Broadway Underpass – Westlink, Belfast

Independent Report into the Flooding Incident on 16 August 2008

October 2008 **Report Reference: IR1/2008**

Amey | Consulting | Highways
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1 Executive Summary

1.1 Broadway Underpass forms part of the Roads Service DBFO Package 1 Contract that includes the upgrading of the M1/Westlink, Belfast. The works have been procured through a Design, Build, Finance and Operate (DBFO) contract, which includes the maintenance of approximately 60km of motorways over a 30 year contract period.

1.2 The DBFO Contract is between the Department for Regional Development (DRD) and Highway Management (City) Ltd (HMG). HMG, termed the DBFO Co, is a Joint Venture, (JV) formed between Bilfinger Berger BOT Limited, John Graham (Dromore) Limited and Northstone (NI) Limited.

1.3 The responsibility for the design, construction, completion, ongoing maintenance and operation of all elements of the road infrastructure that fall within the scope of the Contract rests entirely with HMG, the DBFO Co.

1.4 The Clowney Water had to be accommodated within the construction works as it crossed perpendicular to the line of the Westlink and in the vicinity of the Broadway Underpass. The Clowney Water then connected into the Blackstaff River in a Overflow Structure which incorporated an overflow Relief Culvert outfalling to the River Lagan. The DBFO Co based its original design on the illustrative design, which incorporated the Clowney Water culvert within the roof slab of the new underpass. However, an Alternative Proposal was later promoted by the DBFO Co, as a DBFO Co Change, and this involved diverting the Clowney Water around the underpass. The DBFO Co Alternative Proposal for the culverting diversion was agreed in principle by the Rivers Agency prior to being implemented by the DBFO Co on site.

1.5 The design criteria for the culverts was a 1 in 100 year flood event which was agreed in advance with the Rivers Agency and incorporated within the contract documents.

1.6 Northern Ireland experienced a period of heavy and prolonged rainfall on Saturday 16 August 2008. As a result the Clowney Water overtopped its banks at the inlet to the new culvert works resulting in major flooding of the Broadway Underpass and the surrounding area.

1.7 As the flood water level rose in the Broadway Underpass, an emergency road closure was installed. Nevertheless, a number of cars breached the closure and one became stranded and submerged in the Underpass and several on the slip roads.

1.8 Although no directly measured data is available to assist in confirming the quantity of flow in the Clowney Water, it seems probable that the return period on 16 August 2008 was in the range 1 in 50 years to 1 in 70 years, which would have produced a flow less than the design capacity.

1.9 It is clear that the system linking the Clowney Water, the Clowney Culvert, the Blackstaff River and Culvert and the Relief Culvert failed to perform on 16th August 2008 under a return period of less than 1 in 100 years.

1.10 The design and compliance requirements are examined and, in particular, the detail and process associated with the illustrative design and the Alternative Design.

1.11 Possible causes that could have contributed to the flooding of the Underpass have been investigated by the Amey Review Team. The investigation comprised a series of interviews and an assessment of supporting data and site evidence. A commentary has been provided that focuses on the potential blockage of the Trash Screen at the Clowney Culvert inlet, the setting of the Blackstaff Penstock Valve, the design capacity of the Culverts, and the flow patterns in the Overflow Structure.

1.12 A number of mitigation options have been developed. These include the implementation of an early warning system designed to ensure the safety of the public. Other short and longer term measures have been proposed to help ensure that the risk of further flooding of the Broadway Underpass is minimised.

1.13 The Report includes a series of conclusions that provide a summary of the key findings of the investigation and a set of recommendations that describe a process for the implementation of the key mitigation measures.

2 Introduction

2.1 Brief

2.1.1 Following the flooding of Broadway Underpass on 16 August 2008 the Roads Service appointed Amey to carry out an independent investigation and report into the circumstances surrounding the event within a timescale of 2 months.

2.1.2 The Roads Service (Acting) Director of Strategic Programmes confirmed the appointment of Amey in a letter dated 22 August 2008. Amey then undertook to establish a team which would have the relevant experience to undertake the task. After approval, Roads Service issued a Project Brief to Amey on 12 September 2008.

2.2 Scope

2.2.1 The independent nature of the investigation required Amey to make all enquiries based on the information made available to them and that which arose during the course of the investigation. Roads Service, however, required that the report should give particular attention to the following items:

- The weather conditions which contributed to the flooding
- The identification of the cause(s) of the flooding
- The response to the flooding
- The design and construction standards
- Potential mitigation measures

2.2.2 The investigation has been undertaken by a team of experienced engineers, referred to in the report as the "Review Team". The team considered the information made available to them, undertook site visits and carried out interviews with various parties to the scheme. The following site visits and interviews were conducted during the investigation:

	Date	**Organisation**
Interview	24 September 2008	Roads Service Northern Ireland (Eastern Division & PPP Unit), Scott Wilson
Site Visit	24 September 2008	Site familiarisation
Interview	25 September 2008	HMG, HMM, HMC, Arup
Interview	26 September 2008	Rivers Agency
Site Visit	9 October 2008	Rivers Agency
Interview	9 October 2008	Rivers Agency
Interview	13 October 2008	HMG, HMC, Arup

3 Background Information

3.1 Contract Background

3.1.1 Broadway Underpass forms part of Scheme 1, which is part of the Roads Service DBFO Package 1 Contract. This Scheme was one of three major elements of new works involving the upgrading of the M1/Westlink, Belfast (Scheme 1), the provision of new entry slip roads at Junction 7 on the M2 (Scheme 2) and the widening of the M2 motorway between Junctions 4 and 2 (Scheme 3). The pre-existing drainage at Broadway Roundabout is shown in Appendix A, Fig 1.

3.1.2 To facilitate the construction of these elements of works, these Schemes were incorporated within a Design, Build, Finance and Operate (DBFO) contract. This contract also involves the maintenance of approximately 60km of motorways for the 30 year contract period and it is delivered by a private company termed the DBFO Co.

3.1.3 The concept of DBFO contracts is not new to the civil engineering community with many schools, hospitals and roads being built in the Republic of Ireland and in Great Britain using this principle. The Package 1 Contract represents the first roads project in Northern Ireland where this form of procurement has been used. As a result Roads Service took the decision to base the Form of Contract on the model that has been used widely by the Highways Agency.

3.1.4 The high level contract functions were developed by Roads Service Headquarters under the PPP Unit and the technical aspects progressed by the Strategic Route Improvement Team (SRIT) based in Roads Service Eastern Division. In addition, consultants Scott Wilson were engaged under the Provision of Engineering Consultancy Services – December 2000 framework to assist in the functions of the Department's Nominee under the contract. Prior to this Scott Wilson had assisted in the scheme development, the preparation of the relevant parts of the contract, the tender process and onto the construction phase.

3.1.5 The DBFO procurement process started on 5 January 2004 with the issue of the Works Contract Notice to the Official Journal of the European Union (OJEU). Following evaluation of prequalification submissions, the Invitation to Negotiate documentation was issued on the 28 April 2004. Tender submissions were made by four consortia on the 15 September 2004 and, following evaluation, these were reduced to two. The remaining two consortia submitted a Best and Final Offer on 15 April 2005 and the successful tenderer reached Financial Close on the 17 February 2006, followed by a Commencement Date on the 27 February 2006.

3.1.6 The DBFO Package 1 Contract was awarded to Highway Management (City) Limited (DBFO Co), which engaged a number of organisations through sub-contract arrangements to deliver the contract. This delivery structure is described in detail in Section 4 of this Report but it is important to note that the

main contract is between the DBFO Co and the Department for Regional Development.

3.2 Broadway Underpass – Design Considerations

3.2.1 A Public Inquiry was undertaken at the Spires Centre in Belfast during November and December 2000 into the Environmental Statement prepared by DRD for the M1/Westlink Project Stage 2 Westlink (A12) Improvements. The Inspector who undertook proceedings was Mr FG Guckian. The Roads Service proposal for these improvement works included 3 lanes in each direction between M1 and Grosvenor Road and the construction of flyovers as grade separated junctions at Broadway and Grosvenor Road. In relation to the Broadway junction, Roads Service preferred option was to construct a flyover over Broadway roundabout.

3.2.2 An alternative proposal was submitted at the Inquiry that incorporated an underpass to replace the flyover. Roads Service argued in its response to this alternative design proposal that the underpass, would *'have a longer construction period and would have high construction risks associated with the ground conditions, location of services, diversion of streams, and the pylon foundations. It would also require a pumped drainage system. Roads Service preferred solution, incorporating the flyover, would involve a minimum diversion of watercourses and alterations to existing services'.*

3.2.3 The Inspector's preferred option, as referred to in his report, was the option to provide an underpass (Inspector's Report Paragraph 9.57, page 53).

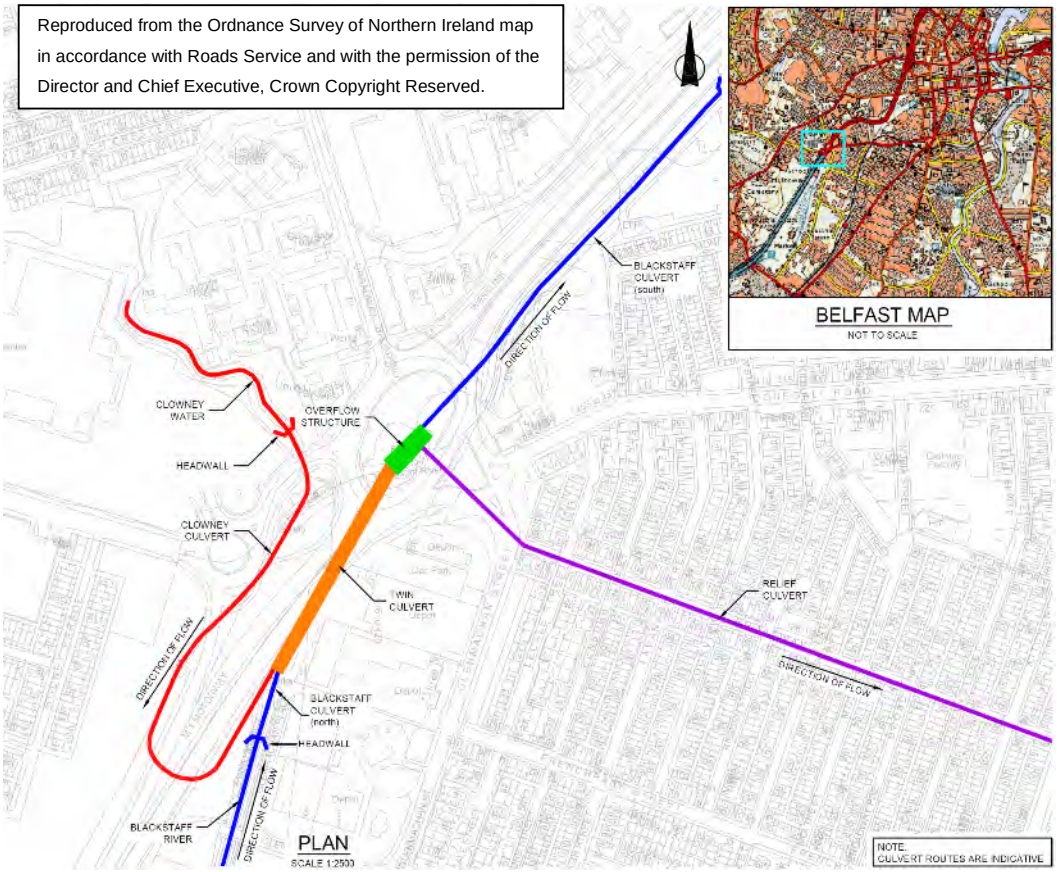
3.2.4 Following the Public Inquiry and the publishing of the Inspectors Report, Roads Service published a Departmental Statement accepting the recommendation of the Inspector on the basis that an underpass was a better option from an environmental viewpoint, even though it had a greater impact on construction, maintenance and existing services.

3.2.5 Roads Service and its advisers undertook a series of Risk Workshops to develop the illustrative design. Within these workshops the potential risk of flooding from the Clowney Water was considered. This is discussed further in Section 7 of this Report.

3.2.6 In the tender process for DBFO Package 1 Contract and in common with industry practice for DBFO contracts, the Department incorporated an illustrative design within the tender documents. This was primarily to enable bidders to submit a 'compliant tender' on a common basis and help ensure that the tender evaluation was robust. The road layout at Broadway in the illustrative design included an underpass

3.2.7 Under the DBFO form of contract the DBFO Co takes responsibility for taking forward the detailed design. Further commentary is given in Section 4 of this Report, which explains the general principles of the Roles and Responsibilities of the contract.

3.2.8 The Clowney Water had to be accommodated within the construction works as it crossed perpendicular to the line of the Westlink and in the vicinity of the Broadway Underpass. The Clowney Water then connected into the Blackstaff River in an Overflow Structure which incorporated an overflow Relief Culvert outfalling to the River Lagan. The DBFO Co based its original design on the illustrative design, which incorporated the Clowney Water culvert within the roof slab of the new underpass. However, an Alternative Proposal was later promoted by the DBFO Co, as a DBFO Co Change, and this involved diverting the Clowney Water around the underpass, as shown in the diagram below, see also Appendix A, Fig 2. The DBFO Co Alternative Proposal was accepted in principle by the Rivers Agency prior to being implemented on site.



Broadway Underpass - Alternative Proposal

Clowney Water Culvert Route

3.2.9 The Broadway Underpass was opened to traffic on 4 July 2008 after the culvert works and the bridge structure were substantially complete. Lane restrictions remained in place throughout the construction site, including through the Underpass, to allow other aspects of work to be completed.

3.3 Flooding Incident

3.3.1 Following a period of heavy and prolonged rainfall across Northern Ireland on Saturday 16 August 2008 the Clowney Water overtopped its banks at the inlet to the new culvert works resulting in major flooding of the Broadway Underpass and the surrounding area.

3.3.2 The works at the Broadway roundabout were not complete at the time of the flooding incident. The construction of the Blackstaff and Clowney Culverts was substantially complete but works to the roundabout carriageway were ongoing and some other works remained outstanding. The significance of this is to recognise that whilst all roads at the Broadway junction were open to traffic, the area still formed part of a construction site.

3.3.3 The sequence of events surrounding the flooding incident, that included one vehicle that became stranded in the Underpass and several that became stranded on the slip roads as the water level rose, are described in Section 6 of this Report.

3.3.4 In the opinion of Rivers Agency, in its capacity as a Relevant Authority, the return period of the flood that occurred on the 16 August 2008 was significantly lower than that stated in the Construction Requirements which required the new culverts to be designed for a 1 in 100 year flood event. Further commentary on this matter is given in Section 4 of this Report.

4 Organisational Roles and Responsibilities

4.1 Contract Structure

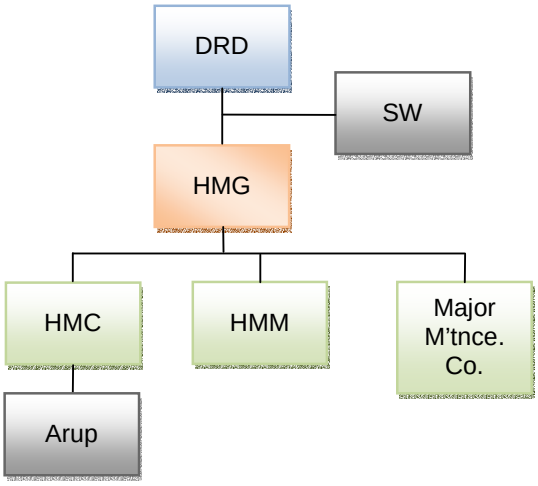
4.1.1 The Department for Regional Development – (DRD), has entered into an agreement under the Private Finance Initiative which includes the M1/Westlink Scheme. The scheme is being carried out under a Design, Build, Finance and Operate (DBFO) form of contract, with a 30 year contract period. Staff from Roads Service, an Executive Agency within DRD manage the contract on the Department's behalf. Roads Service has appointed a Department's Nominee and Department's Nominee for the Works who take on particular contractual functions.

4.1.2 Ferguson McIlveen (FM) and Scott Wilson (SW) were employed in Joint Venture as DRD's Scheme Development Consultant's since 2000, until FM was acquired by SW in 2006. They assisted the Department to take the schemes incorporated in the DBFO Package 1 contract through the necessary statutory procedures and assisted the Department and its central technical advisers Jacobs Babtie in the preparation of the contract documents, including the preparation of an illustrative design. SW is currently the Department's Nominee's Site Representative for the construction aspects of the DBFO Contract.

4.1.3 Rivers Agency (RA), as a Relevant Authority, should be consulted during the design process and its consent is required to all relevant designs.

4.1.4 The DBFO Contract is between DRD and ***Highway Management (City) Ltd (HMG)***, which is the Special Purpose Vehicle (SPV) for the DBFO.

4.1.5 The DBFO Contract delivery structure mirrors that of other privately financed contracts of this type and is shown in the diagram below.



4.1.6 HMG is a Joint Venture, (JV) formed between Bilfinger Berger BOT Limited, John Graham (Dromore) Limited and Northstone (NI) Limited.

4.1.7 HMG has let contracts to three Companies for the for the construction, operation and maintenance activities of the Contract. These are:

- ***Highway Management Construction (HMC)*** (a joint venture between Bilfinger Berger AG Civil, John Graham (Dromore) Limited and Northstone (NI) Limited) is responsible for Design and Construction of the Works, including maintenance and traffic management during the construction period, although HMM do provide winter maintenance coverage to trafficked areas;
- ***Highways Management Maintenance (HMM)*** (a joint venture between John Graham (Dromore) Limited and WSP CIVILS Limited) is responsible for the operation and maintenance of the full network covered by the DBFO contract. On completion (commissioning and testing) of each section of new construction, HMM take over maintenance responsibilities for these.
- ***Major Maintenance Co***, whose operations are not relevant to this Investigation as major maintenance works are not yet required under the Contract within the construction sites.

4.1.8 HMC has let a Design Contract to Arup. This contract includes the drainage design, although it is understood that structural design of the culverts has been carried out by Benaim Ltd under a sub-consultancy arrangement with Arup.

4.2 Responsibilities under the DBFO Contract (Main Contract)

4.2.1 The two parties to the DBFO Contract are DRD (the Department) and HMG (the DBFO Co).

4.2.2 Whilst HMG has sub-contracted the construction, operation and maintenance activities as described in 4.1.7 above, ultimate responsibility for the delivery of these functions rests with HMG.

4.2.3 The responsibilities assigned to the Department and HMG are covered in the DBFO Contract. Key clauses from the Contract have been reproduced below to clarify these responsibilities.

4.2.4 Part II – [Operations] includes at Clause 11 [Design and Construction].

The following two sub-clauses make it clear that the responsibility for the design, construction and completion of all the works that fall within the scope of the Contract rests entirely with HMG, the DBFO Co.

4.2.4.1 Under Clause 11.1 [Responsibility], it is stated that:

'*The DBFO Co shall be responsible for the design, construction, completion, commissioning and testing of the Works'*

4.2.4.2 Under Sub-Clause 11.2.1.1 it is stated that:

'The DBFO Co shall procure that the Designer shall prepare or supervise the preparation of the Design Data in respect of the Works ….'

The following four sub-clauses describe the process relating to design changes that are proposed by the DBFO Co. and the requirement to indemnify DRD in respect of such changes.

4.2.4.3 Under Clause 11.3 [Review Procedure], it is stated at Sub-Clause 11.3.1 that:

'The DBFO Co shall not commence or permit the commencement of construction of any part of the Works until there has been no objection under the Review Procedure to all Design Data and all relevant Certificates required in respect of such part of the Works'.

4.2.4.4 Under Clause 11.4 [DBFO Co's Changes], it is stated that:

'If the DBFO Co proposes to vary or amend the design, quality or quantity of the Works after the date of this Agreement, including making additions, omissions, substitutions, alterations in design and/or variations in or to the Construction Requirements, or the Communications Requirements, such proposal, together with all supporting Design Data and an explanation of the reasons for the proposed change, (including if appropriate the Designer's comments), shall be submitted in accordance with the Review Procedure as a DBFO Co's Change'.

4.2.4.5 Under Clause 11.5 [Breaches], it is stated at Sub-Clause 11.5.1 that:

'In the event that the DBFO Co becomes aware of a breach of any of Clauses 11.1 [Responsibility] to 11.4 [DBFO Co's Changes] (both inclusive), it shall: 11.5.1.1 forthwith notify the Departments Nominee of the fact of such breach and the subject matter thereof; ……..'

4.2.4.6 Under Clause 11.6 [Department's Design Data], it is stated that:

'Save as expressly provided in this Agreement, the DBFO Co shall not seek to recover from the Department and its servants and agents and shall indemnify the Department and its servants against any Loss or Claim which may arise from the adoption, use or application ……of any Design Data or other data and documents made available to it or any of its representatives ……'

4.2.5 Part V – [Change, Liabilities and Termination] includes at Clause 37 [Force Majeure]

A clause has been included in the Contract to address Force Majeure.

4.2.5.1 Under Sub-Clause 37.1 [Relief from Liability] the Parties shall be relieved from liability under the Agreement to the extent that they are not able to perform their obligations by reason of Force Majeure. From the DBFO point of view this only applies if the risk is Uninsurable.

4.2.6 Part VI – [Miscellaneous] includes at Clause 54 [Waiver].

A clause has been included in the Contract relating to waiver and the validity of the terms of the Contract.

4.2.6.1 This Clause states:

'Failure by the Department at any time to enforce any provision of this Agreement or to require performance by the DBFO Co of any of the provisions of this Agreement shall not be construed as waiver of any such provision and shall not affect the validity of this Agreement or any part thereof or the right of the Department to enforce any provision in accordance with its terms'.

4.3 DBFO Contract - Schedule 4 [Construction and Handback Requirements]

The relevant Schedule in the Contract relating to design standards is Schedule 4 and the following sub-clauses relate specifically to the drainage design elements.

4.3.1 Part 1 [Scheme Specific Core Construction Requirements].

At Sub-Clause 1.8 it is stated that the *DBFO Co 'shall fully comply with the requirements of the Rivers Agency and/or the Environmental and Heritage Services'*.

4.3.2 Schedule 4 [Construction and Handback Requirements] includes Part 2 [Construction Requirements]. Annex 6 covers Roadworks and General Requirements and within this Section 6 relates to Drainage and Service Ducts.

4.3.2.1 Clauses 6.16 to 6.21 relate to Hydraulics and Pipework.

Clause 6.16 states, *'The gravity surface water system shall accommodate the 1 in 1 year storm in bore without surcharging and during a critical 1 in 5 year storm event surcharge levels shall not exceed those specified in HD33/96'.*

4.3.2.2 Clauses 6.26 to 6.30 cover Pumped Drainage.

Clause 6.26 states, *'Drainage of any part of the New Road where a gravity outfall to a watercourse cannot be achieved, or where a gravity*

outfall cannot be achieved for any other reason, shall be achieved by pumping'.

Clause 6.28 states, *'Any such pumped system shall: 6.28.1 cover the collection, storage and pumping of all waters however arising, whether from rainfall, surface runoff or groundwater flow.*

4.3.2.3 Clause 6.37 to 6.46 covers Culverts.

Clause 6.38 states that culverts shall be design in accordance with the Institution of Hydrology Report 124 "Flood Estimation in Small Catchments" and with CIRIA Report 168 "Culvert Design Guide".

Clause 6.39 states that. *'Unless otherwise stipulated by the relevant Interested Parties, culverts shall be designed for a 1 in 100 year storm event.'*

4.3.3 No other stipulation, other than that existing culvert dimensions should not be reduced, was made by either the Rivers Agency or DRD and so the design criteria for the culverts remained a 1 in 100 year flood event.

5 Weather Conditions and River Flows

5.1 As indicated by HMC in their Report on Flooding of Broadway Underpass, Saturday 16 August 2008, the Met Office Weather Report for the month of August 2008 indicates that 67.3 mm of rain fell in the Belfast (Newforge) Area in a 24 hours period on 16 August 2008. In addition the Met Office Report indicates that there had been intermittent locally heavy rainfall over the preceding 7 days. Heavy showers and thunderstorms on the afternoon of 13 August 2008 had already caused localised flooding and further showers and outbreaks of rain, occasionally heavy had occurred on the 14th and 15th. This had left the ground in the surrounding areas saturated. On 16 August 2008, a band of prolonged and very heavy rain moved across the area. Overall it is understood from The Met Office sources that it was the wettest August since 1914.

5.2 It is important to appreciate the difference between rainfall return periods and flood flow return periods as required under the Contract. The highway surface water drainage system is to be designed for the surface water run-off from a 1 in 1 year rainfall event without surcharge and from a 1 in 5 year event with surcharged conditions. These drainage systems are relatively small impervious areas and the rain falling on the area can be assumed to be uniform. Flood flow return periods however, are much more complex and are used for rivers and large watercourses which cater for the runoff from larger catchment areas consisting of a wide varying surface impermeabilities and slopes and where the intensity of rainfall varies across the area of the catchment.

5.3 The Rivers Agency commissioned Jacobs Engineering UK Ltd. to carry out an assessment of the flows on 16 August 2008 in the various rivers in the Belfast area. The flow in each of the rivers was assessed using data from measuring stations which were present on all the rivers with the exception of Clowney Water where it had been necessary to remove the gauging as part of the Underpass works. Jacob's initial conclusion was that the flows in the various rivers all peaked in the range 1 in 25 to 1 in 50 years. They concluded therefore that the flow in Clowney Water would also have reached a peak within a similar range. Jacobs caveat their initial conclusions as purely indicative as further evidence could be gathered from the field to refine the flood estimates.

5.4 The Review Team also met with the Rivers Agency, and discussed the river flows with them. The RA provided hydrometric data for the River Blackstaff, Loop, Farset and the Lagan. The profile for the River Lagan indicated that the flow in the Lagan on the 16 August 2008 could be assessed at a 1 in 70 year flood. The data obtained from the gauging station on the Blackstaff 400m upstream of Clowney Water indicates river water depths in the region of 2.90m at 16.30 hrs and at 2.93m at 17.15 hrs. Similar depths of flow could be expected at the Blackstaff Culvert inlet headwall and the Overflow Structure. They concluded therefore that flows in these rivers on the 16 August 2008 lay between 1 in 50 and 1 in 70 years. The RA are of the view that Clowney Water behaves in a similar manner to the Blackstaff and the River Lagan and that the

flood flow in the Clowney Water would have been less than a 1 in 70 year return period and probably nearer a 1 in 50 year return period.

5.5 The River Manager, Belfast City Regeneration Directorate, on the afternoon of Saturday reported that the outflow from the Relief Culvert at about 15.00hrs to 16.00 hrs was running with an exceptionally heavy flow, over half full bore whereas the Blackstaff outfall was a moderate to heavy flow at less than half bore. The River Manager confirmed that the River Lagan Weir setting at the time of the event gave water levels in the River Lagan of approximately -0.3m OD. in the vicinity of the outfalls. The invert levels of the outfalls have been quoted as -1.54m OD for the Relief Culvert and -1.17m OD for the River Blackstaff

5.6 In the Review Team's discussions with the RA it was indicated that the design flow of 20 cumecs represents close to the maximum flow which Clowney Water is capable of delivering. There is likely to be a limiting capacity provided by this upper culvert 170m upstream of the Clowney Water inlet at Broadway which the RA believes to be approximately 18 cumecs. There are no discharge points within this unculverted section of Clowney Water. The RA said that there was no reported flooding upstream of the culverted section above, indicating that the flow coming through the upstream culvert was less than 18 cumecs.

5.7 HMG/HMC/Arup indicated at meetings with the Review Team that based on the possibility that there was effectively no flow in the Clowney Culvert at the time that Clowney Water overflowed they believed that the total flow in Clowney Water would have been 18.5 cumecs. When further allowance is made for the fact that some of the flooding would come from runoff from the adjacent roads, both from slip roads above the Underpass and from existing roads, e.g. Broadway to the roundabout, the various figures quoted for the Clowney Water would appear more compatible.

6 Flooding of Broadway Underpass Timeline and Response to Events

6.1 Table

6.1.1 Chronology of events and the actions taken on site

Time	Event	Source
14 August 2008		
-	The Clowney Water Trash Screen last cleaned.	HMC Report
15 August 2008		
16.00	Daily Trash Screen inspection by HMC.	HMC Report
16 August 2008		
12.30	Trash Screen inspected by HMC Broadway Section Manager and found to be clear	HMC Report
15.45	Water level in the Clowney Water upstream of Trash Screen started to rise	CCTV
16.00	HMC Broadway Section Manger informed by site security that 'Broadway roundabout experiencing some flooding'.	HMC Report
16.00+	Resources mobilised. HMC response gang checked to ensure Trash Screen was not blocked and that water flowing freely into the culvert.	HMC Report
16.15	Water level rises above grass bank and remains constant.	CCTV
16.16	Flow from Clowney Water starts to overflow the bank beside Park Centre.	CCTV
16.30	Broadway Underpass began to fill with water from Clowney Water, which was overflowing upstream from the Clowney Culvert entrance. Trash Screen inspected; reported clear and water flowing into culvert.	HMC Report
16.30	Police implemented emergency closure on approaches to Broadway Underpass. HMC reported that five cars breached the temporary traffic management closure. One of these cars became submerged within the Underpass and had to be recovered once the flood water had subsided. Several cars became stranded and submerged on the slip roads.	HMC verbally reported to the Review Team
Review Team Comment: Permanent traffic management implemented subsequently but precise timing not recorded		

Time	Event	Source
16.45	2m depth of water in Underpass.	HMC verbally reported to the Review Team
17.15	Broadway Underpass filled to 0.5m above soffit of roof slab.	HMC Report
Review Team Comment: Estimated by HMC to contain 50,000 cu m of water.		
17.20	The penstock in the flow control structure moved by HMC from half open to fully open	HMC Report
Review Team Comment: HMC claimed that this made no apparent difference (verbal report HMC to Amey.)		
17.37	Telescopic handler arrived at gates to the Clowney Water to clear Trash Screen	CCTV
17.44	Telescopic handler left without being able to clean Trash Screen.	CCTV
18.15	Objects observed floating out from the Clowney Water into car park	CCTV
18.25	Excavator arrived at gates to the Clowney Water to clear Trash Screen.	CCTV
18.30	Additional resources brought on site by HMC to mitigate flooding effects. Rain stopped and water level started to fall at the culvert inlet. Considerable debris observed being washed down the Clowney Water. HMC deployed resources at Trash Screen to ensure no obstruction caused by this debris.	HMC Report
18.36	Excavator departed and tracked round to front of headwall to clear Trash Screen.	CCTV
18.39	Excavator reached the Clowney Water headwall.	CCTV
Review Team Comment: HMC reported verbally to Amey that it believed the Trash Screen was breached at this time. HMC recovered “about 2 buckets full of debris” and claimed that this “had no effect on the flow”.		
18.42	Water level in car park had fallen. The inflow from the Clowney Water appeared to have ceased.	CCTV
18.52	Flood water appeared to be below the Clowney Water embankment level.	CCTV
19.30	Observed that Clowney Water remained full.	HMC Report
20.00	Overflowing started to abate.	HMC Report
20.34	Flood water started to recede at Park Centre Car Park (at back of Dunnes Store).	CCTV

Time	Event	Source
22.00	Pumps mobilised and started pumping at Underpass	HMC Report
17 August 2008		
am	Bulk pumping commenced.	HMC verbally reported to the Review Team
19 August 2008		
06.00	Road through Underpass opened with slip roads operating with one lane open.	HMC Report also confirmed verbally to the Review Team

7 Approach to Design and Compliance

7.1 Design and Certification Procedure

7.1.1 The Design Data is brought into the Works by means of the Design and Certification Procedure. The principal elements of the procedure are set out in paragraphs 7.1.2 to 7.1.4 below;

7.1.2 ***The Design Certificate***. This certifies that the design meets with the requirements of the DBFO contract. The certificate is signed by the Designer and the representative of the DBFO Co.

7.1.3 ***Third Party Consultation Certificates***. These certificates confirm that, where required by the DBFO Contract, outside bodies have been consulted and that they have no objection to the design proposed. The certificates are signed by the Designer, the Contractor and the representative of the DBFO Co

7.1.4 ***DBFO Co Change Certificate***. The DBFO Co's proposals to vary or amend the requirements of the contract are to be submitted with Design Data and supporting information explaining the reasons for the change. These are submitted as a DBFO Co change under the Review Procedure.

7.1.5 The Department's Nominee must countersign all the Certificates in accordance with the Review Procedure.

7.1.6 The works cannot commence on site until the design has achieved the status of "no objection" under the Procedure.

7.2 Permit to Use

7.2.1 A ***Permit to Use*** is required before the new road, or any part of the new road is brought into permanent use and opened to traffic without restriction.

7.2.2 The Permit confirms that the section or sections of the new road that are to be opened are safe for members of the public to use, without traffic restrictions,

7.2.3 The confirmation is given by the DBFO Co and the Permit is signed by the Departments Nominee.

7.2.4 In addition to a failure to satisfy the requirement that the road shall be safe to use, the Permit can also be withheld on the grounds that requirements of the Design and Certification Procedure have not been complied with in full.

7.3 The Illustrative Design

7.3.1 Consultations commenced between Ferguson McIlveen (FM) (now part of Scott Wilson) acting for DRD Roads Service (DRDRS) and the Rivers Agency (RA) in September 2002, prior to the Public Inquiry which was to be held in November 2002.

7.3.2 Two design options were initially identified:

7.3.2.1 Option 1. This option comprised diverting the Blackstaff into the Blackstaff Relief Culvert and the Clowney into the original Blackstaff Culvert. It was later discarded.

7.3.2.2 Option 2. This option was acceptable to the RA. It maintained the existing arrangement in which the Blackstaff and the Clowney merge in a structure that incorporates an overflow arrangement near the head of the Relief Culvert. In this option, normal flows are directed to the downstream Blackstaff Outfall Culvert and flood flows directed over a weir into the Relief Culvert. Clowney Water is carried in an aqueduct within the soffit of the Broadway Underpass on an approximately straight alignment from a point just upstream of the existing headwall into the Overflow Structure.

7.3.3 FM undertook some further investigation in 2003 to assess the hydraulic impact of the configurations within Option 1 and Option 2 and indicated its understanding as follows:

7.3.4.1 The capacity of the Relief Culvert was calculated under various impounding levels for the River Lagan, -1.3m OD, 0.3m OD and 2.0m OD and the flows of 40, 37.5 and 32.5 cumecs. At the time of the flooding event on 16th August 2008, with an impounding level of -0.30m OD in the River Lagan, the water levels in the area of the Broadway Underpass would be less than 5.03m OD with a flood flow of 40 cumecs in the Relief Culvert. The approximate road levels in this area are 6.1m OD. This would indicate the capacity of the Relief Culvert is a minimum of 40 cumecs.

7.3.4.2 The 1 in 100 year flood flow (Q_{100}) for the Blackstaff upstream of the new works, was 31 cumecs. FM's assessment in its letter of 24th January 2003 indicated 32.4 cumecs as the Q_{100} flow for the Blackstaff catchment. The RA advised in its letter dated 20 January 2003 that Q_{100} flow in the Blackstaff River should be 40 cumecs. FM suggested, therefore, that the maximum Q_{100} flow in the River Blackstaff should be between 32.4 and 40 cumecs.

7.3.4.3 The capacity of the Blackstaff Culvert downstream of the overflow chamber was 20 cumecs.

7.3.4.4 The Q_{100} flow for the River Clowney was 20 cumecs.

7.3.4 In the minutes of a meeting with the RA, dated 8 January 2003, it was noted that a proposal to culvert Clowney Water beside the Park Centre was favoured by the RA from a maintenance point of view. Flooding, in extreme conditions, was currently restricted to the Park Centre Car Park but, with current weather projections, this flooding could overspill and impact the Underpass in the future. Roads Service carried out a review through a risk workshop, with RA in attendance, and through a series of meetings, to explore the risks associated

with flooding, and a requirement was included in the Contract to design all culverts for a 1 in 100 year flood event.

7.3.5 Discussions continued during 2003 in relation to the diversion of the rivers and the outcomes are summarised in the M1/Westlink Road Improvements – River Diversion Report, June 2003.

7.3.6 Discussions continued throughout 2004 regarding the replication of the existing Penstock Valve on the Blackstaff Culvert. FM proposed a concrete downstand, but the RA's preferred solution was to replicate the existing Penstock Valve as this gave its staff the ability to direct flows as necessary, in particular circumstances, and especially in high flow/flood conditions. These circumstances would include closing off the downstream Blackstaff for maintenance purposes.

7.3.7 The illustrative design was completed by FM on the basis of Option 2 and the requirements outlined above.

7.4 The Alternative Design

7.4.1 Following the appointment of HMG as provisional preferred bidder and prior to the award of the DBFO Contract, consultations re-commenced with the RA, which culminated in an alternative proposal from HMC. This proposal was contained in a report entitled 'The Clowney Culvert Report', December 2005. The report proposed an alternative to the illustrative design, under which Clowney Water would be diverted away to the south and west of the Underpass, under the M1 Motorway and back down the eastern side to run parallel to the River Blackstaff in a twin culvert. The flows of the two rivers would merge in an Overflow Structure with a weir. This would provide a similar arrangement to that which currently operated, except that it consisted of an enclosed chamber with a roof slab.

7.4.2 At a meeting on 5 December 2005, which was attended by RA, FM, HMC and HMC's designers, Arup, it was confirmed that the RA had accepted in principle the proposed alternative Clowney Culvert Diversion as set out in the HMC's 'Clowney Culvert Report - December 2005'. Other matters raised at the meeting are referred to in paragraphs 7.4.2.1 to 7.4.2.5 below.

7.4.2.1 At the meeting, HMC confirmed that to meet RA concerns it proposed to raise the banks of Clowney Water above the culvert intake to approximately 300mm above the water level it projected for a 1 in 100 year flood event.

7.4.2.2 RA requested that a sensitivity analysis be carried out for flows in excess of 1 in 100 year flood event or the Trash Screen becoming blocked. Arup confirmed that this issue had not been considered.

7.4.2.3 It was confirmed that a new Trash Screen would be required with access for maintenance.

7.4.2.4 Arup advised that the proposed culvert had been designed to convey 20 cumecs, (agreed as a 1 in 100 year flood event). The RA confirmed approval in principle to the Clowney Culvert dimensions.

7.4.2.5 It was agreed that a detailed design for the trash screen would be provided, based on detailed guidance notes from RA.

7.4.3 In recent discussions with the Review Team, Arup confirmed that it did not carry out hydraulic calculations for the Blackstaff Culvert but adopted the illustrative design dimensions, which are reflected in the Contract Documents. These are understood to be based on existing dimensions.

7.4.4 A further meeting was held on 17 January 2006, at which a revised version of the Clowney Culvert Report was submitted to RA. Matters raised at the meeting are set out in paragraphs 7.4.4.1 and 7.4.4.2 below.

7.4.4.1 Concern regarding flow from Clowney Water getting into the Broadway Underpass in the event that a 1 in 100 year flow was exceeded or the Trash Screen became blocked was again raised as a concern by both RA and FM. Arup agreed to undertake 'some basic flood routing to identify the Clowney flow path at Broadway in the event the aforementioned situations arise'. This would be carried out in conjunction with a sensitivity analysis based on the tail water level in the Broadway Overflow Structure. No documentary evidence of these assessments has been presented to the Review Team.

7.4.4.2 Discussion took place at the meeting regarding the access arrangements for the Overflow Structure. In addition, dimensions for Blackstaff and Blackstaff North Culverts were confirmed.

7.4.5 It is understood that a number of issues continued to be developed with RA staff from this meeting onwards, and these have been further discussed in meetings between the Review Team and the RA and HMG/HMC/Arup, respectively. These covered:

7.4.5.1 ***Design of the Trash Screen.*** It is noted that the spacing used on the lower section of the new Trash Screen is significantly less that that used on the existing Trash Screens. The RA details indicate that the spacing shall be 'to suit the debris size'. It has not been possible to determine the reasons for the reduction in spacing compared to the existing, although this may have been driven by Health and Safety (CDM) considerations. Clearly the smaller the spacing is, the more is the risk of blockage, conversely, the smaller the spacing is the less likely there will be unauthorised access. Also, although the possible use of mechanical cleaning screens was raised early in the discussions, this was not pursued and the present RA maintenance staff do not believe these to be appropriate to the location.

7.4.5.2 ***Design of the Overflow Structure.*** HMC/Arup confirmed that a detailed hydraulic design for the Overflow Structure was not carried

out. The Overflow Structure was designed to mirror the arrangements of the existing overflow. This meant that the weir length, levels and height were replicated. There is broad agreement between all parties that only hydraulic modelling would be appropriate in determining performance under extreme conditions of flow.

7.4.5.3 ***Design of the Blackstaff and Relief Culverts.*** HMC/Arup confirmed that a detailed design was not carried out for these sections of new culverts but that the dimensions indicated in the illustrative design were adopted. There has, therefore, been no further analysis beyond that carried out by FM for the purpose of the illustrative design.

7.4.5.4 ***Design of the Clowney Culvert.***

- ***Design Standards*** – Paragraph 6.38 to Annex 6 to Part 2 of Schedule 4 of the Design Data requires compliance with Hydrology Report 124 (Flood Studies) and CIRIA Report 168 for the design of culverts. CIRIA Report 168 is appropriate to relatively short, straight culverts. Arup indicated that this had been taken into account in the design and confirmed that it had made sufficient allowance for additional head losses due to the bends in the new structure and had based its calculations on a longer effective length. The calculations, based on the 'Culvert Master' programme, allowed for these losses.
- ***Design Assumptions*** – Arup indicated in its first meeting with the Review Team that the Clowney Culvert had been designed based on the assumption that it was under free flow conditions. Under high flow conditions the outlet might not be free flowing and would be affected by the flows in the River Blackstaff. This would affect the choice of tail water level and may actually give rise to submerged conditions, which would reduce the effective design flow in the culvert. Arup's Design Engineer confirmed that, whilst the design had been checked against a submerged outlet condition, the free-flow analysis had been used for the culvert design as this was considered to be the most efficient design. No supporting calculations for the submerged condition were provided.
- ***Flood Studies Report*** – The Review Team has not seen evidence to confirm that the contract requirements in respect of the culvert designs have been met in full. In particular, no Flood Studies Reports or Sensitivity Analysis were presented to the RA. Arup has indicated that a rudimentary desktop study had been carried out but this had not been presented to the RA. The RA did not require the submission of these reports as a condition of acceptance. Both RA and Arup indicate that the lifting of the bank freeboard from 300mm to 500mm above the 1 in 100 yr flood level may have been a response to this issue, but it is the opinion of the Review Team

that, should the Trash Screen become blocked, this increase in height would only have delayed but not prevented the flooding.

7.4.5.5 ***Design of the Underpass Surface Water Pumps***. Following a Designers Risk Assessment a decision was made by the DBFO Co to provide a pumping system within the underpass to accommodate surface water run-off from a 1 in 100 year flood event. The pumping station consists of three pumps, one duty, one duty standby and one standby. The designed output from the duty and duty standby pumps has been quoted at 570l/sec. At the time of the flood event, 16 August 2008, none of the pumps was in place and temporary pumps had been provided. Two pumps, one with an output of 80 l/sec and one of 160 l/sec output, totalling 240 l/sec output were placed in the bottom of the Underpass and a highlift pump with an output of 160 l/sec placed at the roundabout level as standby. The total available output being 400 l/sec, (0.4cumec). These pumps would not have been able to cope with the inflow that occurred in the Underpass but would have provided some small mitigation.

7.4.5.6 ***Design Changes.*** The Alternative Design for the Clowney Culvert diversion became 'Design Change No. 1' under the change procedure detailed in the Contract. At the time of the flooding of the Underpass on 16 August 2008, Rivers Agency had agreed in principle to the culverting diversion route for Design Change No.1, but under the contract final approval had not been granted.

8 Contributory Causes of the Flooding Event

8.1 A number of causes, which could have contributed to the flooding of the Underpass, were suggested by SW and HMC/Arup during the course of the interviews conducted by the Review Team and referenced in paragraph 2.2.2 of this Report. The Review Team has considered each suggested cause, together with the supporting data, and has conducted an assessment of the site evidence in order to reach its conclusions.

8.2 One fact is clear; the system failed to perform on 16 August 2008 under a return period of less than 1 in 100. The contributory mechanisms that have been considered are as follows:

8.2.1 ***Setting of the Blackstaff Penstock Valve.*** The Blackstaff Penstock Valve, which takes the form of a sluice gate, was almost certainly introduced at the time of the construction of the Relief Culvert to close off the Blackstaff Culvert for maintenance purposes. The view taken by the RA maintenance staff for many years was that the system worked well with the Penstock Valve set to restrict flows in the Blackstaff culvert to between ⅓ and ½ bore. The Review Team have seen no technical evidence which would support this view. No evidence was provided that, as suggested by Arup, opening to full bore would cause flooding downstream. It would seem to be a reasonable conclusion that, had the Penstock Valve been left fully open, the discharge into the Blackstaff Culvert on the downstream side of the Overflow Structure would have been significantly increased.

8.2.2 ***Blocking of the Trash Screen.*** The RA has taken the view that the obstruction of the Trash Screens would have been a significant factor in the flooding of the Underpass. However, HMC is firm in its evidence that at the time of its inspection, just after 16.00 hrs, there was no blockage of the Trash Screen and that water levels were equal on both sides of the screen. Further inspection of the Trash Screen took place around 16.45 hrs when the Underpass was approximately 2m deep in water, but the plant used, a telescopic mobile fork, was ineffectual. The Underpass had filled to 0.5m above the soffit at 17.15 hrs. At approximately 18.30 hrs, excavators were brought in to attempt further clearance and little debris was recovered. Visibility through the muddy water was very poor and it is believed that during this clearance attempt, the Trash Screen was accidentally breached. The Trash Screen was breached at 18.39 hrs and water levels in the Park Centre car park began to fall at around 18.42 hrs. It is likely that some blockage did occur at the Trash Screen (unseen below the muddy water) and that the debris was washed through the culvert when the screen was partially ripped away.

8.2.3 ***Design Capacity in the Blackstaff and Relief Culverts.*** The Review Team have considered a number of issues in relation to the design capacity of these culverts:

8.2.3.1 The HMC/Arup team has reported that both the Clowney Culvert and the Overflow Structure were full and that this demonstrated that more

flow was entering the system than was able to leave it. HMC/Arup postulate that the Relief Culvert, in particular, must have been running at capacity.

8.2.3.2 Based on an inspection carried out for the RA by SW on 28/29 August 2008, SW reported that there is evidence from undisturbed stalactites on the soffit and rags on manhole ladders that the flow in the Relief Culvert was running approximately half full. SW also reported that the outfalls were permanently part-submerged as is confirmed by the invert levels quoted of -1.54m OD for the Relief Culvert and -1.17m OD for the Blackstaff, with normal water levels of -0.3m OD in the River Lagan.

8.2.3.3 Eye-witness evidence has been provided by the Lagan River Manager that between 15.00 hrs and 16.00 hrs the Blackstaff Relief Outfall had an exceptionally heavy flow but appeared to be flowing "just over half bore". The Blackstaff Outfall was described as flowing well with a moderate to heavy discharge.

8.2.3.4 The Review Team conclude that it seems likely that the Relief Culvert was flowing well but below its capacity. Similarly, the flow in the downstream section of the Blackstaff suggests that it too was below its capacity.

8.2.3.5 It should be noted that, currently, there are two surface water pumping stations discharging into the outfalls. Glenmachen Street pumping station to the Relief Culvert and Distillery Street pumping station into the downstream Blackstaff. Each of these discharge 4 cumecs during flood events. These quantities will reduce the available capacity in each of the culverts, but is considered not to have been a contributory factor in this event. Both these pumped outfalls will eventually be connected to the new Belfast Sewer Project system currently being constructed.

8.2.4 ***Design Capacity in the Clowney Culvert.*** The hydraulic design for the Clowney Culvert has been based on free flow conditions. It is possible that the flow conditions will change under certain circumstances and become submerged conditions, in which case the flow capacity could be adversely affected. It would appear that a further review and development of the design parameters to determine if the free flow state was the most onerous design condition was not undertaken.

8.2.5 ***Flow Patterns in the Overflow Structure.*** It was not possible to observe what was happening in the Overflow Structure during the flood event. Observations by HMC staff via the access manhole in one corner indicated that the chamber was full and that water was 'swirling around'. However, because of the corner location of this manhole, it gives little guidance as to the flow pattern behaviour in the main body of the chamber. It is entirely possible that extreme turbulence was caused by heavy flow levels and these may well have affected the rates of discharge into the Blackstaff and Relief Culvert outlets, but this can only be

tested by hydraulic modelling. Evidence of debris deposited in the Overflow Structure from a joint inspection report between HMC/Arup/Scott Wilson entitled, Clowney and Blackstaff Relief Culvert Inspection, dated October 2008, could suggest that some form of turbulence occurred. Arup made the point that the Alternative Design, under which the Clowney and Blackstaff flows join each other in parallel, would probably produce less turbulence than the illustrative design where the flows would have joined at right angles. However, if the Blackstaff and Relief Culverts were not running full, and the Overflow Structure was full, then the Review Team conclude that some mechanism was restricting the outflow from the Overflow Structure.

9 Potential Mitigation Options

9.1 In order to ensure that the risk of further flooding of the Broadway Underpass is minimised, consideration should be given to the implementation of the measures outlined below.

9.2 Measure 1 - Early Warning Procedures

9.2.1 Provide advance warning of a potential flooding event to trigger actions that would ensure the safety of the public and minimise damage to the highway and other property.

9.2.2 During the continuing construction of the Package 1 contract works, the DBFO Co. should develop procedures to monitor weather conditions and the flows in the Clowney Water and Blackstaff River. This could be achieved by developing links to the Meteorological Office and the Rivers Agency systems. Following satisfactory completion and handover of the Works, this responsibility would pass to the Rivers Agency.

9.2.3 It is anticipated that the levels at which action would be triggered would change once it had been confirmed that the hydraulic performance of the system meets requirements and all parts of the system are fully operational.

9.3 Measure 2 – Ensure that the hydraulic capacity of the system is adequate

9.3.1 Assess the overall performance of the upstream and downstream culverts, together with the Overflow Structure and Penstock Valve, as one system, using a theoretical approach supported by physical modelling techniques.

9.3.2 Identify and implement any new works or measures required to ensure that the system meets the requirement to manage the flows generated by a 1 in 100 year flood event.

9.3.3 Measure 3 to Measure 7 should take account of the information generated by the assessment to ensure that the hydraulic capacity of the system is adequate.

9.4 Measure 3 – Setting the Penstock Valve

9.4.1 Opening the Penstock Valve on the Blackstaff culvert when heavy rain is forecast would remove the restriction to flow at the outlet from the Overflow Structure. Consideration should be given (in consultation with the Rivers Agency) to maintaining the valve in the open position as a default setting. Other settings could be established to suit maintenance requirements and other specific situations.

9.4.2 This measure can be used in conjunction with other measures to minimise the risk.

9.5 **Measure 4 – Enhanced Trash Screen Cleaning Regime**

9.5.1 The current regime in place for the monitoring of the Trash Screens can be enhanced to include for more regular inspections and an early warning system set up to advise of impending adverse weather. Such a system would enable standby teams to quickly mobilise resources to check/clear any potential blockages. The use of mechanical cleaning methods could also be investigated. An investigation could also be undertaken to determine the source of the trash and identify measures which could be taken to minimise the possibility of trash finding its way into the Clowney Water.

9.5.2 This measure can be used in conjunction with other measures to minimise the risk. It should be noted that responsibility for cleaning the Trash Screen will pass to the RA following completion and handover of the Works.

9.6 **Measure 5 - Raise the banks of the Clowney Water.**

9.6.1 Complete the works to raise the banks of the Clowney Water to 500mm above the 1 in 100 year flood design level on the approaches to the new Clowney Culvert.

9.7 **Measure 6 – Culverting the upstream section of the Clowney Water**

9.7.1 The section of the Clowney Water, immediately upstream of the inlet to the new Clowney Culvert, is currently an open section, approximately 170m in length. Upstream of this is a long length of culverted river. Placing this open section of the river in culvert would contain the Clowney Water flood water and thus prevent flooding from the river at this point. However, as part of the overall assessment of these measures, the design should investigate the affect on the upstream sections of Clowney Water to ensure that the culverting does not increase the risk of flooding upstream.

9.7.2 The culverting proposal has the advantage of removing the need for a Trash Screen on Clowney Water. The proposal to culvert this section was raised and discussed in January 2003 by the RA and FM and the budget cost for the work was £500,000 (this was subsequently revised by FM in April 2003 to £440,000).

9.7.3 The Review Team gave consideration to an increase in the height of the sheet pile walls to give additional protection from raised water levels in the open section of the Clowney Water. However, it concluded that this would give only a limited level of protection and could introduce public safety and Trash Screen maintenance issues that could be addressed with the installation of protective fencing and/or a further increase in height of the sheet piled walls.

9.8 **Measure 7 – Overflow routed to Bog Meadows**

9.8.1 The current culvert design requirement under the Contract is stated as 1 in 100 year flood flow. In the event that this flood event was exceeded, or should the currently constructed culvert / Overflow Structure / outfalls arrangement not meet the 1 in 100 year flood flow requirement, the excess flows could be routed

away from the Clowney Water from a point just upstream of the inlet headwall to run southwards and discharge into the Bog Meadows area.

9.8.2 An initial level survey would suggest that although this route is possible, the level difference is small and careful design would be required. Furthermore, Bog Meadows is a special interest site and consultations with and permissions from the relevant bodies would be required. The excess flood flows would be held within the Bog Meadows and discharged under controlled conditions into the Blackstaff River. This would be similar to the way in which the Bog Meadows currently drains.

9.9 Measure 8 – Attenuation

9.9.1 The excess flows could be routed to underground storage tanks located beneath the car park area of the adjacent Parks Centre Retail Park. The flood water would be held in these tanks and returned to the Clowney Water under controlled conditions. The surface above the tanks would be returned for use as a car park. The amount of excess flood water to be stored in this way would need to be carefully considered bearing in mind the risk of further flooding and the physical sizes of the tanks. The volume of the tanks would be determined following consideration of the level of mitigation that is practicable and revised hydraulic designs

10 Conclusions

10.1 The responsibility for the design, construction, completion, ongoing maintenance and operation of all elements of the road infrastructure that fall within the scope of the Contract rests entirely with HMG, the DBFO Co.

10.2 The DBFO Co Alternative Proposal for the culverting and diversion of the Clowney Water and Blackstaff River was agreed in principle by the Rivers Agency.

10.3 The Broadway Underpass was opened to traffic on 4 July 2008. The construction of the Blackstaff and Clowney Culverts was substantially complete but the works remained a construction site. Lane restrictions remained in place throughout the construction site, including through the underpass, to allow remaining work to be completed.

10.4 During the week preceding the flooding of the Broadway Underpass on 16 August 2008, the Belfast area experienced intermittent and locally heavy rain. There had been some localised flooding and the ground in the surrounding areas was saturated. On the day of the flooding a band of prolonged and heavy rain moved through the area.

10.5 Although no directly measured data is available to assist in confirming the level of flow in the Clowney Water, it seems probable that the return period on 16 August 2008 was in the range 1 in 50 years to 1 in 70 years, which would have produced less than a design flow quantity of 20 cumecs. Similarly, the flow in the Blackstaff would have been below its design flow of 40 cumecs. Under those conditions, the new drainage system did not perform in accordance with its required design capacity of a 1 in 100 year flood event.

10.6 It is not clear exactly how flows within the Overflow Structure behaved under the extreme levels of flow, although it is evident that this chamber was virtually full at one point. No hydraulic design was carried out on this element, but the key dimensions of the new Overflow Structure followed very closely that of the pre-existing Overflow Structure. There is some evidence that the Relief Culvert and Blackstaff Culvert outfalls were not running full and to maximum capacity, indicating that the discharge from the Overflow Structure may have been restricted in some way. There is no evidence that water levels in the River Lagan at the outfalls would have affected these flows. Modelling techniques would be required to determine the flow pattern within the new Overflow Structure.

10.7 The setting of the Penstock Valve on the Blackstaff will have restricted flow from the Overflow Structure into the Blackstaff Culvert. Whilst historically this setting had been found to provide a satisfactory distribution of flows between the Blackstaff and the Relief Culverts, it is not known whether or not it had been tested under high flow conditions through the new configuration, such as those experienced on 16 August 2008.

10.8 Whilst a blockage of the Trash Screen has probably been a contributory cause of the flooding, it is unlikely to have been the sole cause.

10.9 Sections of the Clowney Water banks had been increased in height to approximately 300mm above the 1 in 100 year flood level but not to the design level of plus 500mm. Whilst it is apparent that the Clowney Water would still have overtopped the raised banks, there would have been a delay in this occurrence if these earthworks had been completed.

10.10 It is noted that the permanent pumps, designed to drain the underpass, had not yet been commissioned and three temporary pumps were in place. There is no evidence to suggest that the flooding of the underpass could have been prevented if the permanent pumps had been in place. The permanent pumps have been designed to cater for the surface water runoff from the carriageway in the underpass. The additional capacity provided by the permanent pumps would only have had a very slight mitigating effect on the flood water.

10.11 No detailed hydraulic design was carried out by HMC/Arup on the Blackstaff Culverts. These were constructed to dimensions stated in the illustrative design. The design widths for these culverts were stated in the design data. It is not considered that these culverts contributed to the flooding event.

10.12 There remains a potential for further flooding of the Underpass until the hydraulic efficiency of the system has been checked and any required changes and other mitigation measures are in place. Short term monitoring will be required until mitigation measures are implemented.

11 Recommendations

11.1 Implement Mitigation Measure 5, see Appendix A, Fig 3, Recommendation 1. The DBFO Co should, at the earliest opportunity, complete the works to raise the banks adjacent to the Clowney Water on the section upstream of the new Clowney Culvert to 500mm above the 1 in 100 year designed flood level.

11.2 Implement Mitigation Measure 1, see Appendix A, Fig 3, Recommendation 2. The DBFO Co should develop enhanced procedures to include more regular inspections on the Clowney Water Trash Screen and introduce an early warning system to advise of impending high water levels to ensure the safety of the public, until completion of the Works. Consideration should be given to the continuation of these procedures by a responsible party after completion of the Works.

11.3 Implement Mitigation Measure 2, see Appendix A, Fig 3, Recommendation 3. An assessment of the hydraulic efficiency of the drainage system is required to determine tailwater levels at the Overflow Structure and the water levels in the upstream section of Clowney Water. This should be undertaken by adopting a theoretical approach supported by physical modelling techniques, using a physical model which will determine the flow patterns within the Overflow Structure and the effect that the penstock has on these patterns at alternative positions. It will also determine the significance of a Trash Screen blockage against various flow rates.

11.4 The results of this analysis will allow conclusions to be made as to how flooding occurred and what flood protection measures may need to be put in place to prevent a re-occurrence. Therefore, if required, the following should be investigated:

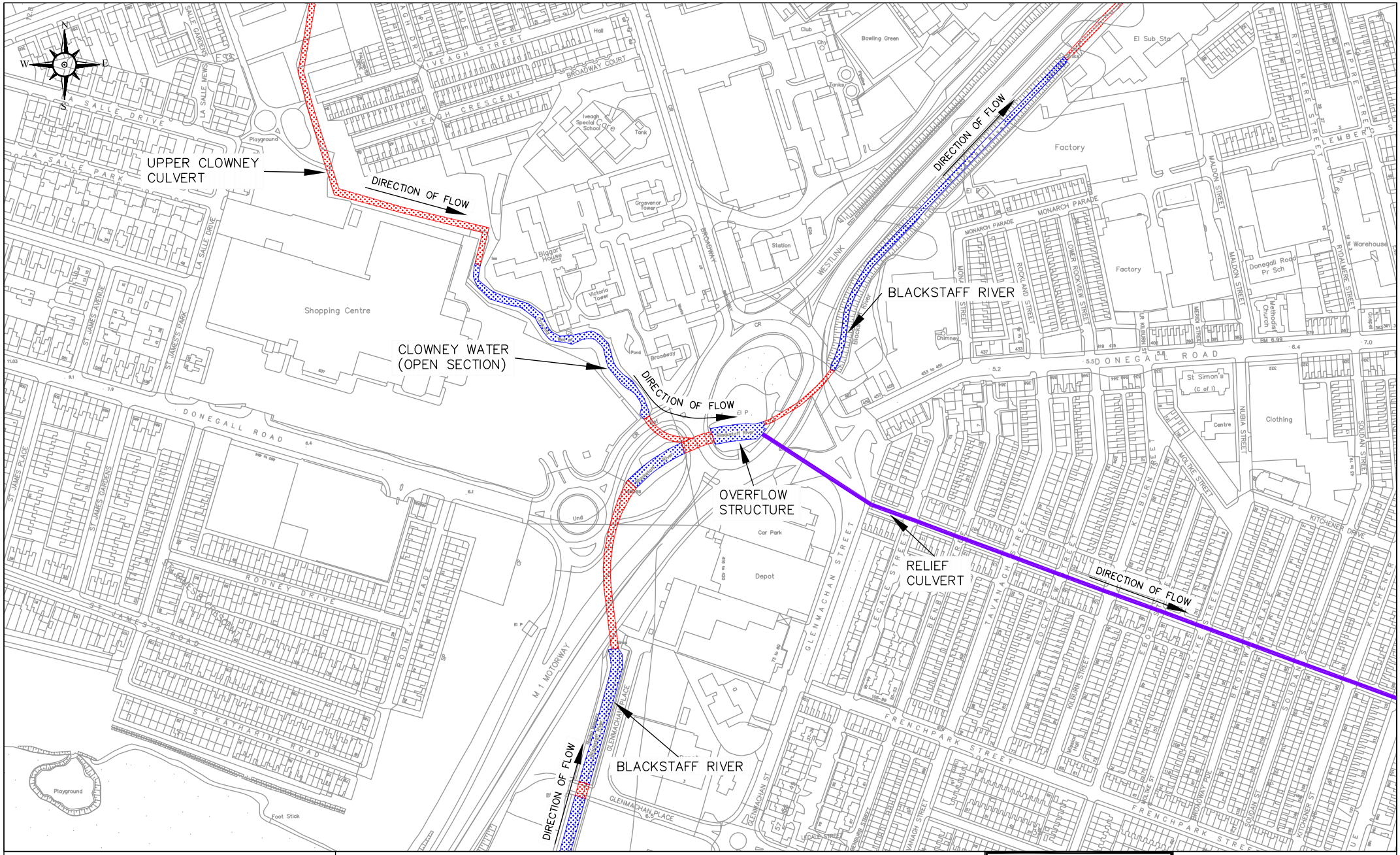
11.4.1 Development of procedures for Mitigation Measure 3; Penstock Valve levels based on the results from the physical model.

11.4.2 Investigate implementation of Mitigation Measure 4; enhanced Trash Screen cleaning such as mechanical methods.

11.4.3 Development of procedures for Mitigation Measure 6; the provision of flood protection works such as a culvert or flood walls in the upstream section of Clowney Water.

Appendix A

Figures



BROADWAY ROUNDABOUT
PRE-EXISTING DRAINAGE SYSTEM

Drawing Number: Figure 1

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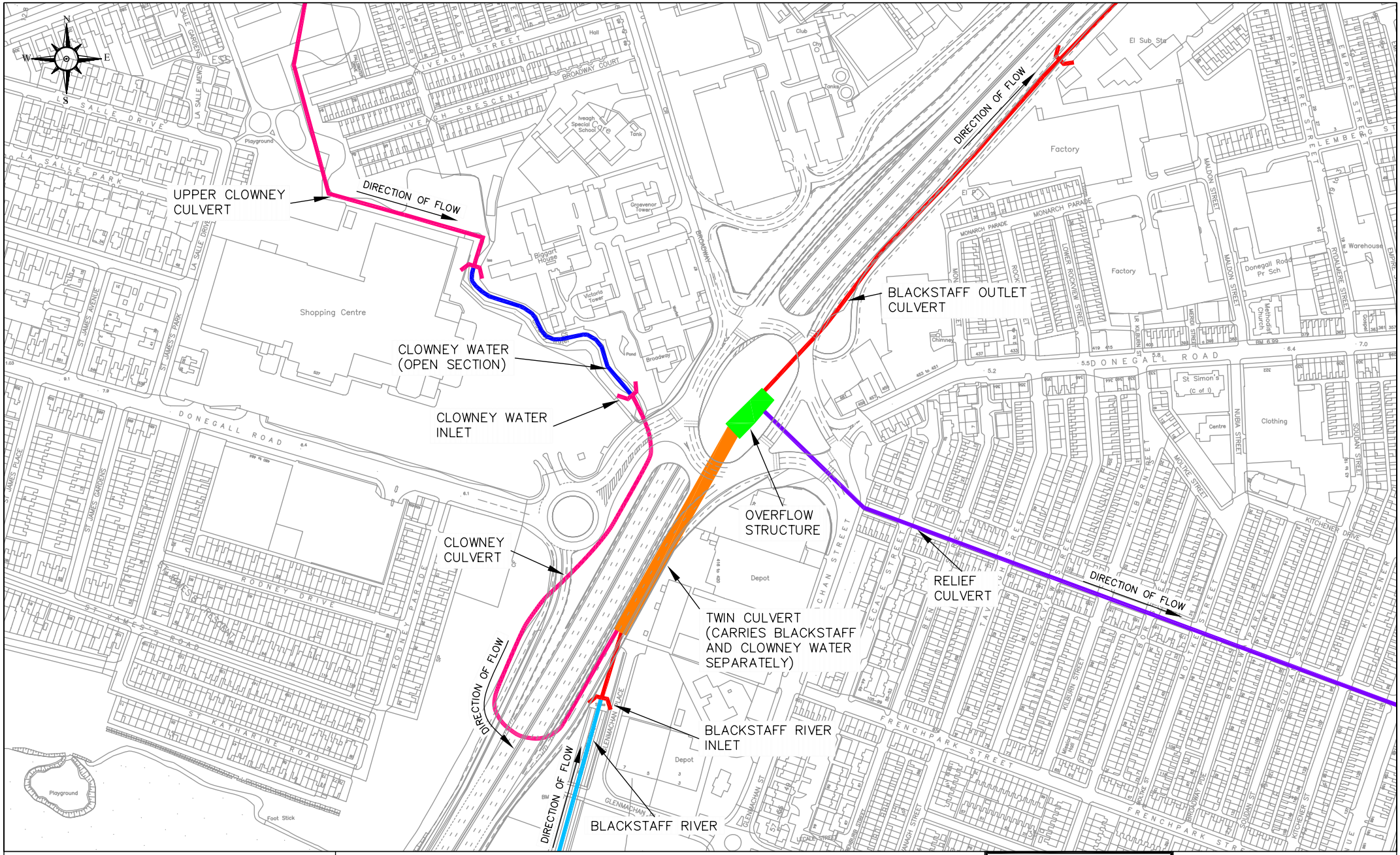
amey



BROADWAY ROUNDABOUT NEW DRAINAGE SYSTEM

Drawing Number

Figure 2

Scale at A3

1 : 2500

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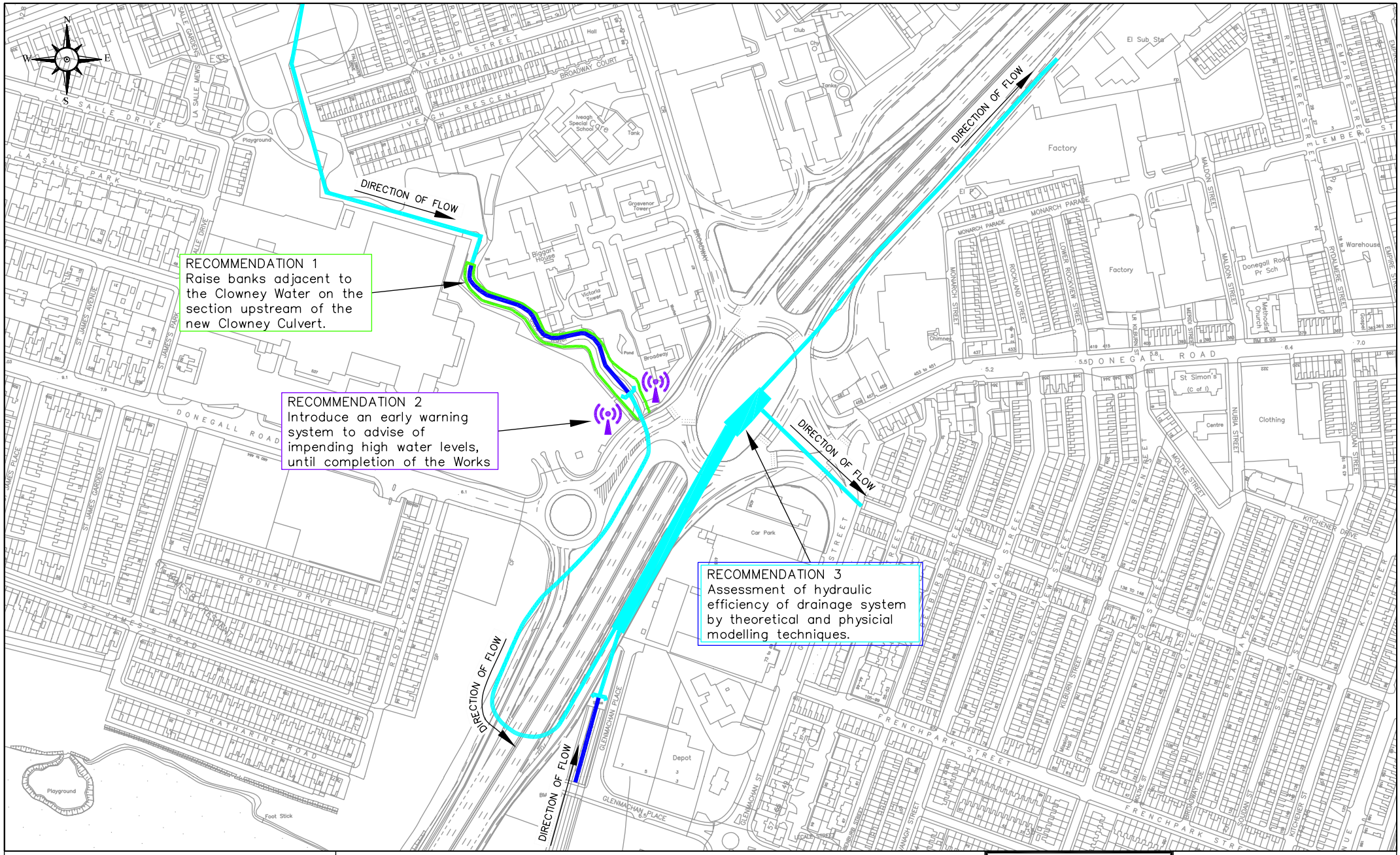

BROADWAY ROUNDABOUT
DRAINAGE SYSTEM RECOMMENDATIONS

Drawing Number
Figure 3

Scale at A3
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