Barnsley Markets

FRA Addendum - Sough Dyke Culvert

Final Report
October 2007

Prepared for:

Halloran Payne Associates HPA

Revision Schedule

Final Report
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Rev	Date	Details	Prepared by	Reviewed by	Approved by
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1 Introduction

1.1 Background Information

This report has been prepared as an addendum to the Flood Risk Assessment (FRA) related to the proposed development of the Barnsley Markets and town centre regeneration project dated April 2007. It also relates to the report on the Barnsley Sough Dyke Proposals dated May 2007.

Both the FRA and the Sough Dyke Report were prepared by Halloran Payne Associates Ltd (HPA) for their client 1249 Regeneration Partnership LLP, the document references being *HPA/774/Reports/MW/R01* and *HPA/774/Reports/Sough Dyke/MB/R01* respectively.

The FRA and the Sough Dyke Report were both submitted to the Environment Agency (EA) for comment. A emailed response, dated 6 June 2007, was sent to Martin Whitchurch of HPA by Roger Dixon, with additional input from his colleague James Mead.

This response raised a number of issues that relate to the hydraulic and structural aspects of the proposed diversion of Sough Dyke in connection with the development proposals.

1.2 Scope of Works

The scope of this report has been determined by the hydraulic issues raised in the EA response described above.

In particular, this report will seek to address the following matters:

Section 1.7 page 3, proposal to carry out assessments of the flood risk in the event of collapse or blockage of the culvert at Mh S11, S14 and S15.

MhS11 is half way down Kendray Street, just prior to the existing bend and the proposed diversion, I think the first assessment point should be at Mh S32, Eldon Street, as this is upstream of the first pinch point near the electricity sub-station.

The third assessment point at Mh S15 is clear of the site, why would anything happen there?

Assessment points should be Mh S32, S11 and S14.

. . . . . no mention of the drainage issue resulting from development platforms being lower than the surrounding roads. This combined with a blockage on Sough Dyke could create quite a serious problem combined with the wrong kind of weather.

. . . . . We have had a hydraulic assessment done to estimate likely flows from the FEH rainfall-runoff method. This report (we can provide this on request) assessed culvert capacity using the inlet conditions and concluded that the inlet of Sough Dyke was adequate to convey the 100 year flow. What it also states

though is that culvert capacity is more likely to be determined by downstream conditions. I would expect this assessment to consider the adequacy of the culvert through and off the site and take into account all significant inflows from other sewers and watercourses within and immediately upstream of the site. Also we would need to see that the proposed surface water drainage systems are able to discharge satisfactorily.

The concerns and issues raised in connection with the method of construction, particularly relating to the building and access road foundations in the vicinity of the diversion and also in connection with future access to the culvert (in the event that any repairs may become necessary rather than for routine inspection and maintenance access) come under the general category of structural issues and are not deemed to be within the scope of this report.

1.3 Methodology and Objectives

- The hydraulic assessment of the Sough Dyke will be obtained from the EA.
- A walk over survey of the site will be undertaken and reference photographs will be taken.
- Light Detection And Ranging (LiDAR) data for the site and the surrounding area will be obtained and used to create detailed contours around the boundaries of the site and also to identify potential off-site flood flow routing.
- Enquiries will be made with Barnsley Council about any known problems with this section of culvert.
- All of the information, plans, reports, etc, supplied by the Client will be reviewed and any further relevant information will be requested.
- A computer model of the existing culvert will be created using the WinDes software. The model will be geo-referenced to the supplied AutoCad drawings and the cover and invert levels also will be taken from the supplied drawing and cross-referenced where possible to any data in the culvert condition and hydraulic assessment reports.
- An assessment of flows for various return periods will be made using the Revitalised Flood Hydrograph (ReFH) method that became available shortly after the hydraulic assessment report was produced.
- The hydraulic model will be tested using input hydrographs from the ReFH method and / or conventional catchment areas as appropriate.
- The model of the existing culvert will be tested under free flow, partial blockage and total blockage conditions at the three points identified by the EA.
- The hydraulic model will be modified to include the proposed diversion and further tests will undertaken to simulate the same flow conditions and critical points that were simulated for the existing culvert.
- The consequences of any resultant flooding will be assessed.

The principal objectives of this study are to:

- Confirm that the proposed diversion of Sough Dyke will not created a system that is hydraulically inferior to the existing culvert.

- Identify and, where appropriate, quantify the effects of any flooding that could arise as a consequence of overloading, partial blockage or structural collapse of the remaining and diverted parts of the Sough Dyke culvert.

2 Site & Surrounding Area

2.1 Site Description and Development Proposals

The site is located in the centre of Barnsley at National Grid Reference SE 346 063. See plan at paragraph 3.1

The site is currently occupied by the Barnsley Market buildings, various retail units, service access, car parking and the like to the west of the railway and offices with surface level car parking to the east of the railway.

It is bounded by Kendray Street to the north, Harborough Hill Road to the east, Lambra Road and the Alhambra Shopping Centre to the south and Cheapside and May Day Green to the west.

2.2 Topographical Data

Topographical data for the study has been extracted from the survey supplied by the Client and also from 2m x 2m grid LiDAR information purchased specifically for this study.

The LiDAR data was processed to produce contours at 100mm vertical intervals that were exported in AutoCAD format.

The contours were then overlaid on the topographical survey supplied, both surveys were compared at the key locations and a small adjustment (-100mm) was made to all of the LiDAR based contours to produce an acceptably close correlation between the two data sets.

Although the 100mm interval contours produce a reasonably consistent indication of the ground profile, the considerable number of closely spaced contour lines can only be interpreted clearly over relatively small areas. Therefore, a subset of the LiDAR based contours, at 500mm vertical intervals, has been produced to enable better appreciation of the larger picture.

2.3 Local Watercourses

Sough Dyke is the main watercourse that has the potential to affect the proposed development. It discharges into the River Dearne about 1km to the east of the site.

There is a significant tributary culvert that connects into the Sough Dyke culvert from a southerly direction close to the junction between Eldon Street and Kendray Street. This probably originated as a natural watercourse many years ago but its catchment is now highly urbanised and it now appears to be fully assimilated into the general surface water drainage system.

The extent of the catchment of this watercourse and also the Sough Dyke culvert itself are discussed in more detail in section 4.2 of this report.

2.4 Historical Flooding Information

We do not have any records of flooding from this culvert in the central Barnsley area.

In the course of our consultations with Barnsley MBC, Mr S Kilner could only recall one flooding incident, that being caused by the storm on the afternoon of 31 August 1997. This was a particularly prolonged and widespread event that affected many parts of South Yorkshire. However, we have been unable to obtain sufficiently detailed rainfall records that could have been used to determine the return period of the storm at that location and thus assisted in the calibration of the culvert model.

3 Environment Agency Data

3.1 Flood Zones

The EA flood map shows the site to be in Flood Zone 1, i.e. not at risk from fluvial flooding, i.e. having a less than 0.1% chance per annum.

3.2 Results of Previous Modelling

The report to the EA North East Region, entitled “Tranche A Critical Ordinary Watercourse Hydraulic Assessment – Priority 4 (Culverted) Watercourses” dated February 2006 and prepared by JBA Consulting (all rights are acknowledged in respect of any sections quoted in this report) has been consulted in respect of the information it contains relating to the relevant section of Sough Dyke.

This report *inter alia* states at paragraph 1.4 Data Sources:

“The main sources of information for the watercourses in this group are the culvert inspection reports that have recently been completed by JBA Consulting. All these watercourses have long culverts that have needed internal survey, either by man-entry or remote-controlled closed-circuit television (CCTV).

The dimensions obtained from these surveys have been used in the hydraulic assessments described in this report. no additional site visits have been carried out."

"We are not aware of any existing hydraulic models on these watercourses"

The report gives further details of the methodology used in the assessment of the culvert capacities in respect of inlet conditions, shape, dimensions etc. and "*The Culvert slope was estimated as a general watercourse gradient, using spot heights and contour lines on 1:50,000 and 1:10,000 OS maps."*

As no detailed information regarding the invert levels has been used, the peak in the report referred to in this section have been arrived at by means other than detailed modelling of the culvert systems.

Using the FEH rainfall-runoff method, JBA Consulting estimated that the 1 in 2 year peak flow in the section of Sough Dyke upstream of the railway (i.e. at the location of the proposed development) was 3.8m³/s and the corresponding 1 in 100 year flow was 13.9m³/s.

At paragraph 2.3.4, JBA Consulting states:

"2.3.4 Hydraulic Capacity of Sough Dike

The study reach on Sough Dike consists of a single culvert, almost 3km long. The capacity of the inlet was calculated to be 6.8m3/s, slightly larger than the estimated 100-year flow. The first 33m of the culvert consists of a pipe with a diameter of 1.5m. However, there are 28 subsequent changes of shape or size. For example, the diameter reduces to 1.3m for the next 42m and then reduces again dramatically to 0.6m for the next 41m. It is therefore quite possible that the actual capacity of the culvert is less than that estimated assuming inlet control."

The following table accompanies this statement.

Table 2-5: Hydraulic capacity estimates for Sough Dike

No.	Location	Capacity under inlet control	Q_{100}	Clear flow flood risk	Clear flow risk rank	Block-age risk rank	Overall risk rank
1	Culvert section 1: at inlet	6.8	5.2	0.8	n/a	n/a	n/a

Note: 1. Culvert and section numbers match those in culvert survey reports
2. Flows are in $m^3 s^{-1}$
3. Clear flow flood risk > 1 (highlighted in bold) indicates inability to convey 100-year return period flood flow.

At paragraph 3.2.4, JBA Consulting states:

"3.2.4 Sough Dike

The study reach is entirely culverted. The capacity assuming inlet control was calculated as greater than the 100-year flow. However, the size of the culvert declines away from the inlet and so the actual capacity may be smaller. This characteristic exacerbates the risk of any debris entering the culvert *becoming trapped within it, but the new debris screen at the inlet should prevent this. There is some potential for ponding of floodwater upstream of the culvert entrance. It is therefore possible that any improvements to the overall capacity of the culvert could lead to an increase in flood flows, but this is inevitable on a long culvert such as this where there is no obvious bypass route. Indeed, there would be little point in carrying out improvements to the capacity if they did not lead to an increase in flows through the culvert.*

Sough Dike is a tributary of the River Dearne, which has a much larger (and relatively more rural) catchment. Peak flows on the dike will occur well in advance of those on the river, and so a small increase in the inflow from Sough Dike is unlikely to have an impact on flooding from the River Dearne. However, the level of the river has contributed to problems on Sough Dike in the past. In summer 1997 the culvert surcharged during a severe storm, and the pressure blew off nearly 50m of the culvert crown near the football ground[5].

[5] See Appendix D of culvert inspection report by JBA Consulting, 2005."

The JBA Consulting report also assessed flows using the FEH statistical method and their calculations relating to Sough Dyke are summarised in Appendix B of their report. Of particular interest, an error in the FEH CD catchment boundaries was noted. The author of this present report had also found this discrepancy before the receipt of the JBA report and had confirmed the true situation with Mr Kilner at Barnsley MBC.

At paragraph 3.5 of Appendix B of their report, JBA Consulting's estimates for flows in the relevant section of the Sough Dyke, based on the statistical method, are stated to be:

Site Code	Flood peak (m³/s) for the following return periods (in years)						
	2	5	10	25	50	100	200
SD2	1.55	2.04	2.29	2.58	2.77	2.96	3.13

At paragraph 4.2 of Appendix B of their report, JBA Consulting's estimates for flows in the relevant section of the Sough Dyke, based on the rational method, are stated to be:

Site Code	Flood peak (m³/s) for the following return periods (in years)						
	2	5	10	25	50	100	200
SD2	4.67	6.51	8.11	10.7	13.15	16.14	18.18

The following note is included:

"Flood Peak estimates for the larger catchments from the rational method will have a lot of uncertainty attached to them as the method is not intended for use on catchments of this size."

At paragraph 5.3 of Appendix B of their report, JBA Consulting's estimates for flows in the relevant section of the Sough Dyke, based on the rainfall-runoff method, are stated to be (extracted from the JBA table):

Site Code	Flood peak (m³/s) for the following return periods (in years)						
	2	5	10	25	50	100	200
SD2	3.8	5.35	6.76	9.01	11.2	13.87	17.71

At paragraph 6.1 of Appendix B of their report, JBA Consulting make the comment:

Item	*Comments*
Final choice of method and reasons	*The results of the rainfall runoff method are the final choice for these catchments. Whilst there are uncertainties associated with the results as no donor could be found, they are considered to be less than the those for the statistical and rational methods.*

4 Hydrology

4.1 Introduction

The following sections describe how the work undertaken previously by others has been interpreted and also supplemented by a flow estimation technique that has become available since the JBA Consulting report was prepared.

4.2 Catchment Descriptors

As alluded to in paragraph 3.2 above, there is a serious discrepancy in the catchment area for the watercourses that drain the centre of Barnsley. This has no doubt arisen as a result of the method by which the flow paths have been assessed coupled with the fact that the watercourses in question are culverted.

The problem arises because the main part of the Sough Dyke catchment to the west of Barnsley is shown to drain towards the northeast roughly along the line of Eldon Street and only the smaller portion of the catchment that comes in from the south is shown draining down Kendray Street.

The current version of the FEH CD ROM (Version 2.0) has been checked and the discrepancy still exists.

The FEH describes a relatively simple method by which the descriptors of catchments can be combined for input into the various software packages that uses such factors and this technique was used to generate the appropriate factors for use in the flow estimation described below.

4.3 Revitalised Flood Hydrograph Method

The Revitalised Flood Hydrograph Method (ReFH) was published in the Spring of 2006. It is an Excel spreadsheet that calculates flow estimates based on some of the catchment descriptors that are obtained from the FEH CD ROM. It has the advantage that the user has control of the input storm duration and time step and the output hydrograph can be used as the input to other design software.

4.4 Scott Wilson Design Flows

The ReFH method was used to derive flow hydrographs for the western and southern parts of the catchment as well as the combination of the two for 1, 30 and 100 year return periods. In addition, it was necessary to derive several flow hydrographs for return periods between 1 in 110 and 1 in 300 year return periods in order to create a flood situation in the model of the existing culvert. The modelling process is described in more detail below.

As the output hydrographs from the ReFH were based on a time increment of one hundredth of an hour and the input hydrographs for the software used to model the culvert were required to be in four minute increments, it was necessary to create a spreadsheet that would calculate and extract the appropriate input values from the ReFH output hydrographs.

The ReFH spreadsheet analyses the FEH catchment descriptors and recommends a duration for a critical design storm. In the case of the Sough Dyke catchment, the recommended duration was 0.9 hour. A value of 0.91 hour was used in order that there would be the requisite odd number of time steps when a time increment of 0.01 hour was specified.

Although the duration of the critical storm event was identified to be slightly less than one hour, the time of concentration meant that the peak of the design hydrograph was at roughly 60 minutes after the commencement of the event. For those elements of the design simulations that required flow to be derived from local areas downstream of the development, a storm duration of 120 minutes was used as this provided a close match to the peak of the applied hydrograph from the catchment upstream. This could be taken to represent the “worst case” scenario of a storm event travelling down the catchment at the at the same velocity as the flow in Sough Dyke.

Peak flows into the Sough Dyke upstream of the level crossing based on the ReFH method							
return period	1 in 1 year	1 in 30 years	1 in 100 years	1 in 150 years	1 in 200 years	1 in 250 years	1 in 300 years
peak flow	1.1 m³/s	4.8 m³/s	6.4 m³/s	6.8 m³/s	7.7 m³/s	8.3 m³/s	8.8 m³/s

It is considered that these values give a more realistic view of the likely flows in the Sough Dyke for the various return frequencies. They are based on the most recently developed technique and the hydraulic capacity of the culvert (described below) is much more closely matched to these figures than those derived by the rainfall-runoff method. In other words, the capacity would not be sufficient for flows much greater than the 1 in 25 year rainfall-runoff value, whereas the culvert at this location does not have a recorded historical problem due to flooding.

These flows, derived from the ReFH method, have been used in the detailed analysis described below.

5 Hydraulic Modelling

5.1 Introduction

A computer model of the main culvert between manhole S32 at the upstream end, close to the junction of Kendray Street and Eldon Street, and manhole S15 at the downstream end to the east of the railway.

This spatial layout of this model was derived from the route of the culvert shown on the drawings supplied and it was transferred into the MicroDrainage WinDes package using the MdCAD interface. The elevation information, i.e. cover and invert levels, and the dimensions and roughness characteristics were derived from the information on the drawings supplied and also from the various JBA Consulting reports described above.

Although the main branch from the southern part of the catchment was modelled initially, this was removed from the final model due to the lack of physical information and the fact that it was found to add little, if any, value to the process. However, the survey noted a “large drop” in the main culvert at manhole S12 where the southern branch joins and such a feature would be necessary as the invert of the southern branch is considerably lower than that of the main culvert upstream. This drop has been included in the model.

5.2 Methodolgy

The basic model is conventional and was constructed using AutoCAD, MdCAD and WinDes with a geo-coordinated single branch “network”.

After a few initial simulation runs, the model was extended downstream through manholes S17 and S16 to manhhole S18. The cover levels for this extension to the model were taken from the LiDAR survey.

It was necessary to introduce a dummy manhole between manholes S15 and S17 because the length was greater than that accepted by WinDes.

A second version of this extended model was then created to enable simulation of the diverted culvert. This second model was also geo-coordinated in plan, it was given realistic cover and invert levels as well as the appropriate diameters and roughness coefficients.

5.3 Key Hydraulic Structures

There are no significant hydraulic structures in the existing or proposed systems. The “large drop” referred to above is thought to be just less than 1m and thus is less than the diameter of the culvert. It was not found to have a significant effect on the overall hydraulic performance of the system.

During the second phase of simulation, i.e. testing the partial and complete blockage scenarios, orifices were introduced into the model to represent these conditions. These are purely hypothetical devices intended to produce an effect rather than to simulate any real condition.

5.4 Roughness Coefficients

The existing culvert in the area of interest is mainly of brick construction and it is generally in reasonably good condition. A roughness coefficient of 5mm has been used for these sections. A coefficient of 10mm has been used for one length that is predominantly constructed from masonry and 0.6mm has been used for existing and proposed concrete sections

5.5 Base Flow

It is evident from the surveys that the culvert carries a base flow in dry weather but this does not appear to have been measured or assessed during the survey operation. A nominal value of 50l/s has been introduced into the model to represent this dry weather flow. In practice this is quite insignificant in comparison to the storm flows generated during the simulation process.

5.6 Sensitivity Analysis and Model Uncertainty

It is considered that there is sufficient physical information available to ensure that the computer model of the length of culvert in question is as accurate as may be created without recourse to extensive calibration using flow survey data calibrated using actual rainfall records. Such an exercise is completely beyond the scope of this report.

The models have been run under a range of surcharged and free flow conditions and were found to run in a stable and predictable manner.

5.7 Calibration and Verification

The first process was to find the return period at which the hydraulic capacity of the culvert would be overcome to cause flooding in the vicinity of the proposed development. The initial model, that only went as far downstream as manhole S15, where it had, in effect, a free outfall, was able to cope with the ReFH derived input hydrographs up to a 1 in 300 year return period event. This was because the culvert has a free flow capacity capable of taking such an event.

In order to provide a more realistic condition downstream, the culvert surveys were reviewed and it was found that the lengths further down stream were initially smaller in diameter (1,200mm) but at a steeper gradient followed by larger sections (1,800mm) at considerably slacker gradients. These details were added and the model was extended down to manhole S18. In addition, it was possible to derive further impermeable area contributing to the extended lengths from the FEH CD ROM catchment descriptors. The initial estimates proved to be too great as they generated enough flow during a 1 in 100 year event to almost fill the capacity of the culvert.

This problem was overcome by deriving ReFH runoff for the relevant points downstream and then determining the effective contributing areas by taking the difference in peak flow between two points and then using the WinDes rainfall generator to produce the relevant rainfall intensity leading to a better estimate of the equivalent area. By an iterative process, it was found that by adding an impermeable area of 4.35ha at manhole S15 and 1,25ha at manhole S18, it was possible to replicate the flows predicted by ReFH within a reasonable degree of accuracy.

No attempt was made to undertake a more detailed or thorough assessment of the downstream catchment; such an exercise would be beyond the brief of this study and be inconsistent with the level of detail applied to the upstream catchments.

The general capacity of these extended lengths is around $7m^3/s$ and this value is consistent with the ReFH estimates tabulated above. It also casts doubt on the figures derived using the rainfall-runoff method.

5.8 Model Results for the Existing Culvert

Full network details of the model of the existing culvert together with a sample simulation showing its performance during a 1 in 150 year return period, 120 minute duration, summer profile storm event are given in Appendix A. This includes a set graphs for the section of the culvert to be diverted and a long section showing the maximum hydraulic level in the system.

This particular simulation is based on an ReFH 1 in 150 year return period input hydrograph applied at manhole S32 with further flow derived from the impermeable areas attached at manholes S15 and S16.

It is included to demonstrate that the existing culvert can be expected to carry a flow greater than $7m^3/s$ without causing flooding, although most of the lengths would be surcharged by an event of this magnitude.

5.9 Model Results for the Proposed Culvert

The simulations of the range of events that were undertaken on the model of the existing culvert were repeated for the model that included the proposed diversion.

Appendix B comprises the results of a simulation of the proposed diversion based on the same storm event that is represented in Appendix A for the existing situation and it will be seen that there are no significant differences between the before and after situations.

In order to address the requirements of the Environment Agency relating to the issue of potential flooding arising from various blockage scenarios, a further set of eighteen simulations of the proposed system were undertaken.

The two requested scenarios were partial (50%) and total blockages at each of three manholes (proposed manhole 3 – equivalent to existing manhole S14 and manholes S11 and S32) with each scenario being considered for return periods of 1 in 1, 1 in 30 and 1 in 100 years. (Two degrees of blockage at three locations for three return periods make eighteen scenarios.)

The results of the eighteen scenarios modelled are tabulated below.

Scenario	Return Period	Blockage Degree	Location	Volume (m³) flooding from : S32	S31	S12	S11	New Mh1	New Mh2	New Mh3 (S14)	Total flood volume (m³)
1	1	half	New Mh3 (S14)	0	0	0	0	0	0	0	0
2	30	half	New Mh3 (S14)	0	0	0	0	0	198	0	198
3	100	half	New Mh3 (S14)	0	0	0	0	0	1336	705	2041
4	1	half	S11	0	0	0	0	0	0	0	0
5	30	half	S11	0	0	0	136	0	0	0	136
6	100	half	S11	43	8	10	1635	0	0	0	1696
7	1	half	S32	0	0	0	0	0	0	0	0
8	30	half	S32	0	0	0	0	0	0	0	0
9	100	half	S32	420	0	0	0	0	0	0	420
10	1	full	New Mh3 (S14)	0	0	0	0	0	2344	3895	6239
11	30	full	New Mh3 (S14)	0	0	0	0	0	10294	11741	22035
12	100	full	New Mh3 (S14)	0	0	0	0	0	13843	15022	28865
13	1	full	S11	0	0	0	6229	0	0	0	6229
14	30	full	S11	0	0	0	21848	0	0	0	21848
15	100	full	S11	164	0	0	28526	0	0	0	28690
16	1	full	S32	5183	0	0	0	0	0	0	5183
17	30	full	S32	20791	0	0	0	0	0	0	20791
18	100	full	S32	27557	0	0	0	0	0	0	27557

5.10 Commentary on the analysis techniques and the results.

The following tabulation gives brief comments on the results from each modelled scenario.

Scenario	Comments
1	50% blockage at New Mh 3 (S14) modelled by a 1,061mm diameter orifice. Evidence on the section of some backing up of flow but no surcharge and no flooding therefore not considered further.
2	50% blockage at New Mh 3 (S14) modelled by a 1,061mm diameter orifice. Extensive backing up and surcharge together with relatively small volume of flooding in the proposed service road. The implications are discussed below.
3	50% blockage at New Mh 3 (S14) modelled by a 1,061mm diameter orifice. Extensive backing up and surcharge together with significant flooding in the proposed service road. The implications are discussed below.
4	50% blockage at S11 modelled by a 1,061mm diameter orifice. Evidence on the section of some backing up of flow but no surcharge and no flooding therefore not considered further.
5	50% blockage at S11 modelled by a 1,061mm diameter orifice. Extensive backing up and surcharge together with relatively small volume of flooding in Kendray Street. The implications are discussed below.
6	50% blockage at S11 modelled by a 1,061mm diameter orifice. Extensive backing up and surcharge together with significant flooding in Kendray Street. The implications are discussed below.
7	50% blockage at S32 modelled by a 1,061mm diameter pipe between S32 and S31 (it is not possible to utilise an orifice at the upstream end of a branch). Only the hydrograph input from the western part of the catchment applied as the southern part of the catchment joins downstream at S12. No surcharge and no flooding therefore not considered further.
8	50% blockage at S32 modelled by a 1,061mm diameter pipe between S32 and S31 (it is not possible to utilise an orifice at the upstream end of a branch). Only the hydrograph input from the western part of the catchment applied as the southern part of the catchment joins downstream at S12. Surcharges upstream of S32 but no flooding therefore not considered further.
9	50% blockage at S32 modelled by a 1,061mm diameter pipe between S32 and S31 (it is not possible to utilise an orifice at the upstream end of a branch). Only the hydrograph input from the western part of the catchment applied as the southern part of the catchment joins downstream at S12. Moderate flooding from S32, the implications are considered below.
10	Effectively 100% blockage at New Mh3 (S14) modelled by a 10mm diameter orifice (the smallest permitted by WinDes).

	Significant volume of flooding in the proposed service road. The implications are discussed below.
11	Effectively 100% blockage at New Mh3 (S14) modelled by a 10mm diameter orifice (the smallest permitted by WinDes). Large volume of flooding in the proposed service road. The implications are discussed below.
12	Effectively 100% blockage at New Mh3 (S14) modelled by a 10mm diameter orifice (the smallest permitted by WinDes). Very large volume of flooding in the proposed service road. The implications are discussed below.
13	Effectively 100% blockage at S11 modelled by a 10mm diameter orifice (the smallest permitted by WinDes). Significant volume of flooding from S11. The implications are discussed below.
14	Effectively 100% blockage at S11 modelled by a 10mm diameter orifice (the smallest permitted by WinDes). Large volume of flooding from S11 and significant surcharge upstream. The implications are discussed below.
15	Effectively 100% blockage at S11 modelled by a 10mm diameter orifice (the smallest permitted by WinDes). Very large volume of flooding from S11. The implications are discussed below.
16	Effectively 100% blockage at S32 modelled by a 100mm diameter pipe between S32 and S31 (it is not possible to utilise an orifice at the upstream end of a branch). Significant volume of flooding from S32. The implications are discussed below.
17	Effectively 100% blockage at S32 modelled by a 100mm diameter pipe between S32 and S31 (it is not possible to utilise an orifice at the upstream end of a branch). Large volume of flooding from S32. The implications are discussed below.
18	Effectively 100% blockage at S32 modelled by a 100mm diameter pipe between S32 and S31 (it is not possible to utilise an orifice at the upstream end of a branch). Very large volume of flooding from S32. The implications are discussed below.

5.11 Flood volumes

The MicroDrainage models all gave stable output without any significant oscillations.

The flood volumes predicted are generally consistent for the varying return periods and the two different degrees of blockage. The only notable apparent inconsistency is the volumes predicted at manhole S32, these being somewhat less than the values that would occur for blockages lower down the system. This is explained by the fact that, for the analysis of the S32 situation, a hydrograph representing just the western portion of the catchment was applied at S32 with the hydrograph relating to the southern part of the catchment being applied downstream at S12.

It should be noted that these scenarios, especially the fully blocked or culvert collapsed version, would be extremely unlikely to occur right at the beginning of a storm event as has been modelled. Such a blockage or collapse would be more likely during an event, maybe at its peak, and the consequential volume of flooding would be far less.

Furthermore, only 50% and 100% restrictions have been considered, whereas if there were to be an incident then it could just as well have produced a 30% or 80% blockage with completely different volumes.

In addition, the input hydrographs from which the volumes are derived are themselves only theoretical and do not relate to any actual rainfall event.

Therefore, the actual volumes of potential flooding are not analysed further and the series of simulations of the various scenarios requested by the EA will be used to determine the points in the system where the flooding would manifest on the surface.

5.12 Flood Flow Rates

The simulations can be best used to understand the weakest point in the system under various blockage situations and also to derive a general estimate of the likely peak flows under the worst circumstances.

The peak rate of flooding for the various scenarios simulated vary from a fairly modest 227l/s for the 1 in 30 year half blockage at S11 situation to about 6,400l/s for the 1 in 100 year full blockage at S11 or New Mh3 situation.

5.13 Flow routes

Please refer to Drawing D117160 - Figure 1.

If it is assumed that suitable measures are taken to prevent flooding from New Mh2 and New Mh3 (see below under Mitigation), then flooding would arise from New Mh1 (and possibly also at S11) for a blockage or restriction at New Mh3 and at S11 and S32 for a blockage or restriction at those respective locations.

Clearly, if restrictions or blockages had been simulated at any of the intervening manholes (S31, S12, New Mh1 or New Mh2) it is very likely that they would have become the principal sources of flooding.

Although 100mm contours have been determined from the LiDAR data, only the contours at 500mm intervals have been shown on Figure 1 as this is a sufficient level of detail to illustrate the topography whilst maintaining legibility. The 92.7m contour is also shown as this is critical to the management of any potential flooding.

It is clear from the contours that the principal overland flow route from S32, S11 and New Mh1 would be down Kendray Street and across the level crossing at Point C on Figure 1. There is a possibility that a small amount of flow could enter the railway to the south but the momentum is likely to carry the majority over the level crossing into the continuation of Kendray Street.

This eastern end of Kendray Street is virtually level but there is a very slight summit at an elevation of 92.7m AOD at Point B on Figure 1. This will create a depth of up to 200mm at the exit / entrance to the proposed car park and any flood water that does not find its way into the normal highway drainage system will flow into the lowest level of the car park.

The proposal shows the finished floor levels of the lower deck of the car park to be generally similar to the existing topography, i.e. with a low point more or less above the culvert to the east of the railway at Point D on Figure 1.

6 Assessment of Flood Risk

6.1 Potential Sources of Flooding

Simulation of the Sough Dyke culvert downstream from manhole S32 at the junction of Kendray Street and Eldon Street has shown that the hydraulic capacity of the culvert is sufficient for normal operation.

At the request of the EA, a number of partial and complete blockages at specific locations have been modelled. There has not been any suggestion that these locations would be particularly susceptible to such blockage.

The simulations have demonstrated that the great majority of any flooding would arise at the same location as the blockage. In reality, a blockage or collapse would be just as likely to occur between manholes so, as a general rule, it could be said that the majority of any flooding would be from the first manhole upstream of such a blockage.

6.2 Residual Risk

As it has been demonstrated that the hydraulic capacity of the culvert is sufficient under normal operating conditions, the partial and total blockage scenarios that have been modelled for this report should be considered to be residual risks.

Rainfall events with a severity worse than 1 in 100 years could be also considered residual risks as they could produce greater volumes and rates of flooding. However, there would be a limit after which such an increase would not affect the outcome as the input hydrograph at S32 would be limited by the capacity of the upstream culvert.

6.3 Mitigation

The lower level of the proposed development is designed to have a finished floor level at 91.875m AOD and the lowest point of the development will be the service road at 90.875m AOD. This lowest level is virtually the same as the existing low point above the culvert to the west of the railway line where there is an existing service access to the present development.

Any manholes on the diverted section of the culvert under this low level part of the service road should be fitted with heavy duty covers, preferably gas and air tight, that are bolted into their frames with the frames in turn being securely fixed into the manhole structure.

There may not be a necessity for the proposed New Mh2 as the distance between New Mh1 and New Mh3 is not excessive, there is no significant connection at that point, there will be no change in alignment and there should be no need for a change in gradient. Therefore, consideration should be given, at the detailed design stage, to the omission of this manhole.

It is understood that the general drainage of the lowest level of the proposed development is to be secured by non-return valves and / pumped output from collection sumps. This subject is beyond the scope of this report and, as no details have been provided, no further comment is offered.

The proposals show a ramp rising about 2.4m up from the low level service road to an exit in Kendray Street at an elevation of about 93.3m AOD. There is a similar ramp between the existing service area and Kendray Street and this rises to an elevation of over 93.5 metres at Point A on Figure 1. It is not clear if this apparently artificial summit is related to vertical highway design, i.e. to do with visibility or removing the need for hill starts into a main road, or if it was intended to prevent surface water from running down into the service area from Kendray Street. The vertical alignment of the proposed ramp down to the service road should be designed to have a similar high point to prevent any flooding (or the normal excessive surface water that may be generated during high intensity rainfall) from running down the service road.

If there were to be a blockage similar to those that have been modelled, it has been demonstrated that the majority of any flooding would find its way into the lower level of the proposed multi-storey car park to the east of the railway. Such flood water would find its way to the lowest point; this will be towards the southern end of the car park where the proposed finished floor level is 90.17m AOD. The railway line adjacent to this low point is at an elevation of about 90.8m AOD and if there were to be an unobstructed ground level flow path then this escape route would limit the depth of flooding in the car park to about 700mm or so. However, it would be preferable to return any flood water to the culvert as soon as possible and oversized gullies at the low point in the car park, connected directly or indirectly to the culvert, could be used to minimise the extent of any flooding.

The proposed finished floor level of the basement to the new development will be below the level of Kendray Street. It will be necessary to ensure that there are no direct connections from street level to the basement market level that would allow flood water or surface water generated during normal high intensity rainfall events to get into the lower level. This should be considered to be part of normal good design practice and does not constitute an additional mitigation procedure.

7 Conclusion

The proposed diversion of the Sough Dyke culvert with 1,500mm internal diameter concrete pipes will not have an adverse hydraulic effect on the system.

It is highly unlikely that a significant partial blockage or total collapse of the culvert will occur between manhole S32 upstream of the proposed Barnsley Markets redevelopment and New Mh3 (existing manhole S14) at the downstream boundary of the development to the west of the railway. Nevertheless, appropriate design of the access manhole(s) within the proposed service road will ensure that any flooding that arose under such improbable circumstances would be restricted to the manholes in Kendray Street.

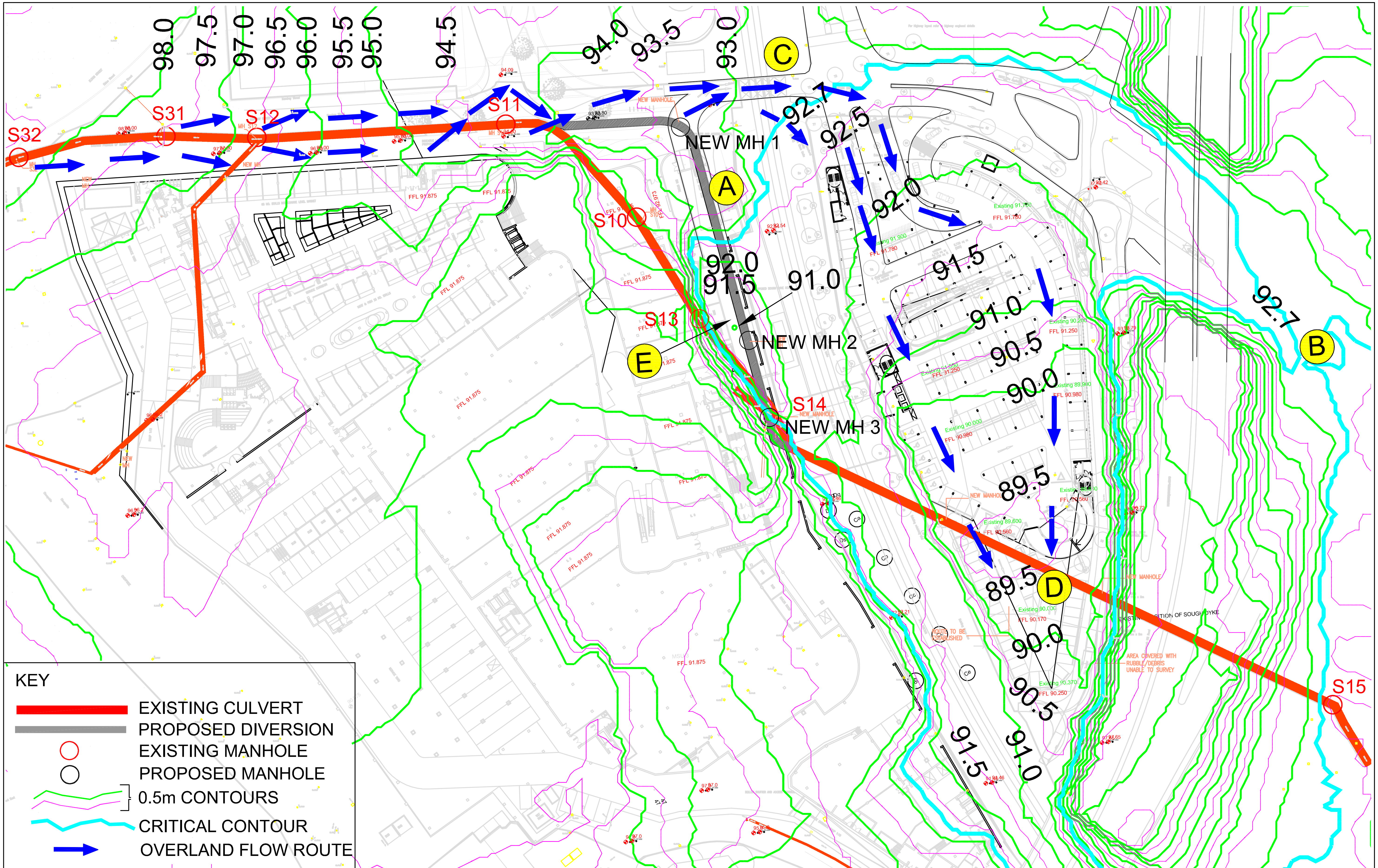
The topography of Kendray Street means that the great majority of such flooding would flow over the level crossing and into the lower level of the proposed multi-storey car park where it could be drained back into the downstream section of the culvert.

8 Figure 1

Plan based on the lowest level of the proposed development showing:

- The route of the existing Sough Dyke culvert.
- The route of the proposed diversion.
- Contours at 500mm intervals from 2m grid LiDAR data. (Contours within the footprint of existing buildings should be ignored as the original digital elevation model that detected the buildings as well as the ground surface has been digitally manipulated to produce the digital terrain model used for the contours)
- The 92.7m contour that is key to limiting the extent of potential flooding.
- The overland flow route that would be taken by floodwater arising from partial or total blockage of the culvert.
- Key reference points.

Plot Date :
AutoCAD File Name :



Drawing Title

BARNSLEY MARKETS
FRA ADDENDUM
SOUGH DYKE CULVERT

D117160-FIGURE 1

Scale at A4 : N.T.S.		
Drw DM	App	Rev
Chk RJM	Date	Date

Scott Wilson
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DR3

9 Appendix A

Global Variables

Region	FEH Rainfall Model
Return Period (yrs)	150
Site Location	(Unknown)
C(1km)	-0.025
D1(1km)	0.375
D2(1km)	0.427
D3(1km)	0.237
E(1km)	0.300
F(1km)	2.364
Volumetric Runoff Coef	0.750
Profile Type	Summer
PIMP (%)	100
Areal Reduction Factor	1.000
Storm Duration (mins)	120
Hot Start (mins)	0
Manhole Headloss Coefficient	0.500
MADD Factor * 10m³/ha Storage	2.000
Foul Sewage/Hectare (l/s)	0.00
Additional Flow - % of Total Flow	0
Number of Input Hydrographs	1
Number of Time/Area Diagrams	0
Number of Bifurcations	0
Number of Overflows	0
Number of Off-Line Controls	0
Number of On-Line Controls	0

Freely Discharging Outfalls

Outfall Pipe Number	Outfall MH/No	C.Level (m)	I.Level (m)	D,L (mm)	B (mm)
1.010	S18	79.400	71.400	1200	0

Input Hydrograph at Pipe Number 1.000
Storm Duration 120 mins (Summer) Return Period 150 years
Input Hydrograph Type: User Specified Input Hydrograph

Input Variables

Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)
4	57	36	2141	68	7051	100	3887	132	1752	164	679
8	76	40	2953	72	6829	104	3574	136	1515	168	660
12	116	44	3808	76	6495	108	3284	140	1290	172	650
16	185	48	4674	80	6084	112	3010	144	1084		
20	299	52	5517	84	5622	116	2747	148	924		
24	486	56	6289	88	5131	120	2492	152	822		
28	823	60	6890	92	4652	124	2243	156	754		
32	1409	64	7108	96	4237	128	1996	160	709		

Network Details

PN	Length (m)	Fall (m)	Slope (1:x)	Area (ha)	T.E. (mins)	Rain Pro	k (mm)	Hyd Sect	Dia (mm)
1.000	37.39	1.050	35.6	0.000	2.00	1	5.000	o	1500
1.001	24.52	0.689	35.6	0.000	0.00	1	5.000	o	1500
1.002	65.29	1.940	33.7	0.000	0.00	1	0.600	o	1500
1.003	40.58	0.290	139.9	0.000	0.00	1	0.600	o	1500
1.004	28.94	1.370	21.1	0.000	0.00	1	5.000	o	1500
1.005	30.39	1.850	16.4	0.000	0.00	1	5.000	o	1500
1.006	169.62	4.724	35.9	0.000	0.00	1	5.000	o	1500
1.007	92.88	4.455	20.8	4.350	0.00	1	0.600	o	1200
1.008	88.42	4.241	20.8	0.000	0.00	1	5.000	o	1200
1.009	49.71	0.430	115.6	0.000	0.00	1	10.000	o	1800
1.010	150.29	1.300	115.6	1.250	0.00	1	5.000	o	1800

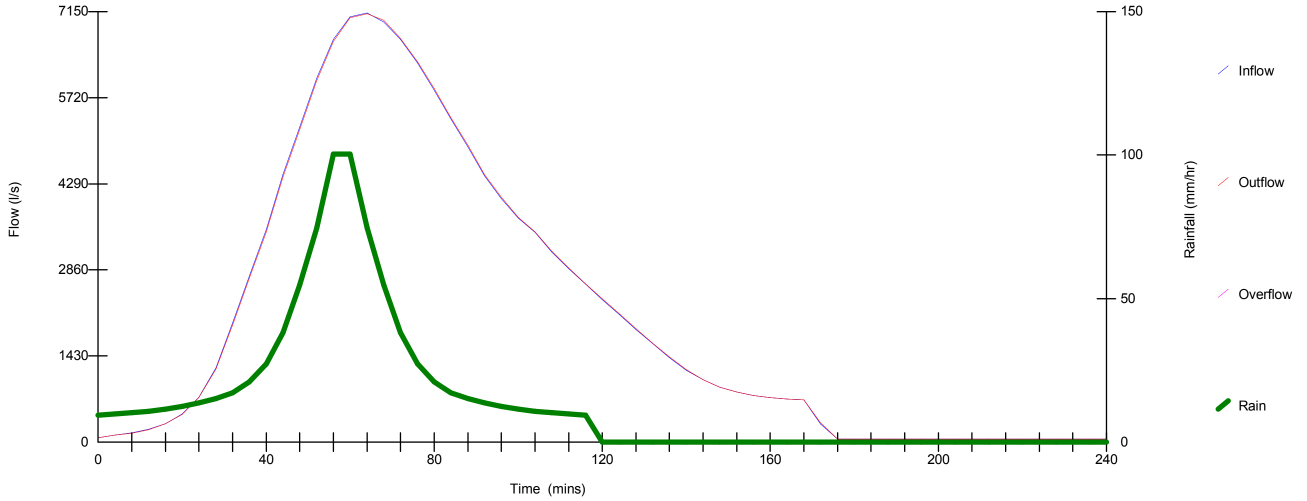
PN	USMH No.	US/CL (m)	US/IL (m)	US/Dep (m)	DS/CL (m)	DS/IL (m)	DS/Dep (m)	Ctrl No.	US/MH (mm)
1.000	S32	98.380	94.580	2.300	97.530	93.530	2.500		1800
1.001	S31	97.530	93.530	2.500	96.680	92.841	2.339		1800
1.002	S12	96.680	92.000	3.180	94.260	90.060	2.700		1800
1.003	S11	94.260	90.060	2.700	95.170	89.770	3.900		1800
1.004	S10	95.170	89.770	3.900	91.100	88.400	1.200		1800
1.005	S13	91.100	88.400	1.200	91.050	86.550	3.000		1800
1.006	S14	91.050	86.550	3.000	92.426	81.826	9.100		1800
1.007	S15	92.426	81.826	9.400	92.426	77.371	13.855		1800
1.008	DUMMY	92.426	77.371	13.855	84.500	73.130	10.170		1800
1.009	S17	84.500	73.130	9.570	80.500	72.700	6.000		1800
1.010	S16	80.500	72.700	6.000	79.400	71.400	6.200		1800

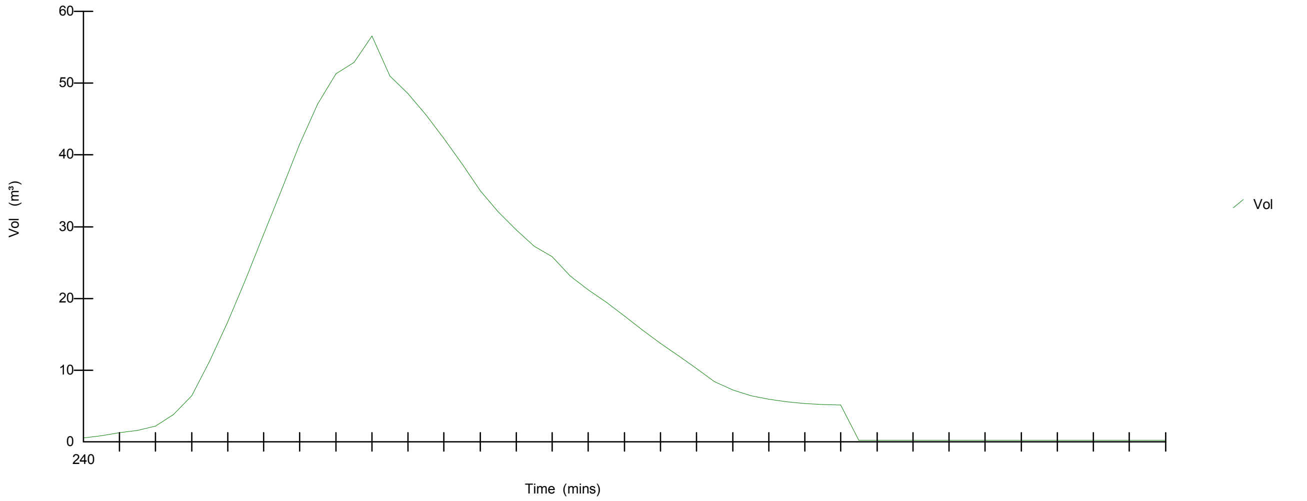
Summary of Results

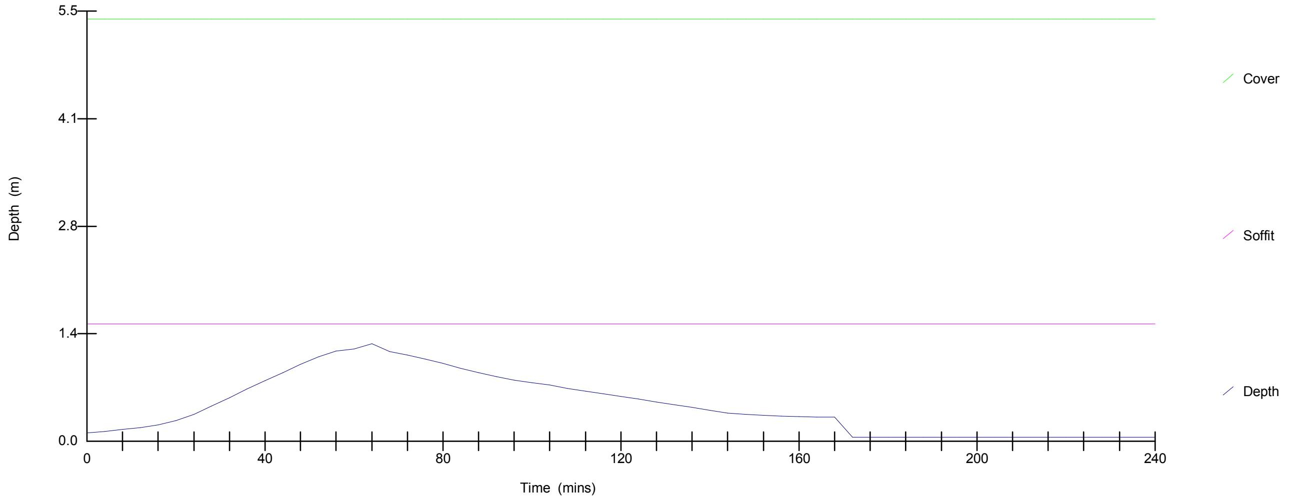
Return Period (years)	150	Analysis Time Step	Fine
Storm Duration (mins)	120	DVD Status	OFF
Profile Type	Summer	Inertia Status	OFF
Margin for Flood Risk warning (mm)	300		

PN	Water Lev. (m)	Surcharged Depth (m)	Flooded Vol (m³)	Flow/ Capacity	Overflow (l/s)	Pipe Flow (l/s)	Status
1.000	96.879	0.799	0.000	1.11	0	7148	SURCH'ED
1.001	95.572	0.542	0.000	1.37	0	7135	SURCH'ED
1.002	93.807	0.307	0.000	0.82	0	7116	SURCH'ED
1.003	92.501	0.941	0.000	2.08	0	7125	SURCH'ED
1.004	91.017	-0.253	0.000	0.97	0	7111	O K
1.005	89.745	-0.155	0.000	0.83	0	7078	O K
1.006	88.482	0.432	0.000	0.78	0	7073	SURCH'ED
1.007	85.627	2.601	0.000	0.97	0	7686	SURCH'ED
1.008	81.350	2.779	0.000	1.21	0	7694	SURCH'ED
1.009	75.140	0.210	0.000	1.30	0	7696	SURCH'ED
1.010	74.141	-0.359	0.000	0.99	0	7869	O K

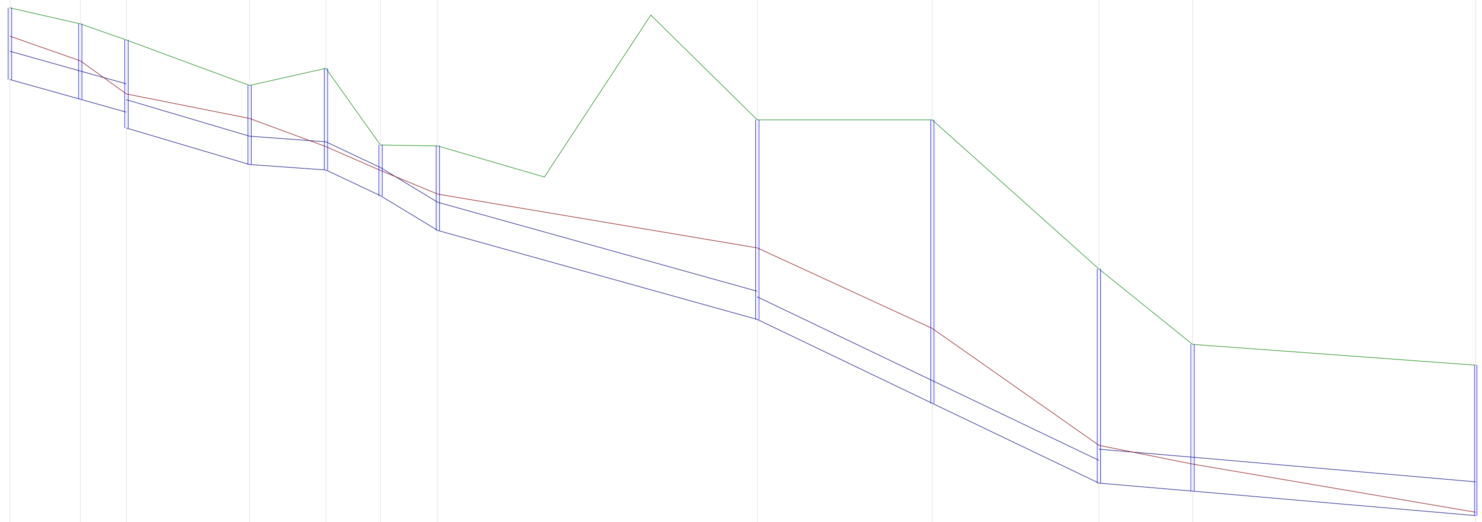
Graphs for Pipe 1.004 USMH Number S10
Storm Duration 120 mins (Summer) Return Period 150 years
Status : OK







MH Name: S32 | S12 | S11 | S14 | S15 | DUMMY | S17 | S16 | S18



Hor Scale 4000

Ver Scale 400

Datum (m) 62.000

PN	1.000, 1.002, 1.003, 1.006, 1.007, 1.008, 1.009, 1.010
Diameter (mm)	1500, 1500, 1500, 1500, 1200, 1200, 1800, 1800
Slope (1:x)	35.6, 33.7, 139.9, 35.9, 20.8, 20.8, 115.6, 115.6
Cover Level (m)	98.380, 97.530, 96.680, 94.260, 95.170, 91.100, 91.050, 89.400, 98.000, 92.426, 92.426, 84.500, 80.500, 79.400
Invert Level (m)	94.580, 93.530, 93.530, 92.841, 92.000, 90.060, 90.060, 89.770, 89.770, 88.400, 88.400, 86.550, 86.550, 81.826, 81.826, 77.371, 77.371, 73.130, 73.130, 72.700, 72.700, 71.400
Length (m)	37.39, 65.29, 40.58, 169.62, 92.88, 88.42, 49.71, 150.29

10 Appendix B

Global Variables

Region	FEH Rainfall Model
Return Period (yrs)	150
Site Location	(Unknown)
C(1km)	-0.025
D1(1km)	0.375
D2(1km)	0.427
D3(1km)	0.237
E(1km)	0.300
F(1km)	2.364
Volumetric Runoff Coef	0.750
Profile Type	Summer
PIMP (%)	100
Areal Reduction Factor	1.000
Storm Duration (mins)	120
Hot Start (mins)	0
Manhole Headloss Coefficient	0.500
MADD Factor * 10m³/ha Storage	2.000
Foul Sewage/Hectare (l/s)	0.00
Additional Flow - % of Total Flow	0
Number of Input Hydrographs	1
Number of Time/Area Diagrams	0
Number of Bifurcations	0
Number of Overflows	0
Number of Off-Line Controls	0
Number of On-Line Controls	0

Freely Discharging Outfalls

Outfall Pipe Number	Outfall MH/No	C.Level (m)	I.Level (m)	D,L (mm)	B (mm)
1.010	S18	79.400	71.400	1200	0

Input Hydrograph at Pipe Number 1.000
Storm Duration 120 mins (Summer) Return Period 150 years
Input Hydrograph Type: User Specified Input Hydrograph

Input Variables

Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)	Time (mins)	Flow (l/s)
4	57	36	2141	68	7051	100	3887	132	1752	164	679
8	76	40	2953	72	6829	104	3574	136	1515	168	660
12	116	44	3808	76	6495	108	3284	140	1290	172	650
16	185	48	4674	80	6084	112	3010	144	1084		
20	299	52	5517	84	5622	116	2747	148	924		
24	486	56	6289	88	5131	120	2492	152	822		
28	823	60	6890	92	4652	124	2243	156	754		
32	1409	64	7108	96	4237	128	1996	160	709		

Network Details

PN	Length (m)	Fall (m)	Slope (1:x)	Area (ha)	T.E. (mins)	Rain Pro	k (mm)	Hyd Sect	Dia (mm)
1.000	37.39	1.050	35.6	0.000	2.00	1	5.000	o	1500
1.001	24.52	0.689	35.6	0.000	0.00	1	5.000	o	1500
1.002	65.29	1.940	33.7	0.000	0.00	1	0.600	o	1500
1.003	41.56	2.164	19.2	0.000	0.00	1	0.600	o	1500
1.004	57.92	0.930	62.3	0.000	0.00	1	0.600	o	1500
1.005	25.87	0.416	62.2	0.000	0.00	1	0.600	o	1500
1.006	166.29	4.724	35.2	0.000	0.00	1	5.000	o	1500
1.007	92.88	4.455	20.8	4.350	0.00	1	0.600	o	1200
1.008	88.42	4.241	20.8	0.000	0.00	1	5.000	o	1200
1.009	49.71	0.430	115.6	0.000	0.00	1	10.000	o	1800
1.010	150.29	1.300	115.6	1.250	0.00	1	5.000	o	1800

PN	USMH No.	US/CL (m)	US/IL (m)	US/Dep (m)	DS/CL (m)	DS/IL (m)	DS/Dep (m)	Ctrl No.	US/MH (mm)
1.000	S32	98.380	94.580	2.300	97.530	93.530	2.500		1800
1.001	S31	97.530	93.530	2.500	96.680	92.841	2.339		1800
1.002	S12	96.680	92.000	3.180	94.260	90.060	2.700		1800
1.003	S11	94.260	90.060	2.700	95.170	87.896	5.774		1800
1.004	NewMh1	95.170	87.896	5.774	91.100	86.966	2.634		1800
1.005	NewMh2	91.100	86.966	2.634	91.050	86.550	3.000		1800
1.006	NewMh3	91.050	86.550	3.000	92.426	81.826	9.100		1800
1.007	S15	92.426	81.826	9.400	92.426	77.371	13.855		1800
1.008	DummyMh	92.426	77.371	13.855	84.500	73.130	10.170		1800
1.009	S17	84.500	73.130	9.570	80.500	72.700	6.000		1800
1.010	S16	80.500	72.700	6.000	79.400	71.400	6.200		1800

Summary of Results

Return Period (years)	150	Analysis Time Step	Fine
Storm Duration (mins)	120	DVD Status	OFF
Profile Type	Summer	Inertia Status	OFF
Margin for Flood Risk Warning (mm)	300		

PN	Water Lev. (m)	Surcharged Depth (m)	Flooded Vol (m³)	Flow/ Capacity	Overflow (l/s)	Pipe Flow (l/s)	Status
1.000	96.879	0.799	0.000	1.11	0	7148	SURCH'ED
1.001	95.572	0.542	0.000	1.37	0	7135	SURCH'ED
1.002	93.340	-0.160	0.000	0.82	0	7115	O K
1.003	92.061	0.501	0.000	0.77	0	7050	SURCH'ED
1.004	90.802	1.406	0.000	1.17	0	7038	SURCH'ED
1.005	89.550	1.084	0.000	1.74	0	7035	SURCH'ED
1.006	88.299	0.249	0.000	0.77	0	7028	SURCH'ED
1.007	85.514	2.488	0.000	0.97	0	7644	SURCH'ED
1.008	81.279	2.708	0.000	1.20	0	7654	SURCH'ED
1.009	75.133	0.203	0.000	1.29	0	7656	SURCH'ED
1.010	74.135	-0.365	0.000	0.99	0	7830	O K

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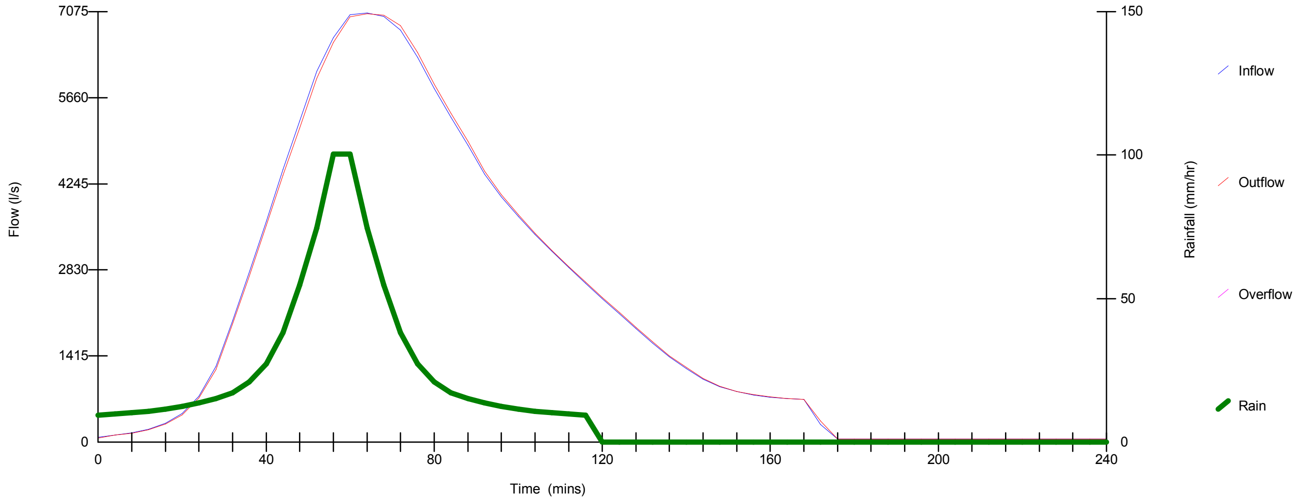
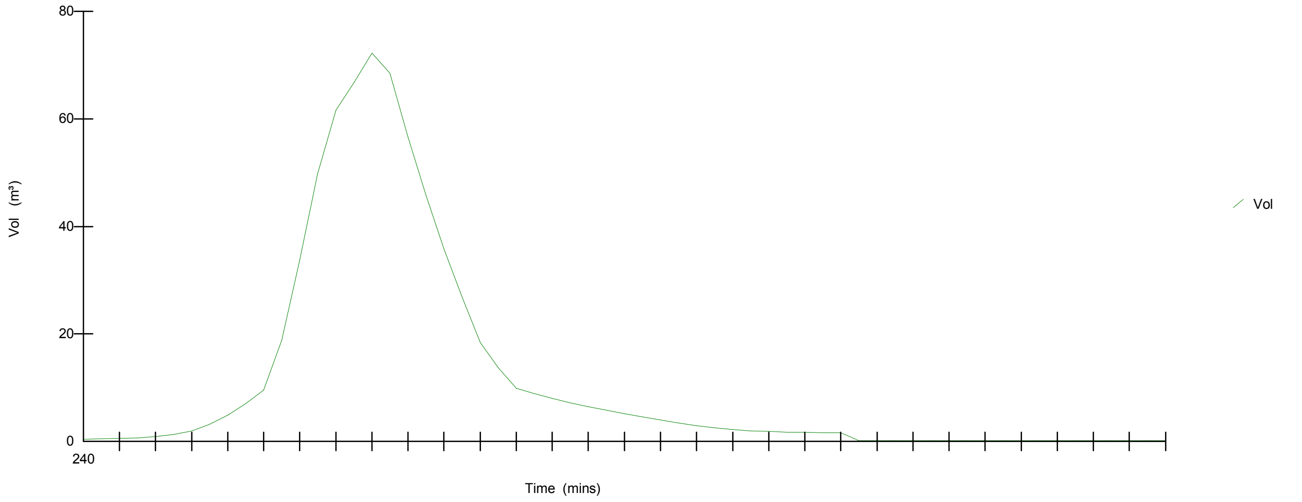
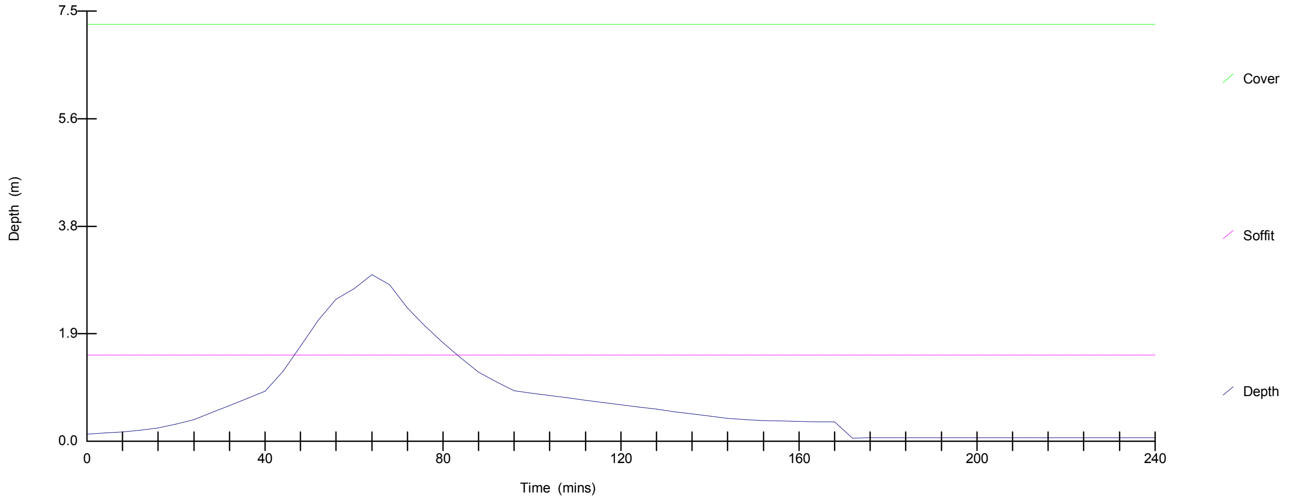
Scott House Basingstoke Hants RG21 4JG	Barnsley Markets Sough Dyke Culvert Proposed diversion	
Date 11 October 2007 File Proposed culvert extended - 150 year ReFH combined.SIM	Designed By R J Marshall Checked By	
Integer	Simulation W.10.2	

Graphs for Pipe 1.004 USMH Number NewMh1
Storm Duration 120 mins (Summer) Return Period 150 years
Status : SURCHARGED







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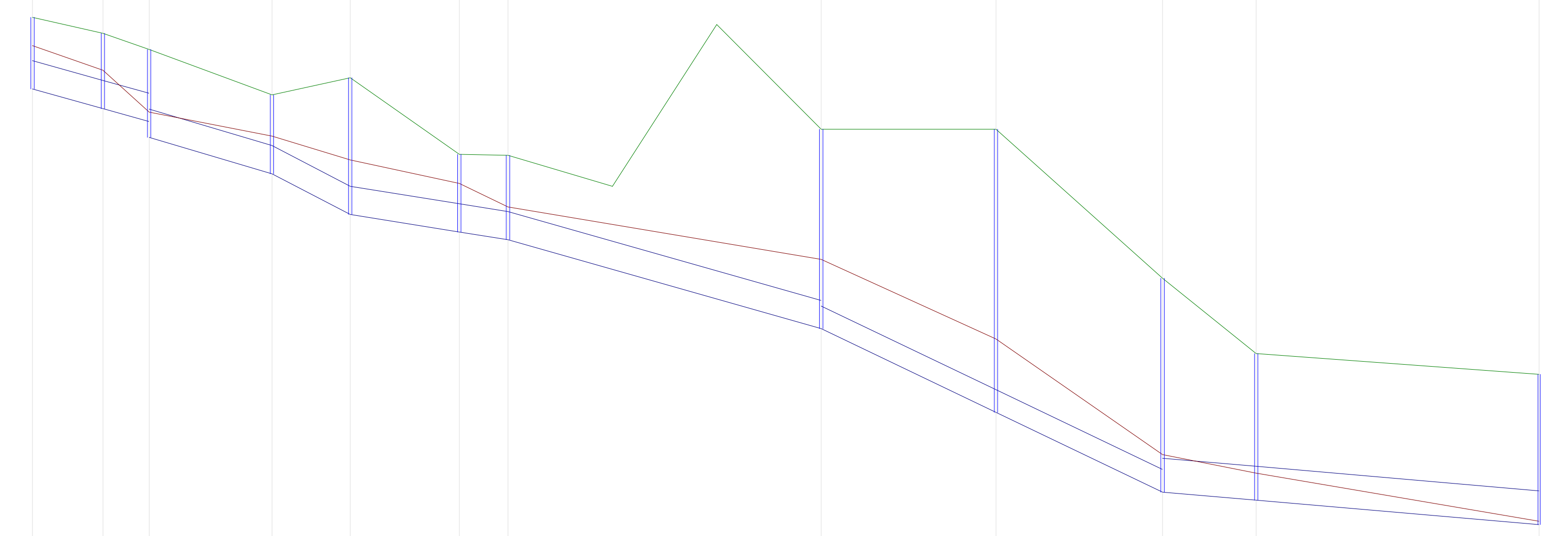
Scott House Basingstoke Hants RG21 4JG	Barnsley Markets Sough Dyke Culvert Proposed diversion	
Date 11 October 2007 File Proposed culvert extended - 150 year ReFH combined.SIM	Designed By R J Marshall Checked By	
Integer	Simulation W.10.2	

MH Name: S32, S12, S11, NewMh1, NewMh3, S15, DummyMh, S17, S16, S18



Hor Scale 4000

Ver Scale 400

Datum (m) 62.000

PN	1.000	1.002	1.003	1.004	1.006	1.007	1.008	1.009	1.010
Diameter (mm)	1500	1500	1500	1500	1500	1200	1200	1800	1800
Slope (1:x)	35.6	33.7	19.2	62.3	35.2	20.8	20.8	115.6	115.6
Length (m)	37.39	65.29	41.56	57.92	166.29	92.88	88.42	49.71	150.29

Cover Level (m): 98.380, 97.530, 96.680, 94.260, 95.170, 91.100, 91.050, 89.400, 98.000, 92.426, 92.426, 84.500, 80.500, 79.400

Invert Level (m): 94.580, 93.530, 93.530, 92.841, 92.000, 90.060, 90.060, 87.896, 87.896, 86.966, 86.966, 86.550, 86.550, 81.826, 81.826, 77.371, 77.371, 73.130, 73.130, 72.700, 72.700, 71.400