	£ -	£ 148.00
		148		**£ 281,200.00**	**£ 2,068,146.61**		**£ 148.00**		**£ -**	**£ 148.00**

Option 4 - Temporary Defences

4a - Temporary Riverside Defences (Harbour Route)

Year	Construction Cost (£)	Construction Cost plus 25% General & Prelims Cost & Supervision (£)
2016	£ 2,274,020	£ 2,842,525
2065	£ 2,383,540	£ 2,979,425
Total Construction Costs	£ 4,657,560	£ 5,821,950
Annual Cost 2016-2065	£ 250,142	
Annual Cost 2065-2115	£ 262,189	

Option 4 a - Medium Term Costs

Type	Cell	Height above GL (m)	Length (m)	Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Belfast Harbour / City Centre	1.0	785	£ 740.00	£ 580,900.00		£ 37.00	£ 29,045.00	£ 44.40	£ 34,854.00	£ 63,899.00
Temporary Barrier	Belfast Harbour / City Centre	1.0	2288	£ 740.00	£ 1,693,120.00		£ 37.00	£ 84,656.00	£ 44.40	£ 101,587.20	£ 186,243.20
			3073		**£ 2,274,020.00**			**£ 113,701.00**		**£ 136,441.20**	**£ 250,142.20**

Option 4 a - Additional Future Costs

Type	Cell	Height above GL (m)	Approx Length m	Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Belfast Harbour / City Centre	1.5	148	£ 740.00	£ 109,520.00		£ 37.00	£ 5,476.00	£ 44.40	£ 6,571.20	£ 12,047.20
			148		**£ 109,520.00**	**£ 2,383,540.00**		**£ 5,476.00**		**£ 6,571.20**	**£ 12,047.20**

4b - Temporary Riverside Defences (M2 Route)

Year	Construction Cost (£)	Construction Cost - No G&P
2016	£ 1,173,714	£ 1,173,714
2065	£ 1,283,234	£ 1,283,234
Total Construction Costs	£ 2,456,948	£ 2,456,948
Annual Cost 2016-2065	£ 129,109	
Annual Cost 2065-2115	£ 141,156	

Option 4 b - Medium Term Costs

Type	Cell	Height above GL (m)	Length (m)	Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Belfast Harbour / City Centre	1.0	801.1	£ 740.00	£ 592,814.00		£ 37.00	£ 29,640.70	£ 44.40	£ 35,568.84	£ 65,209.54
Temporary Barrier	Belfast Harbour / City Centre	1.0	785	£ 740.00	£ 580,900.00		£ 37.00	£ 29,045.00	£ 44.40	£ 34,854.00	£ 63,899.00
			1586.1		**£ 1,173,714.00**			**£ 58,685.70**		**£ 70,422.84**	**£ 129,108.54**

Option 4 b - Additional Future Costs

Type	Cell	Height above GL (m)	Approx Length m	Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Belfast Harbour / City Centre	1.5	148	£ 740.00	£ 109,520.00		£ 37.00	£ 5,476.00	£ 44.40	£ 6,571.20	£ 12,047.20
			148		**£ 109,520.00**	**£ 1,283,234.00**		**£ 5,476.00**		**£ 6,571.20**	**£ 12,047.20**

Sydenham & East Belfast Flood Cell

Option 2 - Weir + Permanent Defences (deferred)

Year	Construction Cost (£)	Construction Cost plus 25% General & Prelims Cost &
2035	£ -	£ -
2080	£ 3,141,720.00	£ 3,927,150
Total Construction Costs	£ 3,141,720.00	£ 3,927,150
Annual Costs 2035-2080	£ -	
Annual Costs 2080-2115	£ 7,557.30	

Option 2 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
		0		£ -	£ -		£ -		£ -	£ -

Option 2 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Wall Extension	Sydenham / East Belfast	2423	£ 250.00	£ 605,750.00		£ 2.50	£ 6,057.50	£ -	£ -	£ 6,057.50
Glass Flood Wall	Sydenham / East Belfast	1151.3	£ 1,900.00	£ 2,187,470.00		£ 1.00	£ 1,151.30	£ -	£ -	£ 1,151.30
Flood Wall H	Sydenham / East Belfast	348.5	£ 1,000.00	£ 348,500.00		£ 1.00	£ 348.50	£ -	£ -	£ 348.50
		3922.8		£ 3,141,720.00	£ 3,141,720.00		£ 7,557.30		£ -	£ 7,557.30

Option 3 - Permanent Riverside Defences

Year	Construction Cost (£)	General & Prelims Cost & Supervision (£)
2018	£ -	£ -
2065	£ 3,141,720.00	£ 3,927,150
Total Construction Costs	£ 3,141,720.00	£ 3,927,150
Annual Costs 2018-2065	£ -	
Annual Costs 2065-2115	£ 7,557.30	

Option 3 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
		0		£ -	£ -		£ -		£ -	£ -

Option 3 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Wall Extension	Sydenham / East Belfast	2423	£ 250.00	£ 605,750.00		£ 2.50	£ 6,057.50	£ -	£ -	£ 6,057.50
Glass Flood Wall	Sydenham / East Belfast	1151.3	£ 1,900.00	£ 2,187,470.00		£ 1.00	£ 1,151.30	£ -	£ -	£ 1,151.30
Flood Wall H	Sydenham / East Belfast	348.5	£ 1,000.00	£ 348,500.00		£ 1.00	£ 348.50	£ -	£ -	£ 348.50
		3922.8		£ 3,141,720.00	£ 3,141,720.00		£ 7,557.30		£ -	£ 7,557.30

Option 4 - Temporary Defences

Year	Construction Cost (£)	Construction Cost - No G&P
2016	£ -	£ -
2065	£ 2,270,750.00	£ 2,270,750.00
Total Construction Costs	£ 2,270,750.00	£ 2,270,750.00
Annual Costs 2016 - 2065	£ -	
Annual Costs 2065-2115	£ 128,157.50	

Option 4 - Medium Term Costs

Type	Cell	Height above GL (m)	Length (m)	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
			0		£ -			£ -		£ -	£ -

Option 4 - Additional Future Costs

Type	Cell	Height above GL (m)	Approx Length m	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Wall Extension	Sydenham / East Belfast	1.5	2423	£ 250.00	£ 605,750.00		£ 2.50	£ 6,057.50	£ -	£ -	£ 6,057.50
Temporary Barrier	Sydenham / East Belfast	1.5	1500	£ 1,110.00	£ 1,665,000.00		£ 37.00	£ 55,500.00	£ 44.40	£ 66,600.00	£ 122,100.00
			3923		£ 2,270,750.00	£ 2,270,750.00		£ 61,557.50		£ 66,600.00	£ 128,157.50

Ravenhill Flood Cell

Option 2 - Weir + Permanent Defences (deferred)

Year	Construction Cost (£)	Construction Cost plus 25% General & Prelims Cost &
2035	£ 249,645.00	£ 312,056
2080	£ 249,645.00	£ 312,056
Total Construction Costs	£ 499,290.00	£ 624,113
Annual Costs 2035-2080	£ 8,488.50	
Annual Costs 2080-2115	£ 8,488.50	

Option 2 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Demountable Barrier	Ravenhill	102	£ 900.00	£ 91,800.00		£ 37.00	£ 3,774.00	£ 44.40	£ 4,528.80	£ 8,302.80
Flood Wall L	Ravenhill	185.7	£ 850.00	£ 157,845.00		£ 1.00	£ 185.70	£ -	£ -	£ 185.70
		287.7		£ 249,645.00	£ 249,645.00		£ 3,959.70		£ 4,528.80	£ 8,488.50

Option 2 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
		0		£ -	£ 249,645.00		£ -		£ -	£ -

Option 3 - Permanent Riverside Defences

Year	Construction Cost (£)	Construction Cost plus 25%
2018	£ 277,500.00	£ 346,875
2065	£ 277,500.00	£ 346,875
Total Construction Costs	£ 555,000.00	£ 693,750
Annual Costs 2018-2065	£ 8,488.50	
Annual Costs 2065-2115	£ 8,488.50	

Option 3 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Demountable Barrier	Ravenhill	102	£ 900.00	£ 91,800.00		£ 37.00	£ 3,774.00	£ 44.40	£ 4,528.80	£ 8,302.80
Flood Wall H	Ravenhill	185.7	£ 1,000.00	£ 185,700.00		£ 1.00	£ 185.70	£ -	£ -	£ 185.70
		287.7		£ 277,500.00	£ 277,500.00		£ 3,959.70		£ 4,528.80	£ 8,488.50

Option 3 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
		0		£ -	£ 277,500.00		£ -		£ -	£ -

Option 4 - Temporary Defences

Year	Construction Cost (£)	Construction Cost - No G&P
2016	£ 212,898.00	£ 212,898.00
2065	£ 1,766,898.00	£ 1,766,898.00
Total Construction Costs	£ 1,979,796.00	£ 1,979,796.00
Annual Costs 2016 - 2065	£ 23,418.78	
Annual Costs 2065-2115	£ 137,378.78	

Option 4 - Medium Term Costs

Type	Cell	Height above GL (m)	Length (m)	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Ravenhill	1	287.7	£ 740.00	£ 212,898.00		£ 37.00	£ 10,644.90	£ 44.40	£ 12,773.88	£ 23,418.78
			287.7		£ 212,898.00			£ 10,644.90		£ 12,773.88	£ 23,418.78

Option 4 - Additional Future Costs

Type	Cell	Height above GL (m)	Approx Length m	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Ravenhill	1.5	1400	£ 1,110.00	£ 1,554,000.00		£ 37.00	£ 51,800.00	£ 44.40	£ 62,160.00	£ 113,960.00
			1400		£ 1,554,000.00	£ 1,766,898.00		£ 51,800.00		£ 62,160.00	£ 113,960.00

Ormeau Embankment Flood Cell

Option 2 - Weir + Permanent Defences (deferred)

Year	Construction Cost (£)	General & Prelims Cost & Supervision (£)
2035	£ 1,603,955.25	£ 2,004,944
2080	£ 3,003,955.25	£ 3,754,944
Total Construction Costs	£ 4,607,910.50	£ 5,759,888
Annual Costs 2035-2080	£ 3,358.00	
Annual Costs 2080-2115	£ 4,058.00	

Option 2 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Gate	Ormeau	25	£ 2,686.21	£ 67,155.25		£ 37.00	£ 925.00	£ 25.00	£ 625.00	£ 1,550.00
Flood Wall L	Ormeau	1808	£ 850.00	£ 1,536,800.00		£ 1.00	£ 1,808.00	£ -	£ -	£ 1,808.00
		1833		£ 1,603,955.25	£ 1,603,955.25		£ 2,733.00		£ 625.00	£ 3,358.00

Option 2 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Wall	Ormeau (right bank)	1400	£ 1,000.00	£ 1,400,000.00		£ 0.50	£ 700.00	£ -	£ -	£ 700.00
		1400		£ 1,400,000.00	£ 3,003,955.25		£ 700.00		£ -	£ 700.00

Option 3 - Permanent Riverside Defences

Year	Construction Cost (£)	General & Prelims Cost & Supervision (£)
2018	£ 1,875,155.25	£ 2,343,944
2065	£ 3,275,155.25	£ 4,093,944
Total Construction Costs	£ 5,150,310.50	£ 6,437,888
Annual Costs 2018-2065	£ 1,541.50	
Annual Costs 2065-2115	£ 2,241.50	

Option 3 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Gate	Ormeau	25	£ 2,686.21	£ 67,155.25		£ 0.50	£ 12.50	£ 25.00	£ 625.00	£ 637.50
Flood Wall H	Ormeau	1808	£ 1,000.00	£ 1,808,000.00		£ 0.50	£ 904.00	£ -	£ -	£ 904.00
		1833		£ 1,875,155.25	£ 1,875,155.25		£ 916.50		£ 625.00	£ 1,541.50

Option 3 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Wall H	Ormeau (right bank)	1400	£ 1,000.00	£ 1,400,000.00		£ 0.50	£ 700.00	£ -	£ -	£ 700.00
		1400		£ 1,400,000.00	£ 3,275,155.25		£ 700.00		£ -	£ 700.00

Option 4 - Temporary Defences

Year	Construction Cost (£)	Construction Cost - No G&P
2016	£ 1,356,420.00	£ 1,356,420.00
2065	£ 2,392,420.00	£ 2,392,420.00
Total Construction Costs	£ 3,748,840.00	£ 3,748,840.00
Annual Costs 2016 - 2065	£ 149,206.20	
Annual Costs 2065-2115	£ 263,166.20	

Option 4 - Medium Term Costs

Type	Cell	Height above GL (m)	Length (m)	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Ormeau	0.9	1833	£ 740.00	£ 1,356,420.00		£ 37.00	£ 67,821.00	£ 44.40	£ 81,385.20	£ 149,206.20
			1833		£ 1,356,420.00			£ 67,821.00		£ 81,385.20	£ 149,206.20

Option 4 - Additional Future Costs

Type	Cell	Height above GL (m)	Approx Length m	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Ormeau (right bank)		1400	£ 740.00	£ 1,036,000.00		£ 37.00	£ 51,800.00	£ 44.40	£ 62,160.00	£ 113,960.00
			1400		£ 1,036,000.00	£ 2,392,420.00		£ 51,800.00		£ 62,160.00	£ 113,960.00

Lockview & Stranmills Flood Cell

Option 2 - Weir + Permanent Defences (deferred)

Year	Construction Cost (£)	Construction Cost plus 25% General & Prelims Cost & Supervision (£)
2035	£ 709,589.68	£ 886,987
2080	£ 1,773,517.35	£ 2,216,897
Total Construction Costs	£ 2,483,107.03	£ 3,103,884
Annual Costs 2035-2080	£ 5,047.60	
Annual Costs 2080-2115	£ 7,713.00	

Option 2 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Amend Existing Wall	Lockview, Stranmillis	44	£ 250.00	£ 11,000.00		£ 5.00	£ 220.00	£ -	£ -	£ 220.00
Flood Gate	Lockview, Stranmillis	8	£ 2,686.21	£ 21,489.68		£ 37.00	£ 296.00	£ 25.00	£ 200.00	£ 496.00
Flood Wall L	Lockview, Stranmillis	750	£ 850.00	£ 637,500.00		£ 1.00	£ 750.00	£ -	£ -	£ 750.00
Demountable Barrier	Lockview, Stranmillis	44	£ 900.00	£ 39,600.00		£ 37.00	£ 1,628.00	£ 44.40	£ 1,953.60	£ 3,581.60
		846		£ 709,589.68	£ 709,589.68		£ 2,894.00		£ 2,153.60	£ 5,047.60

Option 2 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Gate	Lockview, Stranmillis	27	£ 2,686.21	£ 72,527.67		£ 37.00	£ 999.00	£ 25.00	£ 675.00	£ 1,674.00
Flood Wall H	Lockview, Stranmillis	991.4	£ 1,000.00	£ 991,400.00		£ 1.00	£ 991.40	£ -	£ -	£ 991.40
		1018.4		£ 1,063,927.67	£ 1,773,517.35		£ 1,990.40		£ 675.00	£ 2,665.40

Option 3 - Permanent Riverside Defences

Year	Construction Cost (£)	Construction Cost plus 25%
2018	£ 709,589.68	£ 886,987
2065	£ 1,773,517.35	£ 2,216,897
Total Construction Costs	£ 2,483,107.03	£ 3,103,884
Annual Costs 2018-2065	£ 3,374.00	
Annual Costs 2065-2115	£ 6,039.40	

Option 3 - Medium Term Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Amend Existing Wall	Lockview, Stranmillis	44	£ 250.00	£ 11,000.00		£ 5.00	£ 220.00	£ -	£ -	£ 220.00
Flood Gate	Lockview, Stranmillis	8	£ 2,686.21	£ 21,489.68		£ 37.00	£ 296.00	£ 5.00	£ 40.00	£ 336.00
Flood Wall L	Lockview, Stranmillis	750	£ 850.00	£ 637,500.00		£ 1.00	£ 750.00	£ -	£ -	£ 750.00
Demountable Barrier	Lockview, Stranmillis	44	£ 900.00	£ 39,600.00		£ 37.00	£ 1,628.00	£ 10.00	£ 440.00	£ 2,068.00
		846		£ 709,589.68	£ 709,589.68		£ 2,894.00		£ 480.00	£ 3,374.00

Option 3 - Additional Future Costs

Type	Cell	Approx Length m	Construction Cost (£/m)	Total Construction Cost	Total Construction Cost	O&M Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Flood Gate	Lockview, Stranmillis	27	£ 2,686.21	£ 72,527.67		£ 37.00	£ 999.00	£ 25.00	£ 675.00	£ 1,674.00
Flood Wall H	Lockview, Stranmillis	991.4	£ 1,000.00	£ 991,400.00		£ 1.00	£ 991.40	£ -	£ -	£ 991.40
		1018.4		£ 1,063,927.67	£ 1,773,517.35		£ 1,990.40		£ 675.00	£ 2,665.40

Option 4 - Temporary Defences

Year	Construction Cost (£)	Construction Cost - No G&P
2016	£ 817,230.00	£ 817,230.00
2065	£ 1,947,210.00	£ 1,947,210.00
Total Construction Costs	£ 2,764,440.00	£ 2,764,440.00
Annual Costs 2016 - 2065	£ 69,084.40	
Annual Costs 2065-2115	£ 151,949.60	

Option 4 - Medium Term Costs

Type	Cell	Height above GL (m)	Length (m)	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Lockview, Stranmillis	1.5	487	£ 1,110.00	£ 540,570.00		£ 37.00	£ 18,019.00	£ 44.40	£ 21,622.80	£ 39,641.80
Temporary Barrier	Lockview, Stranmillis	1.0	359	£ 740.00	£ 265,660.00		£ 37.00	£ 13,283.00	£ 44.40	£ 15,939.60	£ 29,222.60
Amend Existing Wall	Lockview, Stranmillis		44	£ 250.00	£ 11,000.00		£ 5.00	£ 220.00	£ -	£ -	£ 220.00
			890		£ 817,230.00			£ 31,522.00		£ 37,562.40	£ 69,084.40

Option 4 - Additional Future Costs

Type	Cell	Height above GL (m)	Approx Length m	Purchase Cost (£/m)	Total Purchase Cost	Total Purchase Cost	O&M & Storage Cost (£/m)	Total Annual O&M Cost	Annual / Event Cost (£/m)	Total Annual Event Cost	Overall Annual Cost
Temporary Barrier	Lockview, Stranmillis	1.5	1018	£ 1,110.00	£ 1,129,980.00		£ 37.00	£ 37,666.00	£ 44.40	£ 45,199.20	£ 82,865.20
			1018		£ 1,129,980.00	£ 1,947,210.00		£ 37,666.00		£ 45,199.20	£ 82,865.20

Appendix L. Mitigation Action Plan

Appendix M. Lagan Weir Joint Probability Analysis

Julie Templeton
Atkins
71 Old Channel Road
Belfast
BT3 9DE

Email: Julie.templeton@atkinsglobal.com
Telephone: 028 9078 8600
Direct telephone: 028 9078 8676
Fax: 028 9078 8688