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HULL FLOODING JUNE 2007

EXPERT OPINION

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SUMMARY

In June 2007 the city of Kingston upon Hull experienced unusually high volumes of rainfall. It was the wettest month recorded in Yorkshire since 1882 (EA), with over 250 mm of rainfall being recorded at the University of Hull. Over 70 mm of rain fell on the 15th June, further precipitation occurred over the following days, culminating in approximately 105 mm rain on the 25th June ⁽¹⁾.

The 25th June rainfall was both heavy and prolonged, it has been estimated that this was a one in 150 year event ⁽¹⁾. Furthermore, it is likely that the ground in and around Hull will have already been saturated by rainfall that fell on the 15th June and following days. These “worst case” conditions resulted in severe flooding, widespread disruption occurred with damage to over 8600 residential properties and over 1300 businesses ⁽¹⁾. Unfortunately, one person lost their life. It has been reported that, in just two hours, the cost to the insurance industry was the equivalent of the annual cost of drainage floods for the whole of the UK ⁽²⁾.

Hull City Council, following the flooding, commissioned an Independent Review Body (IRB) to examine the key factors leading to the flooding and to make recommendations for actions to improve flood prevention in the future. The IRB, particularly in their Final Report, were critical of Yorkshire Water and some aspects of the water industry in general.

Ofwat, the economic regulator of the water industry in England and Wales, subsequently commissioned WRc to assess the criticisms made by the IRB and to provide an expert view and commentary. This review included:

- a) Assessing the actions of Yorkshire Water in the light of the IRB report.
- b) Providing a preliminary view of the adequacy of Yorkshire Water’s response.
- c) Identifying issues where further detailed review is required.

The majority of this report focuses on the issues in the main Hull catchments, i.e. the Humbercare scheme and the West Hull and East Hull sewer systems terminating at the inlets to the transfer tunnel. However, flooding also occurred in the smaller Bransholme/Kingswood catchment and this is also investigated in this report.

There are many factors that contributed to the 25th June 2007 floods. The combination of exceptional rainfall falling onto what was probably saturated ground with a very high water table is the main reason. No amount of drainage improvements will have been sufficient to avoid much of that flooding.

The ‘special’ aspects of the Hull drainage system will not have helped during such a very heavy and prolonged storm. In particular:

- Land drainage and watercourse inputs into the piped sewer system will have been a significant reason for the sewers becoming full in some areas.
- Overland flows from outlying rural areas and higher ground may have contributed to some of the problems on the urban fringes.

Issues with blocked gullies and/or local drainage capacity may well have caused some of the more isolated and local area flooding. These problems may well have been an additional factor in the main areas of flooding.

Performance issues were identified with the Humbercare scheme in 2004 and actions were being and had been taken to mitigate these problems when the 25th June 2007 storm

occurred. It is uncertain how significant these issues will have been in contributing to the flooding because much of the modelling work provided either looks at a future scenario situation and/or does not take into account the post Humbercare improvements already in place.

The Bransholme/Kingswood catchment, which is hydraulically isolated from the remainder of the Hull sewer system terminates in surface water (SW) and foul water (FW) pumping stations. The surface water flows are pumped up to the River Hull and the foul water flows are pumped up into the East Hull sewer catchment. The foul pumping station worked continuously throughout the flooding and the following days with no reported problems. The surface water pumping station worked continuously on the 25th June but succumbed to thrust bearing failure when it became inundated on the 26th June.

The issues surrounding the June flooding have been reviewed, in particular the following key questions:

- 1) Was the initial Humbercare design robust?

It is uncertain if the Humbercare design was robust because there are many outstanding questions, as detailed in this report.

- 2) Is the 1:30 year flooding standard appropriate for Hull/Humbercare urban drainage system?

It is our opinion that a 1 in 30 year standard is not appropriate for the Hull catchment.

- 3) Following commissioning of Humbercare, and the emergence of performance issues, was Yorkshire Water's response timely and robust enough?

It is uncertain if Yorkshire water's response was timely and robust. This is because there are a number of outstanding questions, as detailed in this report.

- 4) Do operational problems inhibit the performance of the system as operated on the 25th June 2007?

Operational problems make the system difficult to operate. However, it is uncertain if the operational problems inhibit the performance of the system. This is because there are a number of questions that have not been clarified, as detailed in this report.

1. INTRODUCTION

In June 2007 the city of Kingston upon Hull experienced unusually high volumes of rainfall. It was the wettest month recorded in Yorkshire since 1882 (EA), with over 250 mm of rainfall being recorded at the University of Hull. Over 70 mm of rain fell on the 15th June, further precipitation occurred over the following days, culminating in approximately 105 mm rain on the 25th June ⁽¹⁾.

The 25th June rainfall was both heavy and prolonged, it has been estimated that this was a one in 150 year event ⁽¹⁾. Furthermore, it is likely that the ground in and around Hull will have already been saturated by rainfall that fell on the 15th June and following days. These “worst case” conditions resulted in severe flooding, widespread disruption occurred with damage to over 8600 residential properties and over 1300 businesses ⁽¹⁾. Unfortunately, one person lost their life. It has been reported that, in just two hours, the cost to the insurance industry was the equivalent of the annual cost of drainage floods for the whole of the UK ⁽²⁾.

The urban drainage system in Hull is unusual in that most of the local watercourses and land drainage connects into the piped combined drainage system. Furthermore, in the event of the piped drainage system becoming overwhelmed with stormwater, there are few natural watercourses for the storm flooding to drain to. Thus, almost the entire storm drainage of the city is discharged via Yorkshire Water’s piped drainage system and terminal pumping stations.

Hull City Council, following the flooding, commissioned an Independent Review Body (IRB) to examine the key factors leading to the flooding and to make recommendations for actions to improve flood prevention in the future. The IRB subsequently reported back with an Interim Report on the 24th August ⁽¹⁾ and a Final Report on the 21st November 2007 ⁽³⁾. The IRB, particularly in their Final Report, were critical of Yorkshire Water and some aspects of the water industry in general.

Ofwat, the economic regulator of the water industry in England and Wales, subsequently commissioned WRc to assess the criticisms made by the IRB and to provide an expert view and commentary. This review included:

- a) Assessing the actions of Yorkshire Water in the light of the IRB report.
- b) Providing a preliminary view of the adequacy of Yorkshire Water’s response.
- c) Identifying issues where further detailed review is required.

In a preliminary meeting (Ofwat/WRc) on 13th December 2007, it was agreed that the investigation would focus around the following four key questions:

- 1) Was the initial Humbercare design robust? (see Section 2.4 for details of Humbercare).
- 2) Is the 1:30 year flooding standard appropriate for Hull/Humbercare urban drainage system?
- 3) Following commissioning of Humbercare, and the emergence of performance issues, was Yorkshire Water’s response timely and robust enough?
- 4) Do operational problems inhibit the performance of the system as operated on the 25th June 2007?

This study is based primarily on:

- The documentation that Yorkshire Water provided to the IRB before the publication of their final report, ;
- The IRB's Interim ⁽¹⁾ and Final Reports ⁽³⁾;
- Yorkshire Water's Initial Response to the IRB Final Report, dated 21st November 2007 ⁽⁴⁾; and
- Yorkshire Water's Initial Review of the IRB Final Report, dated 17th December 2007⁽⁵⁾.

The majority of this report focuses on the issues in the main Hull catchments, i.e. the Humbercare scheme and the West Hull and East Hull sewer systems terminating at the inlets to the transfer tunnel. However, flooding also occurred in the smaller Bransholme/Kingswood catchment and this is discussed in Chapter 10 of this report.

2. BACKGROUND TO THE HULL/HUMBERCARE CATCHMENT PROBLEMS

2.1 Pre 1949

Hull's combined/foul drainage system is somewhat unique for the UK. Unlike most cities, the trunk sewer system is relatively modern and does not date back to Victorian times. Also, unlike most other drainage systems in large urban areas, the piped drainage system is the primary and only system for the removal of surface water and land drainage. There are very few natural watercourses/culverts remaining for storm drainage/land drainage to connect to.

In the late 19th century Hull was drained by a series of surface and culverted watercourses. These took both foul and surface water and discharged into the Humber Estuary via a number of gravity outfalls. The main sewers consisted of small egg-shaped sewers, these provided storage during high tides when the outfalls became tide locked ⁽¹⁾.

Improvements followed and in 1884 a steam driven pumping station was constructed. This helped to discharge flows from the very flat and low-lying catchment to the Humber Estuary. A further pumping station was built following the end of the First World War, this enabled drainage to be provided for new expansive housing estates ⁽¹⁾.

However, in the early 1930's it became apparent that further improvements to the main drainage system were required. The outbreak of war in 1939 delayed any further progress until 1949 ⁽¹⁾.

2.2 1949 to 1973 (Development of the modern drainage system)

2.2.1 New trunk sewer system

Significant changes were made to the surface water and foul drainage systems between 1949 and 1975. A new trunk sewer system was constructed. This was split between West and East Hull, each system terminating in a new pumping station that pumped all flows to the Humber Estuary. The River Hull forms the natural boundary between the two catchments ⁽¹⁾.

These trunk sewers would have been designed and sized before hydraulic modelling had become the norm. WASSP, the first widely used sewer system analysis programme in the UK, became available in the early 1980's and was subsequently succeeded, in date order, by WALLRUS, HydroWorks and InfoWorks.

The accepted way of designing systems, pre computer modelling, was via spreadsheet methods based on the Lloyd Davies approach.

The data used in drainage system hydraulic analysis includes catchment data, sewer system data and climatic data. Catchment data includes characteristics such as size of contributing areas, type of contributing area (paved/impermeable, permeable) and soil type/permeability. These can be more accurately represented with modern computer software, such as InfoWorks, than used to be the case. Sewer system data includes pipe size/gradient/ length, connectivity and direction of runoff of contributing area (i.e. to which sewer length). Climatic data is essentially rainfall and ground conditions (wetness). Today quite complex rainfall and ground wetness conditions can be taken into account. Prior to computer modelling rainfall representation was far simpler.

In the late 1950's and 1960's, when many of the trunk sewers were constructed, it is likely that the Ministry of Health formula would have been used to estimate rainfall intensity. Ground wetness and water table would not have been assessed in the degree of detail that is now possible in InfoWorks.

Thus, earlier methods to assess the catchment runoff and required size of the sewer system will not have been able to take into account catchment wetness issues and land drainage in any degree of detail. This may be significant because catchment wetness issues and land drainage are both important features of the Hull urban drainage catchment.

2.2.2 Surface land drains and watercourses

The IRB, in their Interim Report ⁽¹⁾, comment that “*between 1957 and 1972 nearly all of the surface land drains were in filled and diverted into sewers*”. Two drainage plans (for 1957 and 1972) included in the report illustrate this point.

The infilling or diversion to sewers of the surface land drains may have been the first of many decisions and actions that contributed to the June 2007 flooding. This is because open land drainage will also allow some storage of floodwater within its banks following a significant rainfall. Culverting will remove the vast majority of the flood storage capacity – once the pipe is full the excess water will have nowhere to go and result in surface flooding. The infilling could have been even more critical, it may have resulted in the total removal of valuable flood storage.

Clearly these actions alone did not cause the June 2007 flooding. However, the removal of surface watercourses, and the stormwater storage that they provided, are likely to have resulted in an increase in surface flooding.

2.2.3 East Hull

The first improvements in the East Hull catchment were completed in 1950. A new pumping station (completed in 1949) enabled the pumping of the Holderness Drain during high tides. Two trunk sewers were also constructed and connected to the pumping station ⁽¹⁾.

Further construction took place between 1968 and 1972. A new much larger pumping station was constructed adjacent to the original station and the trunk sewer network was extended. According to the IRB ⁽¹⁾ the total **installed pumping capacity** was now 26 m³/s. Further details are given in the Arup Feasibility Study (January 2006) ⁽⁶⁾ and the Arup report on the June 2007 Floods (November 2007) ⁽⁷⁾. These indicate that flows were split between:

- a) 1949 station 8.6 m³/s, comprising of:
 - Two dry weather flow (DWF) pumps, each of 0.75 m³/s capacity.
 - Two storm pumps, each of 3.55 m³/s capacity.
- b) 1972 station 13 to 16 m³/s (depending upon the tide), comprising of:
 - Three DWF pumps (electric).
 - Four storm pumps (electric).

The original station was retained for use in times of maximum flow. Today it is used to pump Holderness Drain.

The 1972 station was retained following the commissioning of Humbercare, though with a reduced capacity as detailed in Section 3.3.3 of this report.

It should be noted that the terms **total installed capacity** and **capacity of the pumping station** are not the same: -

- **Total installed capacity** - Is the sum of the capacity of each pump installed at the pumping station.
- **Capacity of the pumping station** - Is the maximum flow rate that the station can pump. This is dependant upon the size and configuration of the outgoing pipework and rising main.

In many pumping stations, the **total installed capacity is** greater than the **capacity of the pumping station**. This is because of a number of possible factors, such as the provision of additional pumping capacity, to act as standby pumps, to enable pumps to be removed for maintenance/servicing.

The IRB, in their interim Report ⁽¹⁾, state “The *construction of the new pumping station and trunk sewer resulted in the filling in and/or culverting of many water courses*”. As previously mentioned, the culverting or filling in of surface land drains and watercourses will reduce storm water storage capacity.

A scheme that includes the removal of flood storage capacity, for example by infilling ditches/watercourses, should be balanced by an equal or greater provision of new storage, for example swales and lagoons. Whilst this is current policy this has not always been the case and, if this was not carried out in Hull, the loss of storage is likely to have been a contributory factor to the June 2007 floods.

2.2.4 West Hull

A network of major trunk sewers were constructed during the late 1950's and 1960's. These discharged to a new pumping station built in 1957 and enabled both foul and storm flows to be pumped out of the catchments sewers.

The station was significant, comprising of (according to the Arup Feasibility Study, January 2006) ⁽⁶⁾:

- Four DWF pumps, each of 1.4 m³/s capacity;
- Eight storm pumps, each of 4.2 m³/s capacity (two diesel and six electric).

Whilst the total installed capacity was 39.2 m³/s, the capacity of the pumping station was 32m³/s. This would have allowed some redundancy to cover breakdowns and maintenance.

The Northern and Western Branches of the new trunk sewer system enabled the outlying areas of Cottingham, Willerby, Analby and Hessle to be connected to the main drainage system. This extension of the sewer system to outlying areas may have been a contributory factor in the June 2007 floods. This is because Cottingham, Analby and parts of Hessle are on higher ground. Flows from these areas may have taken priority over flows from the lower parts of the catchment.

Setting Dyke and Cottingham Drain also connect into the Northern trunk sewer. Significant flows from these watercourses are likely to have entered the piped drainage system on the 25th June and reduced the ability of the sewer system to take runoff from the urban catchment.

A comparison of the areas in the West Hull catchment with property flooding on the 25th June 2007 (see Figure 1.4, IRB Interim Report) ⁽¹⁾, the higher outlying areas and adjacent rural areas (also Figure 1.4) ⁽¹⁾, and the connected land drainage systems (see Arup January 2006 report, unnamed figure on page 14) ⁽⁸⁾ indicates that:

- The majority of the property flooding occurred in the estates on the urban fringes of the main urban area.
- Most of the areas that flooded were adjacent to either large areas of rural land, higher ground or close to where a rural land drainage system(s) connected into the piped drainage system, or a combination of two or all three factors.

Thus, it is possible that the connection of rural land drainage systems and the Cottingham and Analby residential areas to the Hull drainage system were a contributory factor to the flooding.

2.2.5 Summary, 1949-1975

The IRB in their summary of the 1948 to 1973 period (Section 6.1.2.4 of their Interim Report) ⁽¹⁾ again state that “*many of the open watercourses in and around Hull were either culverted or filled in altogether*” and it goes on to explain that this was “*generally in the name of child safety*”.

2.3 1973 to 2000 (Separation of functions)

2.3.1 Water Act 1973

The Water Act 1973 created ten regional water authorities and the responsibility for the management and operation of most of the functions of the Hull drainage system passed to the newly created Yorkshire Water Authority. However, the generic responsibility for highway drainage and certain land drainage/drainage planning functions in England and Wales remained in local authority control.

Subsequent privatisation of the water authorities brought about by the 1989 Water Act meant that the drainage functions were further split. The privatised Yorkshire Water became responsible for sewerage (as well as water supply and associated treatment) whilst the river functions were transferred to a new body, the National Rivers Authority (NRA). The NRA were also responsible for some land drainage functions and ensuring that watercourses were protected from pollution.

The NRA subsequently amalgamated with most aspects of Her Majesty's Inspectorate of Pollution (HMIP) in 1995 to become the Environment Agency (EA).

2.3.2 Split functions

Thus, between 1973 and 1989 the drainage function had passed from one organisation, the local authority (Hull City Council) to three organisations – Hull City Council, Yorkshire Water and the NRA. Whilst this split of responsibility has worked reasonably well in most catchments, it has become apparent that the split surface water drainage function can be a source of ‘local problems’. This issue has been highlighted as being a contributory factor in many flooding problems elsewhere in England and Wales in recent years. It has led to the government beginning to examine surface water drainage issues through such initiatives as “Making Space for Water”.

2.3.3 'Special case'

As already mentioned the Hull catchment is something of a special case, the piped drainage system is the main drainage route for surface water runoff and land drainage. There are very few open watercourses to take storm water, should the piped system become overwhelmed. Thus, in many respects the land drainage and rivers function in Hull is being undertaken by Yorkshire Water.

This 'special' case is illustrated by the operation of the East Hull pumping stations. The older (1949) pumping station pumps the Holderness Drain and is owned by the EA. However, in 1989 an agreement was made between the then NRA and Yorkshire Water, whereby Yorkshire Water are required to operate the station. The electricity and pump maintenance costs are covered by the EA; other costs are borne by Yorkshire Water. Furthermore, Arup inspected the 1949 station in 2006 and found two of the four pumps to be inoperable and a post June 2007 inspection by Arup has found the same two pumps to be inoperable ⁽⁷⁾. It is also understood that pumps from the Yorkshire Water station (1972 station) are often used to pump Holderness Drain.

Given the 'special' circumstances in the Hull catchment, the applicability (or not) of a 1 in 30 year no flooding standard should be considered. This is discussed in more detail in Chapter 4.

Both the IRB and Yorkshire Water pick up on the 'special' land drainage function of the Hull sewer system. Both agree that long term improvements to the system need to be a multi agency initiative. However, it is somewhat surprising that there seems to have been an apparent lack of multi agency thinking (from all agencies) prior to the June 2007 flooding.

2.4 2000 to 2005 (Humbercare)

2.4.1 Need for Humbercare

It became apparent in the 1990s that, with various new European Directives (Urban Waste Water Treatment Directive etc) and corresponding UK legalisation, it would become necessary to treat raw sewage prior to its discharge to the natural environment (river, estuary or sea). In the case of Hull there was a particular desire to make the Humber Estuary a SSSI, which was subsequently achieved ⁽⁷⁾.

With the above requirements in mind, the discharges of raw sewage to the Humber Estuary from West and East Hull pumping stations would no longer be acceptable.

2.4.2 The scheme

Yorkshire Water subsequently developed a scheme to treat the raw sewage and only to spill screened effluent in certain high storm flow situations. This scheme was called "Humbercare"; the scheme is described in more detail in Chapter 3 of this report.

The main aspects of the scheme were:

- A transfer tunnel, 3.6 m in diameter and 10.5 km in length, running parallel to the estuary from the West Hull Pumping Station, in an easterly direction, via East Hull Pumping Station, to a new sewage treatment works at Saltend.

- Under the terms of the discharge consent agreed with the EA, storm flows would no longer be able to be spilled from the former West and East Hull Pumping Station sites.

Storm flows would only be able to be spilled from Saltend, and then only once certain flow rates had been reached and screening had occurred. The discharge consent agreed with EA would only allow spills at West and East Hull pumping stations in the event of a power failure at Saltend or a failure in the transfer tunnel.

Yorkshire Water, in their Initial Review to the IRB ⁽⁵⁾, point out that, under the Water Resources Act, West and East Hull Pumping Stations can also be operated legally when all reasonable efforts have been made to ascertain that there is danger to life or health (presumably due to flooding in the upstream urban catchments).

Thus, in order to operate the system in a manner that met the above mentioned consents, it was necessary to first use up the maximum storage possible in the catchment and the transfer tunnel. This was achieved by constructing weirs at the trunk sewer outfalls to the tunnel mixing chambers, thus ensuring that 'in sewer' storage was utilised.

The Humbercare scheme was designed to provide a level of flooding protection in the upstream urban catchments at least as good as pre-Humbercare. In this respect the new tunnel and pumping arrangements were designed so as not to be overwhelmed from a 1 in 30 year storm(s). In order to achieve this, hydraulic modelling was undertaken using HydroWorks. At that time HydroWorks was accepted as being one of the leading and best tools for modelling urban drainage systems.

The scheme was designed in such a way that enabled some of the pumping capacity at East and West Hull Pumping Stations to be decommissioned. A combination of new pumping capacity at Saltend and over 100,000 m³ of storage in the transfer tunnel would make this possible.

The Humbercare scheme is discussed in more detail in Chapter 3.

It is uncertain how the modelling took into account the 'special' situation in the upstream catchments, i.e. deliberate connection of significant land drainage into the piped drainage system. This issue is returned to in Chapter 5 of this report.

2.5 2005 to 2007 (Addressing issues with Humbercare)

Issues with the operation of the Humbercare scheme began to emerge in the years following its commissioning. These issues are discussed in more detail in Chapter 5.

The result was that the Humbercare scheme not offering the level of flooding protection that was previously thought. The IRB and Yorkshire Water disagree about the level of protection provided. The IRB ⁽³⁾ claim that the protection was only between 1 in 1 year and 1 in 2 years. Yorkshire Water suggests that it was higher. These issues are returned to in Chapter 5 of this report.

Yorkshire Water, in order to increase flooding protection in the catchment, implemented a number of alterations at the East and West Hull inlets to the transfer tunnel. These were:

- a) Reducing weir levels between the trunk sewers and mixing chambers, thereby reducing the level of 'in-system' storage before storm spills to the transfer tunnel

commenced. (This would give a greater volume of storage not taken up and available for further storm runoff).

- b) Restoring pumping capacity, particularly at West Hull Pumping Station, thereby allowing greater volumes of flow to be removed from the system. However, given the strict conditions when discharges could be made from the East and West Hull sites, the increased pumping was only to be used when:
 - i) All reasonable efforts have been made to ascertain that there is danger to life or health (i.e. under the Water Resources Act); or
 - ii) In the event of a power failure at Saltend treatment works or a transfer tunnel failure.

Furthermore, in order to satisfy condition (i), the pumps could only be activated manually.

It is unclear what technical assessments and/or hydraulic modelling was undertaken prior to the above mentioned alterations being undertaken. The options are first mentioned in the Arup January 2006 Feasibility Study report ⁽⁶⁾. Reference to model re-verification is mentioned in the same report, though the link with the updated assessments is uncertain.

Yorkshire Water's response to these emerging issues is discussed in Chapter 6 of this report.

2.6 Effectually drain

The IRB in their Interim Report ⁽¹⁾ correctly make the point (Section 6.1.3, paragraph 2) that Yorkshire Water have the statutory duty to "*provide an effective system of public sewers, to maintain sewers so as to ensure effectual drainage...*". However, this duty to effectually drain under the Water Industry Act, set in the context of sewers which are for the purpose of draining "*buildings and yards appurtenant,*" does not include the duty to provide extensive land drainage.

Thus, whilst most sewer systems will include a small amount of land drainage (often illicitly), the Hull system is very different in that significant land drainage/watercourse systems are intentionally connected to the system.

The practical needs of the Hull drainage system are therefore somewhat different, and probably more demanding, than the usual practical application of '*effectual drainage*'.

3. HUMBERCARE SCHEME

3.1 Development of the scheme

The original scheme was to pump flows from East and West Hull Pumping Stations via rising mains to the site of the proposed sewage treatment works at Saltend. However, a Yorkshire Water document, dated 20 March 1997 ⁽⁹⁾, gives details of a “**Re-examination of flow transfer options**”. In this document it is explained that the approach has changed and a deep transfer tunnel option is preferred. It goes on to explain that the scheme would:

- Allow the de-commissioning of East and West Hull Pumping Stations; and
- Have the ability to retain up to a 1 in 70 year storm event.

One of the main features of the scheme was the use of a transfer tunnel to store storm flows prior to treatment.

3.2 Flows used in designing the Humbercare scheme

A HydroWorks computer based model was used to assist in the hydraulic design of the Humbercare scheme. At the time the model was said to be one of the most ‘up to date’ tools available.

The Humbercare scheme, based on the HydroWorks model, gave a solution that combined storage and the pumping of flows generated in storm events. From information contained in a MWH report “**West Hull SPS, Options Report**”, dated October 2004 ⁽¹⁰⁾, and an Executive Summary of those findings ⁽¹¹⁾, it is understood that:

Storage

- i) ‘In sewer’ storage for flows up to a 1 in 5 year event. This was made possible through the use of weirs and vortex brakes that would hold flows back in the city sewers – Many of these sewers had originally been designed to be oversized, to enable flows to be stored during high tides prior to the construction of East and West Hull Pumping Stations.
- ii) In greater than a 1 in 5 year event excess flows spill over the weirs into the transfer tunnel and are stored in the tunnel.

Pumping

Flows would be pumped from the transfer tunnel to the inlet works at a maximum rate of 14 m³/s in flows up to a 1 in 5 year storm. For events in excess of 1 in 5 years the tunnel fills and pumping at Saltend increases to 22 m³/s.

Arup report “**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**” ⁽⁶⁾ gives further details of the arrangements at the former East and West Hull Pumping Stations. It explains that:

- Flows enter the transfer tunnel via vortex drop arrangements. The capacities of these are:
 - West Hull 14 m³/s
 - East Hull 8 m³/s

- In the event of the incoming flows exceeding the capacity of the vortex drop then overtopping weirs exist to allow excess flows to enter the tunnel.

The report goes on to explain that the vortex drop arrangement was developed to utilise as much storage as possible within the drainage system before maximising the pass forward flow to the WwTW.

3.3 The removal of pumping capacity at East/West Hull and use of tunnel storage

The scheme picked up the combined sewer discharges that were previously pumped to the Humber Estuary from East and West Hull Pumping Stations.

At Saltend flows could be pumped from the transfer tunnel at rates up to 22m³/s. The treatment works was designed to full treat flows up to 6 m³/s and partially treat flows up to 12 m³/s, above that flows would spill, via screens, to the Humber Estuary.

East and West Hull Pumping Stations would no longer be required for the pumping of flows from the sewers, although the East Hull 1949 station was retained for land drainage purposes (see Section 3.3.1 of this report). Whilst the new pumping station at Saltend was less than the combined capacity of East and West Hull Pumping Stations, the shortfall was made up for by the significant storage available in the transfer tunnel.

3.3.1 Use of East and West Hull Pumping Stations following commissioning of Humbercare

East Hull surface water pumping station (the 1949 station) was to remain operational for pumping of the Holderness Drain at high tides. East Hull sewage pumping station (1972 station) was retained for use in emergencies ⁽⁷⁾.

The intended status of West Hull Pumping Station is unclear from the documentation that we have seen, there is conflicting information (see Section 3.3.2 of this report).

The **IRB Interim Report** ⁽¹⁾ gives details of pumping capacity pre and post Humbercare. There appears to be some confusion if these capacities refer to **total installed capacity** or the **capacity of the pumping station** (see Section 2.2.3 of this report for definitions). Perusal of the Arup Feasibility Study (January 2006) ⁽⁶⁾ and the Arup report on the June 2007 floods (November 2007) ⁽⁷⁾ suggests:

Pre Humbercare

- East Hull 26 m³/s (total installed capacity from both stations, of which 8.6 m³/s was installed in the 1949 station)
- West Hull 32 m³/s (capacity of the pumping station)
- Bransholme 5.4 m³/s. (capacity of the pumping station) pumped to East Hull gravity system. (The total installed capacity was 7.2 m³/s).

Post Humbercare (2000-2005)

- East Hull 15 m³/s (this is a reduction on previous and includes the 1949 station (8.6 m³/s) to pump Holderness Drain)
- West Hull 8 m³/s (a reduction of 24 m³/s)
- Saltend 22 m³/s
- Bransholme 5.4 m³/s (no change in arrangements)

3.3.2 West Hull Pumping Station

A Yorkshire Water Executive Summary ⁽¹¹⁾ of the findings of the MWH report “**West Hull SPS, Options Report**” ⁽¹⁰⁾, states that West Hull Pumping Station had been mothballed.

A further report, the Arup report “**Hull Pumping Stations, June 2007 Floods in Hull and Haltemprice**” ⁽⁷⁾ gives a further account of the situation at West Hull. It states that:

- West Hull Pumping Station was partially decommissioned.
- There was no discharge consent from West Hull Pumping Station after Humbercare was commissioned.
- Two of the storm pumps remained available for operation.

An Emergency Outfall discharge consent was subsequently obtained from the EA in 2002. This stipulates that the pumping station can only be operated:

- In the event of mechanical and/or electrical failure at the WwTW pumping station or a tunnel collapse.
- By manual intervention, i.e. not started automatically at a preset level.

As previously mentioned, under the Water Resources Act, West and East Hull Pumping Stations can also be operated when all reasonable efforts have been made to ascertain that there is danger to life or health (presumably due to flooding in the upstream urban catchments).

The intended function of West Hull Pumping Station post Humbercare commissioning is unclear. Similarly, it is uncertain when, or if, decisions were taken regarding a change in the function of West Hull Pumping Station between the Humbercare scheme conception and 2004/2205 (the decision to refurbish West Hull Pumping Station).

3.3.3 East Hull Pumping Station

Arup report “**Hull Pumping Stations, June 2007 Floods in Hull and Haltemprice**” ⁽⁷⁾, explains that:

- The 1949 pumping station was retained for land drainage pumping purposes (Holderness Drain).
- A connection from the East Hull trunk sewers to the 1972 station still remained, in case of emergencies. However, the connection was restricted to two small penstock controlled openings, giving an effective capability at the pumping station of 8 m³/s. This was approximately half of the pre Humbercare combined sewer pumping capacity (see Section 2.2.3 of this report).

It is unclear from the report what the ‘emergency’ covered and how a flow rate of 8 m³/s was decided upon.

3.4 Scheme construction and commissioning

The Humbercare scheme was subsequently constructed and commissioned in 2001.

3.5 Robustness of the design

3.5.1 HydroWorks model

The capacities in the Humbercare scheme (i.e. pumping capacities and storage volumes) should have been developed from the results of the hydraulic modelling of the catchments (see Section 2.2.1 of this report for brief explanation of hydraulic modelling). The pumping should have been modelled with the pump rates that were realistic for both the pump and outgoing pipework arrangements/condition, not the maximum capacity. It is uncertain how the pumps were represented in the model.

Whilst it is acknowledged that the HydroWorks hydraulic analysis tool has limitations, there is no reason why the resulting design should not have been robust. If there were concerns, for example about slow runoff representation, due consideration should have been given to those limitations and a factor of safety allowed for in the design. This approach is exactly the same as used in any other hydraulic modelling tool.

3.5.2 Verification of the model

The IRB in their Interim Report ⁽¹⁾ in Section 6.1.6 comment that they are concerned about the lack of flow data from the pumping operations or sewer flow rates. It goes on to explain that, with the exception of Saltend, there is very little data and that this data is vital to validate the numerical model.

Whilst it is essential that a model is checked with real flow/performance data to ensure its representation of reality, this verification should be undertaken with event/storm flows that are typical and can be modelled. The modelling of overland flows and flood routes in extreme events, such as the 25th June, is outside the scope of most urban catchment sewer hydraulic models. Attempting to try and verify a model under such conditions could be very misleading and lead to incorrect assumptions about the runoff in more normal storm events.

Yorkshire Water, in their review of the IRB findings ⁽⁵⁾, correctly point out that the routine measurement of flows in large sewers and at pumping stations is not normally carried out. Whilst it would be technically feasible to measure such flows, it would be a very costly and technically challenging operation and it is questionable if it would be a good use of funds.

Verification of models is normally undertaken by using short-term flow survey data. Typically this will involve the measurement of flows, rainfall and possibly pump rates at various locations across a catchment for at least three 'verifiable' events. It is understood that this was done for the HydroWorks model, though no details have been made available.

The WaPUG Code of Practice ⁽¹²⁾ and WRc Guide to Short Term Flow Surveys ⁽¹³⁾ give details of storms that should be suitable to check runoff from predominantly paved areas (i.e. normal urban catchments). It should be noted, however, that catchments that contain significant inputs from land drainage, watercourses and other groundwater sources may need special attention given to their validation. It is uncertain if, or how, these issues were dealt with in the original HydroWorks modelling.

3.5.3 Model audit report

An interesting comment is made in the Arup report "**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**" ⁽⁶⁾. This mentions that the audit report

stated “that the model was suitable for the prediction of peak flows at the pumping station only”.

The reason for this comment about “.peak flows...only” is not clear. It could infer that, while the representation of paved area inputs, i.e. immediate runoff, is reasonably well represented, the same cannot be said for the longer-term impermeable area runoff. The longer-term runoff would be from land drains, connected watercourses, groundwater infiltration and, possibly, overland runoff from saturated rural areas.

The longer-term runoff would probably be of little significance in very intense short lived events such as an isolated summer thunderstorm. This is because the peak flows from the immediate runoff will have subsided before the longer-term runoff is seen.

Conversely, longer-term runoff could be of great significance in longer duration storms, double peaked storms and storms falling on already saturated ground. A significant under representation of long term runoff could result in storage capacity being significantly underestimated. The underestimation of volume is returned to in Section 5.2.3 of this report.

Alternatively, the audit report comment could refer to the model not being suitable for the prediction of peak flows in the upstream catchments. (Compensating errors only making the model reliable lower down the catchment, at the pumping stations etc).

Unfortunately, the original modelling report has not been made available for perusal, nor has the model audit report. This information would be necessary to confirm, or otherwise, the above mentioned issues.

3.5.4 Approximations to represent groundwater

The Arup report “**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**”⁽⁶⁾ goes on to explain that “As a result of the limitations of the software and data available at the time approximations were made for the contribution of groundwater and watercourses which are known to affect the sewerage system”. There is nothing inherently wrong with this approach. It was commonly used (and to an extent still is) to ensure that the unknowns and limitations were taken care of.

No other information is given so it is not possible to comment further about the appropriateness of this approach. In order to obtain a far better understanding of the 'approximations' made for the previous modelling, relevant information would be needed, such as:

- i) Original modelling report, with appropriate supporting information
- ii) Original model audit report, with supporting information.

including:

- a) The degree of detail that was known regarding the land drainage and watercourses, and their interaction with the sewer system.
- b) The way in which the watercourses and land drainage was represented in the model.

4. FLOODING PROTECTION STANDARDS

4.1 Background – No flooding in 1 in 30 year storm

“**No flooding in a 1 in 30 storm**” is generally accepted by sewerage undertakers as being a goal for urban sewer systems. This is not an **absolute requirement**. However, the Sewerage Rehabilitation Manual, First Edition (1983) ⁽¹⁴⁾, refers to standards and suggests that “*It is the responsibility of Water Authorities and Regional Councils to set their own standards of performance...*”. Appendix C of the same document gives an example with a target for upgrading of 1 in 30 and 1 in 20 years for flooding of premises and streets respectively. The return periods for new designs are suggested as 1 in 50 and 1 in 25 years for property and streets respectively.

BS 8005: Part 1: 1987 ⁽¹⁵⁾ also refers to flood protection. It states that, for larger schemes, the “*client authority’s requirements should again be followed, but in their absence a 30 year flood protection level should be assumed against surface flooding*”. BS EN 752-4: 1997 ⁽¹⁶⁾: takes a similar approach.

A requirement in “**Sewers for Adoption**” ⁽¹⁷⁾ is to provide for surface water drainage for no flooding in a once in 30-year event in new developments. Whilst a 1 in 30 year protection for existing urban catchments is not an absolute standard, it is an approach that works well in most catchments. In the rare event that the surface water piped drainage system becomes overwhelmed the excess drainage should be able to flow towards, and be removed by, natural watercourses. “**Sewers for Adoption**” applies to new sewers. It does, however, provide a 'benchmark' for performance assessments of existing systems.

Where there are few (or no) natural watercourses, a ‘1 in 30 year’ protection is questionable. This is because the consequences of the sewers becoming overwhelmed may be far more serious. This is becoming more apparent with the observed and predicted changes in rainfall severity being brought about by climate change as discussed, for example, in the 2004 Foresight Future Flooding research programme.

4.2 Other standards

It is incorrect for the IRB to say that the water industry has no ‘standard’ against flooding. One of the main ways to measure the performance of the sewerage system is through the Ofwat Level of Service Indicator DG5. This is a register of the number of properties with a likelihood of flooding from sewers for a number of different return periods.

Ofwat and the sewerage undertakers take sewage flooding of property as a very serious issue. Nationwide there has been significant capital expenditure and progress in recent years to reduce this problem. Comparison of current and earlier DG5 registers illustrate this point.

It should be pointed out that not all flooding is the responsibility of the sewerage undertaker. Flooding from land drainage, watercourses and overland rural runoff is not normally seen as being related to the ability of a sewer system to **effectually drain** a catchment.

The situation in Hull may be somewhat unusual given that land drainage and watercourses are intentionally connected to the piped sewer system. This issue is further discussed in Section 4.5 of this report.

4.3 The 'special case' in Hull

Hull is an example of a catchment where there are few open watercourses remaining to take surface water once the piped drainage system becomes overwhelmed. Furthermore, the catchment is in a bowl with many of the residential areas being very flat and below high tide level.

With the above considerations in mind Hull is as an atypical urban catchment and a 'special case'.

4.4 Was a 1 in 30 year standard appropriate?

In most catchments a 1 in 30 year standard is reasonable – it is a compromise between the inconvenience and cost of flooding, and the cost of providing a larger sewer system.

However, where the risks of a failure are significantly higher than the 'norm' it would be appropriate to apply a far more stringent level of protection. This approach should apply to all aspects of water industry infrastructure although historically this has not generally been the case. This weakness has only started to become apparent in recent years with more extreme weather patterns.

It should be noted that previously flood protection has been based upon relatively stable rainfall conditions. It would appear that climate change is already starting to influence rainfall patterns – most Sewerage Utility sewer flooding managers will be able to give examples of atypical rainfall and flooding that has only been experienced in the last three or four years. Thus, the previously relatively stable rainfall-sewer flooding situation may be starting to become unstable.

A greater protection from sewer flooding should be considered in catchments where the consequences of the piped drainage network becoming overwhelmed are particularly serious. The Hull catchment is an example of this.

4.5 A more appropriate standard for Hull

It will be necessary for all the stakeholders in Hull to debate and decide what an appropriate pluvial flooding protection standard should be.

Clearly a 1 in 30 year standard is hardly acceptable, it means that a resident of Hull could expect significant disruption perhaps three or four times in their lifetime. On the other hand a level of protection that would have avoided flooding on the 25th June 2007 may well be unrealistic and prohibitively expensive (1 in 150 years protection or greater).

It may also be appropriate to consider alternatives to simply making the drainage systems larger. These alternatives could include better flood resilience of property and the provision of 'sacrificial' flood storage areas. Most property only flooded to a shallow depth so better protection at doorways/airbricks may be a more affordable alternative. Similarly, new property in low-lying areas should be built above the surrounding ground level.

There is no easy answer to the level of protection and form that it should take. However, as the problem involves the sewer system, land drainage and watercourses, it would be appropriate for Yorkshire Water, the Environment Agency and Hull City Council to jointly agree and jointly fund a way forward.

5. PERFORMANCE ISSUES WITH THE HUMBERCARE SCHEME

5.1 Emergence of 'in-catchment' issues

5.1.1 Higher levels in sewers, land drain contributions etc

Yorkshire Water, in an **Executive Summary** of the findings of the **2004 catchment re-modelling** ⁽¹¹⁾, explain that the reasons for undertaking further investigations were:

- “After commissioning of Humbercare staff have been alerted to difficulties within the West and East Hull catchments.
- One several occasions in the last three years the sewers have been surcharged causing sewage escape (three areas in West Hull and one area in East Hull). One event caused floodwater to reach within 25 mm of a door threshold in West Hull”.

The paper goes on to mention that the local population have been alerted to increased levels of flooding and that local councillors are involved.

Yorkshire Water in a **report of a public meeting** ⁽¹⁹⁾ (22 April 2004) explain that:

- They undertook CCTV investigations of the local sewer following the most recent flooding event. This was to see if the flooding was a localised problem. No sewer related problems were found, though, perhaps significantly, there is a reference to the recent clearing of Acre Head Drain.
- An investigation of the sewage flows in the Hull area is being undertaken. This includes a flow survey and hydraulic modelling (a reference to the new InfoWorks model). Furthermore, it is explained that the problems “are likely to be sources of water entering the public sewerage system which were not known about previously”. Issues with land drains and infiltration are mentioned, as is a previously unknown overflow from the Acre Head Drain to the sewerage system.

Arup report “**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**” ⁽⁶⁾, dated January 2006, gives further information. It explains that suspicions were raised about the system possibly not operating and reacting to rainfall as originally intended. This was because:

- Larger flow rates and volumes than had been expected in the transfer tunnel. This had resulted in a similar higher operating frequency of the storm pumps at Saltend. The levels in the wet well suggested that storms of greater than 5 year return periods were occurring relatively frequently.
- During a storm in 2001 very high water levels were noted at the pumping station and operations teams checked the levels in the interceptor sewers. They noted that they were full and about to flood, something that had not been experienced in the past. (Flooding did not occur).

5.1.2 IRB comments

The IRB, in their **Final Report** ⁽³⁾ (Section 5.3.4) state that between scheme commissioning in 2001 and 2004: there have been:

- Several reports of “sewers being unusually full despite relatively low rainfall levels”.
- Reports of “local flooding in areas which had not experienced flooding pre-Humbercare”.

The IRB also allege “a significant increase in the number of properties and roads included in the DG5 register”.

Furthermore, in their **Final Report** ⁽³⁾ (Section 5.3.5) the IRB state that Yorkshire Water commissioned MWH to revisit the Hull urban catchment model in response to the abovementioned increased incidents of flooding. **Yorkshire Water**, in their **Initial Reponse** to the IRB ^(4, 5), explain that the new modelling work was commissioned because of area flooding. (This appears to be a reference to local problems, not problems relating to Humbercare).

5.1.3 Alterations in DG5 register

Yorkshire Water, in their **Initial Review** to the IRB Final Report ⁽⁵⁾ (December 2007), refute the IRB allegation of a significant increase in the DG5 register. Particular points raised by Yorkshire Water are:

- What did the IRB base their assessments on?
Yorkshire Water had been requested, and provided, information for 2003 and 2007, which are both post Humbercare commissioning.
- Yorkshire Water subsequently undertook a statistical analysis of the DG5 figures. This covers the period 1996/7 to 2006/7 and, according to Yorkshire Water, the results “showed that at the 5% significance level there is no evidence to suggest, in either case, that the values pre and post the new works being installed are statistically different”. (The new works refers to Humbercare).

Yorkshire Water also explain:

- That the maximum number of properties on the 1 in 10 and 2 in 10 register in the last 10 years was 14; and
- The basis for including properties on the register.

Given the clear difference of opinion, Yorkshire Water should set out their reasoning in more detail.

5.2 Model migration from HydroWorks to InfoWorks / reasons for increased flows

5.2.1 Background

In early 2004 MWH were appointed by Yorkshire Water to review and update the original HydroWorks Model. The results of the new modelling were reported in October 2004 ⁽¹⁰⁾.

The modelling subsequently raised issues with the Humbercare scheme and Yorkshire Water responded by appointing Arup to undertake a study to **Investigate Increased Flooding Risks**. This study reported in January 2006 ⁽⁶⁾.

5.2.2 InfoWorks model

A **Yorkshire Water Executive Summary** ⁽¹¹⁾ of the findings of the MWH report ⁽¹⁰⁾ explains that the remodelling was required because of concerns about:

- Unusually high levels in the sewers and flooding (from Yorkshire Water's own operational staff) and flooding (from the general public), as previously explained in Section 5.1.1 of this report.
- Losing all pumping in the event of a tunnel failure.

Migration from HydroWorks to InfoWorks

In early 2004 MWH were appointed by Yorkshire Water to review and update the original HydroWorks model ⁽¹⁰⁾. The new model uses InfoWorks; this is also produced by Wallingford Software and is essentially an updated and improved HydroWorks model. Improvements of particular importance to these investigations included better simulation of land drainage and catchment wetness issues.

The InfoWorks model should give more accurate predictions for:

- Runoff from long duration multi-peaked storms
- The contribution of slow response runoff.

It is uncertain to what extent the catchment specific data, as input into the model, had been improved between the HydroWorks and InfoWorks models. Of particular relevance would be improvements to more realistically and better represent land drainage, watercourses and groundwater. This needs to be investigated.

Arup report "**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**" ⁽⁶⁾, dated January 2006, refers to the InfoWorks model. It mentions that InfoWorks should give an improved representation of the catchment, mainly due to the use of the New UK Runoff Model and Ground Water Module. Neither of these features were available in the earlier HydroWorks model.

The Arup report goes on to mention that the original model did indeed underestimate delayed runoff within the catchment. However, the model's results did support the original model audit statement that the model was acceptable for designing peak flows.

5.2.3 Increased flows

The InfoWorks model, when compared to the HydroWorks model predicts the following increases in flow:

- + 10% in peak flows
- + 100% in total runoff volume

Report **Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**" ⁽⁶⁾, dated January 2006, explains that different design storms were used in the new model. The InfoWorks model uses Flood Estimation Handbook (FEH) storms. The data used

to generate these events is more recent than the Flood Studies Report (FSR) method used in the earlier HydroWorks model. As such, the FEH storms should be more representative of current rainfall and are approximately 10% larger than the equivalent return period FSR storms.

There is no explanation as to why total runoff volume should have increased so significantly. Some of this could be due to the better simulation of groundwater, land drainage and multi peaked long storms. However, there may be other reasons that are not model related, such as the inclusion of previously omitted land drainage and watercourse inputs. Yorkshire Water should clarify this issue.

5.2.4 Likelihood of flooding

MWH reported their findings in **West Hull SPS, Options Report**, dated October 2004⁽¹⁰⁾. The report goes on to state that the overall protection provided by Humbercare is:

- i) Between 1 in 1 and 1 in 2 years, given WwTW SPS pumping at 15 m³/s
- ii) Between 1 in 2 and 1 in 5 years, given WwTW SPS pumping at 22 m³/s

This indicates a significantly reduced level of protection from what was previously expected (1 in 30 or 1 in 70 years).

It would be incorrect to assume that the significantly reduced protection is simply because the model has been migrated from HydroWorks to InfoWorks. A number of other changes were applied to the catchment input data in the new model. This was to better represent reality and included:

- a) Flows from trade effluent discharges increased to represent the consent. (This may be higher than the actual discharge).
- b) Per capita water consumption, and hence wastewater discharges, increased in anticipation of increased water usage.
This may be a trend that will be reversed in future. The Code for Sustainable Homes (CSH), for example, calls for a substantial reduction in water use in new developments.
- c) An assumption of no pumping other than at the WwTW SPS. (It is uncertain if the original HydroWorks model also made this assumption).
- d) Future developments (residential, commercial and industrial) up to a 2015 planning horizon.
- e) A maximum capacity of the pumping station at the inlet works at Saltend of between 15 and 18 m³/s.

This is a significant change from the original assumptions made in the HydroWorks model where a maximum pumped flow of 22 m³/s was used. However, as noted above, the protection when 22 m³/s is used only increases to between 1 in 2 and 1 in 5 years.

The significance that the issues (a) to (e) have on the predicted 100% increase in runoff in the InfoWorks model is uncertain, and should be clarified by Yorkshire Water.

5.2.5 Current situation

It should be pointed out that the aforementioned predictions are not representative of the current situation. This is because:

- i) They are a worst-case scenario for a 2015 horizon. This assumes maximum wastewater flows into the sewer system, which may, or may not, occur. Yorkshire Water make a similar observation in their Initial Review (page 39) to the IRB Final Report (paragraph 5.3.5).
- ii) The model assumes no pumping from East or West Hull Pumping Stations. This was not the situation that existed on 25th June 2007, as explained in Chapter 7 of this report.
- iii) The overtopping weir at West Hull would have been in its original configuration in the model (higher spill level). It is uncertain if the weir was subsequently lowered before the 25th June 2007 storm (see Section 6.3.2 of this report).

Thus, the level of protection currently provided appears likely to be somewhat less than the 1 in 30 (implied in Arup feasibility study)⁽⁶⁾ or 1 in 70⁽⁹⁾ protection originally intended. However, it may well be somewhat greater than a 1 in 1, 1 in 2 and 1 in 5 year protection suggested in the modelling.

5.2.6 Summary

The InfoWorks model should be far more able to predict the runoff from a large, groundwater significant and already saturated catchment. These were the conditions that would have existed in the Hull catchment on the 25th June 2007.

In order to get a more representative indication of the level of flooding protection on the 25th June 2007 (and also current level of protection), it is suggested that the model is used with the sewer system/pumps in the configuration as at 25th June 2007:

- a) In combination with the storms used in the earlier (2004) modelling, and
- b) Using the following inlet works capacity at Saltend:
 - i) As on the 25th June (19 m³/s).
 - ii) Once the belt screen upgrading has been completed (22 m³/s).

The catchment configuration should include:

- Current (not 2015 horizon) flows.
- Pumping available at East and West Hull Pumping Stations.
- The setting of the overtopping weirs as on 25th June 2007.

5.3 Deficiency in screening at Saltend WwTW

A Yorkshire Water Executive Summary⁽¹¹⁾ of the findings of the MWH report “**West Hull SPS, Options Report**”⁽¹⁰⁾, dated October 2004, explains that there have been problems with screening at the inlet works, in particular:

- “The band screens are unable to cope with the screen loading and are having to be manually controlled (switched off in some cases) to prevent damage to screen panels.

- *The manual control ...is reducing the pumping capacity of the SPS to something around 15 – 18 m³/s on most storm events.*
- *The under pumping is reducing storage capacity....”*

Arup report “**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**”⁽⁶⁾, dated January 2006, similarly mentioned the screening capacity issue. It states that because of this the pumping station could only deliver 15m³/s under certain conditions.

5.4 Conclusions

A Yorkshire Water Executive Summary⁽¹¹⁾ of the findings of the MWH report “**West Hull SPS, Options Report**”⁽¹⁰⁾ concludes that

The overall protection provided by Humbercare is:

- a) Between 1 in 1 and 1 in 2 years, given WwTW SPS pumping at 15 m³/s
- b) Between 1 in 2 and 1 in 5 years, given WwTW SPS pumping at 22 m³/s

However, as explained in Section 5.2 of this report this is not a true comparison with the earlier (HydroWorks) predictions of flooding protection. The true protection provided by Humbercare, as of 2004, was in excess of the above predictions but likely to be less than the assumed 1 in 30 (or 1 in 70) protection originally intended.

The refurbishment of West Hull Pumping Station in 2005/6 enabled an increase in available pumping capacity. This will have further increased the flooding protection.

6. YORKSHIRE WATER'S RESPONSE TO EMERGING ISSUES WITH THE HUMBERCARE SCHEME

6.1 Flow (peak and volume) predictions from the new model

Yorkshire Water appears to have taken on board the emerging issues, in particular following the results of the new 2004 InfoWorks model. The following recommendations are made in a Yorkshire Water Executive Summary ⁽¹¹⁾ of the findings of the MWH report "**West Hull SPS, Options Report**" ⁽¹⁰⁾:

- *"The modelling work be continued....."*
- *Investigate ways of pumping sewage at West and East Hull Pumping Stations.*
- *Dialogue start with the EA on the possibility of pumping sewage into the Humber Estuary at the old East and West Hull Pumping Stations.*
- *Yorkshire Water develop an emergency procedure to provide the best levels of service given the current arrangement".*

It is not possible to say if the Yorkshire Water response was timely or not. It is known that MWH were commissioned to revisit the modelling in early 2004 and that they reported on it in October 2004 ⁽¹⁰⁾, however there is no date on the Yorkshire Water Executive Summary ⁽¹¹⁾. Clarification of this is therefore required.

6.2 Return of pumping capacity/increase in pumping capacity at West/East Hull

6.2.1 West Hull

A **Yorkshire Water Executive Summary** ⁽¹¹⁾ of the findings of the MWH report ⁽¹⁰⁾ explains that "*West Hull SPS has been mothballed with M&E equipment in a very poor state of repair*". A recommendation in the same report calls to "*Investigate ways of pumping sewage at West Hull SPS*".

Arup report "**Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks**" ⁽⁶⁾ gives details of a workshop held on 26 July 2005; one of the points mentioned was that "*West Hull pumping station could not be physically brought back into operation in an emergency*".

Work costing £1.8 m commenced in 2005. Yorkshire Water state that the pumping station was refurbished in November 2005 and the full scheme was completed in May 2006.

It is uncertain when Yorkshire Water began to take action to restore pumping capacity. None of the documentation that we have examined mentions this and it may be that the notes of the 26th July 2005 workshop fail to mention that work is in progress. This issue needs to be clarified.

Pumping capacity was increased to 20 m³/s. This is somewhat less than the 32 m³/s pre Humbercare situation. However, the combined post 2005 pumping capacity (20 m³/s) and capacity of the vortex drop into the transfer tunnel (14 m³/s) should, in theory, be greater than pre Humbercare capacity. (This assumes that there is capacity in the transfer tunnel to take the flows).

6.2.2 Nature of the upgrading – permanent short/medium term or temporary

The IRB describe the 2005/6 works at West Hull Pumping Station as temporary⁽³⁾. Yorkshire Water disagree^(4,5) and point out that the refurbishment extends the operational life, though as with any M&E equipment, there will be a need for further maintenance and renewal in the future.

There may be a need to significantly alter/rebuild the pumping station in the longer term. Such a decision should await a more detailed investigation of the 'wider' drainage requirements of Hull. Given that land drainage, watercourse drainage and paved urban drainage all interact in the piped drainage system there is a significant risk that insufficient information is currently available to confidently predict the capacity requirements of any future scheme. (It is appreciated that the InfoWorks model is a significant improvement over the earlier HydroWorks model. However, there still appears to be some doubt about the interactions between the sewer system and land drainage/watercourse/groundwater systems).

It may be appropriate for the investigation and any potential upgrading works to be a multi agency funded. This is because the sewer system is atypical in that it is the recipient for a significant volume of flow from watercourses and land drainage.

The consideration should not be 'is the upgrading temporary or permanent', rather 'are there plans in place to deliver the appropriate level of service, in the short and long term'.

6.2.3 East Hull

There is no mention in the documents that we have examined of changes to the available pumping capacity at East Hull Pumping Station. This needs to be clarified by Yorkshire Water.

6.3 Other alterations to reduce likelihood of flooding

6.3.1 Emergency procedures

Yorkshire Water in a **report of a public meeting** (22 April 2004)⁽¹⁹⁾ explain that emergency procedures have been put in place following the recent floods. These include:

- i) The activation of Goulton Street pumps (West Hull Pumping Station) in the event of high flows.
- ii) Actively considering the installation remote monitoring devices (these could give earlier warning of rising levels at flood prone locations).
- iii) Monitoring of sensors at the WwTW. When the flows reach a certain level a senior member of staff will be informed and, depending on weather conditions and other warning signs, may attend problem areas. If these investigations find that the sewers are getting full then the West Hull pumps will be turned on.

The procedure was tested on 18th April 2004 during heavy rain, though there was subsequently no need to activate the pumps.

This information suggests that West Hull pumps were available for operation in 2004. This contradicts other information, as outlined in Section 3.3 and 6.2 of this report. This issue requires clarification from Yorkshire Water.

Yorkshire Water in their Initial Review ⁽⁵⁾ to the IRB Final Report explain that, through its application, they have adapted and improved the Emergency Procedure. The procedure, which is on Version 6, is a practical document and gives operating guidelines in the form of a matrix. It explains that operation of the pumps depends upon the prevailing conditions, for example, the weather, proceeding weather, flow rate etc.

Given that the pumps cannot be operated automatically (a condition of the consent) and the complex considerations regarding the pumping operation (see Chapter 8 of this report), the approach being taken by Yorkshire Water seems reasonable.

6.3.2 Overtopping weir at West Hull Pumping Station

As part of the Humbercare scheme overtopping weirs were constructed to enable flows for up a 1 in 5 year storm to be stored in the sewer system. Subsequently there has been concern regarding the levels in the sewers, in particular during rainfall in the West Hull system.

One way of improving flood protection in the upstream catchments would be to reduce the levels of the overtopping weirs. There is a suggestion in the Arup January 2006 Feasibility Report ⁽⁶⁾ to reduce the spill level on the weir into the vortex drop at West Hull mixing chamber. The proposal was to reduce the level from -3.43 m AOD to -6.00 m AOD.

The effect of this would be to reduce the volume of sewage backed up in the sewers. That would 'free' capacity and, in so doing, enable a greater volume of storm runoff to enter the sewer system in the event of a heavy storm and reduce the likelihood of the sewers surcharging/flooding occurring.

Yorkshire Water should clarify their intentions regarding this work.

6.4 Contingency plans – East and West Hull pumping stations

It is implied, from some of the reports commissioned by Yorkshire Water and Yorkshire Water's responses to the IRB Final Report ^(4,5), that there are contingency plans for West Hull and East Hull Pumping Stations and that these are tied into the 'Emergency procedures'. However, details regarding the contingency plans have not been made available.

Yorkshire Water should clarify their contingency plans and emergency procedures.

6.5 Inlet works at Saltend

Yorkshire Water commenced a £6.8 m upgrading of the inlet works in March 2006. This should resolve the problems with the loading of the band screens and enable screening capacity to be increased to the design flow rate of 22 m³/s.

Work was in progress when the storm occurred on 25th June 2007. The flow rate at that time was 19 m³/s ⁽⁷⁾.

This work was in its final stages in December 2007.

6.6 Was the response timely?

The IRB in their Final Report ⁽³⁾ claim that Yorkshire Water has:

- Carried out sufficient modelling: and

- Have taken a long time to react to provide additional pumping capacity.

The problems were confirmed in 2004 and in late 2005/early 2006 refurbished West Hull Pumping Station to provide 20 m³/s capacity. This is a significant capacity, in particular when compared with the maximum 22 m³/s pumping from the transfer tunnel provided at Saltend inlet works.

It is uncertain if any other associated work, for example reducing the level of the overtopping weirs, has been undertaken.

Yorkshire Water is also taking action to solve the screening capacity problems at Saltend inlet works. These problems became apparent in 2004. Work to rectify this commenced in March 2006 and should be completed in early 2008.

There is always more that can be done to increase pumping capacity. However the rebuilding or replacement of a major pumping station both takes time and is costly. It is therefore essential that there is a firm basis for designing and constructing any further capacity improvements. Whilst the InfoWorks model of the piped drainage system is a significant improvement over the older HydroWorks model, there is significant interaction between the sewer system and field drain/watercourse systems and it appears that this is not fully understood.

It is essential that the hydrology of the field drain and watercourse systems and their interaction with the sewer system is fully understood before any significant improvements are embarked upon. Arup also make this point in their report into the June 2007 floods ⁽⁷⁾. Ideally this will require a multi agency investigation both in terms of funding and participation (Yorkshire Water, Environment Agency and Hull City Council).

Finally, it is not clear whether action was taken between the problems first becoming apparent to Yorkshire Water in 2001 (as referred to in the January 2006 Arup Feasibility Report) ⁽⁷⁾ and 2004. It is also not clear if other agencies with drainage responsibility became involved following the 2001 'high water levels' observation.

6.7 Was the response robust?

Yorkshire Water responded by adding pumping capacity at West Hull Pumping Station and Saltend inlet works.

West Hull pumping station

The refurbishment at West Hull has brought back 20 m³/s pumping capacity. This is less than the pre Humbercare 32 m³/s capacity but, when taking into account the vortex drop into the transfer tunnel (14 m³/s), it provides a roughly similar capacity. This assumes that the transfer tunnel has sufficient storage capacity. However, in a long duration storm occurring on a saturated catchment, this may not be the case and there could be a more frequent flooding threshold in the upstream catchment.

Unfortunately, the correct determination of required capacity (a combination of storage and pumping) will first require a far better understanding of the interaction between the land drains and watercourses with the sewer system. As previously mentioned multi agency investigations are required, ideally this should involve Yorkshire Water, the Environment Agency and Hull City Council.

Saltend

The improvements at Saltend will increase capacity to the design flow. This was a reasonable short/medium term response.

In the longer term terminal pumping station capacity* arrangements may need to be revisited. This will first require a detailed investigation of the interactions between the land drainage/watercourse/groundwater systems and the piped drainage system.

*"Terminal pumping station capacity" refers to the combination of East Hull, West Hull and Saltend Pumping Stations.

7. YORKSHIRE WATER'S RESPONSE ON THE 25TH/26TH JUNE STORM

7.1 The 25th June storm

In June 2007 the city of Kingston upon Hull experienced unusually high volumes of rainfall. It was the wettest month in Yorkshire since 1882 (EA), with over 250 mm of rainfall being recorded at the University of Hull. Over 70 mm of rain fell on the 15th June, further precipitation occurred over the following days culminating in approximately 105 mm rain on the 25th June ⁽¹⁾.

On Sunday 24th June the Met Office issued a weather warning, a 24-hour flood incident room was set up in the evening. Hull City Council declared a Major Incident at 09:30 on the 25th June – Silver Command was established.

On the 25th June the following rainfall was recorded in the Hull catchment:

- Saltend WwTW 105 mm (Yorkshire Water site)
- River Hull 96 mm (Environment Agency site)
- University of Hull 110 mm

The autographic recordings from the University of Hull gauge indicate that the storm significantly exceeded the '1 in 30 year' return period criteria commonly used to assess 'no flooding from sewers' performance. Although the storm was not particularly intense, it was heavy and prolonged. Thus, whilst the storm did not exceed the 1 in 30 year criteria for durations of less than 6 hours, the prolonged nature meant that it significantly exceeded the 1 in 30 year criteria for durations of and over 6 hours. Over the 15 hours of main rainfall it has been estimated, using the Flood Estimation Handbook (FEH) approach, that this was a one in 150 year event.

Furthermore, it is likely that the ground in and around Hull will already have been saturated on the 25th June. These "worst case" conditions resulted in severe flooding, widespread disruption occurred with damage to over 8600 residential properties and an estimated over 1300 businesses ⁽³⁾.

7.2 Silver Command

Yorkshire Water's response to the heavy rainfall and high sewer flows is described in Section 7.3 of this report. However, as pointed out by the IRB in their Interim Report ⁽¹⁾, it is surprising that, given the crucial role of Yorkshire Water, they were still asking for a Liaison Officer with Silver Command as late as 16:19 on the 25th June.

Also, did the decision to go to Silver Command and not Gold Command affect Yorkshire Water's response? This is particularly so in the case of the failure at Bransholme Surface Water Pumping Station – valuable mobile pumping equipment that would normally have been the contingency equipment for Yorkshire Water's pumping stations had been requisitioned to Ulley Reservoir (a non Yorkshire Water facility). Ulley had taken priority because Gold Command had been established in South Yorkshire.

7.3 Yorkshire Water's response

The Arup report on the 2007 floods ⁽⁷⁾ describes Yorkshire Water's response. The main points are:

- i) Yorkshire Water staff worked continuously to provide as much protection as possible. Many staff worked long hours, despite their own homes being flooded.
- ii) **15th June**
Exceptionally heavy rain fell across the catchment.
 - Bransholme and Saltend pumping stations worked continuously.
 - West Hull Pumping Station was operated between 06:00 and 24:00.
 - East Hull Pumping Station was operated intermittently, as and when required.
- iii) **22nd June**
A further Weather warning was issued by the Met Office. (Subsequently updated on the 24th).
- iv) **25th June**
Exceptionally heavy rainfall fell across the catchment. (See 7.1 above).
 - Bransholme and Saltend Pumping Stations worked continuously.
 - West Hull and East Hull Pumping Stations were operated from 07:00. (See 7.4 below for details)
- v) **26th June**
Bransholme Surface Water Pumping Station failed – The station flooded, the thrust bearings could not be maintained and seized.

7.4 Events leading up to the decision to operate the pumps at West/East Hull

Yorkshire Water, being aware of the expected heavy rain, monitored levels in the system, in particular at West Hull Pumping Station. It is understood that this monitoring was in accordance with the Emergency Procedure (see Section 6.3 of this report). It was the procedure that was used successfully during the heavy rain on the 15th June.

As previously mentioned the pumps cannot be operated automatically on pre-set start levels. This is because the consent only allows operation when:

- i) There is an electrical or mechanical equipment failure at the inlet works pumps at Saltend, or a tunnel failure.
- ii) There is a risk to life or property in the upstream catchment.

When it was clear that there was a risk to life and property the decision to start the pumps was taken. Both West Hull and East Hull Pumping Stations effectively started operating at 07:00.

7.4.1 Performance of pumps at West Hull.

The IRB state ^(1,3) that the overall pumping capacity was 15 m³/s. Yorkshire Water point out that is incorrect ^(4,5). Pumping capacity was 20 m³/s for the first few hours reducing to approximately 16m³/s for the remainder of the pumping operation.

The pumping station, which was and always had been reliant on significant operator intervention, was manned continuously in response to the 25th June rainfall. Pump operation depends both upon satisfying the consent conditions (see above) and a number of variables in the catchment requiring experienced operator judgement. These include:

- Previous rainfall.
- Current rainfall, flows and levels in the upstream catchment.
- Volume of flow in and entering the mixing chambers.
- Likely rainfall.

All five refurbished storm pumps were operated. For the first 2 to 3 hours there were no problems and the station operated at 20 m³/s capacity (i.e. 5 x 4 m³/s).

Various faults subsequently occurred. This caused the pumps to trip occasionally and the operators addressed these problems as and when they happened. From then the true pumping capacity at the station was probably closer to 16 m³/s than 20 m³/s. Typically the pumps were run in rotation, one pump would be out of action for attention/maintenance, this included re-greasing to prevent over-heating.

It is uncertain if the flooding problems in the West Hull urban catchment were exacerbated by a lack of pumping capacity at former West Hull Pumping Station or by capacity restrictions within the sewer system, or by a combination of both. Capacity restrictions within the sewer system, if an issue, may well have held flow back in certain parts of the middle/upper catchment.

Furthermore, procedures which require the flow to be regulated as it reaches West Hull Pumping Station may suggest that the flow was unable to get to the pumping station, not that the pumps were unable to cope. Similarly, would the surge problems in the transfer tunnel have occurred if there was always sufficient storm flow arriving at the West Hull site?

Clearly there are more questions than answers regarding the perceived causes of flooding in the West Hull catchment. Yorkshire Water's account of what happened on the 25th June 2007 sheds some light onto this. There are, however, a number of outstanding questions as to what really happened and what impacted upon what. These issues need to be explained by Yorkshire Water.

7.4.2 Performance of pumps at East Hull

The pumping station, which is reliant on significant operator intervention, was manned continuously in response to the 25th June rainfall.

The station was operated at available capacity (8 m³/s sewer system pumps) to pump both storm flows from the sewer system and the Holderness Drain. Pumping down of the Holderness Drain continued for several days.

7.5 Pumping from the transfer tunnel to Saltend inlet works

The IRB state ^(1, 3) that the overall pumping capacity was 15 - 18 m³/s. Yorkshire Water point that the upgrading of the band screens at the inlet works was in progress when the storm occurred. Yorkshire Water state ^(4, 5) that a pumping capacity of 19 m³/s was available.

7.6 Was the response appropriate and adequate?

The response by Yorkshire Water's staff was both appropriate and adequate, taking into account the age and nature of the pumps at West and East Hull Pumping Stations.

The age of the pumps may have been a contributory factor to the faults that developed at West Hull Pumping Station. However, operator intervention ensured that the majority of pumping capacity was maintained. It is worth noting that there are no reports of problems at West Hull Pumping Station during the previous heavy rain on the 15th June 2007.

It is uncertain if the 20 m³/s pumping capacity re-established at West Hull Pumping Station was intended to be

- The pumping capacity anticipated to be available at all times during a major storm;
- or
- The pumping capacity included a contingency and a lower capacity was expected to be available.

The lower capacity would be more attainable because relatively large and old pumps are most likely to require maintenance (greasing etc) during extended periods of continuous operation. It is essential that Yorkshire Water demonstrate that they are taking account of the experience in operating pumps under stressful conditions in their planning for the future.

8. OPERATIONAL PROBLEMS WITH REVISED HULL/HUMBERCARE SYSTEM

8.1 Manual pumping regime at West Hull

8.1.1 Conflicting considerations

As previously mentioned the pump operation requires requiring experienced operator judgement. For example:

- Late operation of the pumps will result in the upstream sewers being too full with an increased likelihood of flooding.
- Early operation of the pumps will result in the pumping dry of the vortex mixing chamber and a breach of the consent conditions.

Also, a condition of the spill consent is that maximum flows must be passed to the treatment works. This in turn requires maximum flows to be presented to the transfer tunnel. Only when this maximum has been reached, and there is a risk to life or property in the upstream catchment, can the pumps be activated at West Hull.

A further consideration is the need to not suddenly reduce the volume of flow being passed to the tunnel. This could result in water pressures at the tunnel entrance being lower than further downstream, a backflow could then develop and lead to potentially catastrophic oscillations in the tunnel.

Given the size and nature of the pumps, it is also important that stopping and starting are kept to a minimum.

Thus, in order to satisfy the various operating requirements, a penstock is used to control flows into the pumping station. This is achieved by a modulating penstock that moves up and down within the flow, thereby enabling:

- i) Flows into the tunnel to be controlled
- ii) Spills to be in accordance with the consent
- iii) The minimum stopping and starting of pumps.

The operating regime would appear to be quite complex and require significant experienced operator intervention. It is a system that has evolved because of the need to:

- Keep levels in the upstream catchment such that the likelihood of upstream flooding is minimised
- Not suddenly reduce flows to the transfer tunnel, for example by the sudden operation of the pumps.

8.1.2 Pump on/off levels

The IRB note that

- i) Arup, in their January 2006 feasibility report ⁽⁶⁾, suggest that the pump on/off levels should be:
 - Pump on -5 m AOD
 - Pump off -6 m AOD
- ii) MWH in their model simulations to address flooding ⁽⁸⁾ have assumed a pump on level of -3 m AOD.

However, Yorkshire Water operates the station with a much higher 'pump on' level. This depends upon the prevailing conditions and experienced operator judgement, in accordance with the Emergency Procedure ⁽⁵⁾. For example, on the morning of the 25th June 2007 the pumps appear to have been activated at approximately -1m AOD.

This has led the IRB to question ⁽³⁾ whether Yorkshire Water, by adopting a much later and higher 'pump on' regime, were increasing the likelihood of flooding because flows in the sewers were not being kept as low as they could be. Yorkshire Water in their Initial Response ^(4,5) explain that the pump on/off levels are based on:

- a) The consent conditions, which do not allow premature pump operations; and
- b) Practical considerations at the pumping station.

For example the lower pump operating levels would run a significant likelihood of the vortex mixing chamber being pumped dry. In order to avoid this, sudden changes in pump operation would be required; this is impractical and undesirable when operating large pumps. Furthermore, sudden alterations in the pumping regime could run the likelihood of inducing oscillations in the transfer tunnel.

Yorkshire Water's explanation seems reasonable given the complex operating circumstances.

8.2 Manual pumping regime at East Hull

The spill consent requires pumping of sewage to be activated by manual intervention. As at West Hull this is to ensure that the maximum flow is first passed forward to Saltend WwTW. Spills can only be made when there is a risk to life and property in the upstream catchment.

Presumably this will require a fairly complex operating procedure as at West Hull. However, these issues are not mentioned in any degree of detail in any of the reports supplied. This is an issue that requires clarification from Yorkshire Water.

The main issues at East Hull appear to be with the 1949 pumping station. These include:

- The unserviceable condition of two of the four pumps.
- The inoperable condition of adjustable inlet gates that control the flow from the Holderness Drain.

8.3 Capacity at Saltend inlet works

The screening arrangements were in the middle of being upgraded on the 25th June 2007. Apart from these screen-loading issues, no other operational problems are recorded in the documentation.

8.4 Oscillations in the transfer tunnel

Pumping at West Hull had to be controlled to reduce pressure oscillations in the transfer tunnel. If not controlled the oscillations could have resulted in serious structural damage to the transfer tunnel.

These oscillations had not been identified as a risk following the refurbishment of West Hull Pumping Station. The reasons for the oscillations are now being investigated.

8.5 Action/proposed action by Yorkshire Water to address the above mentioned issues

The upgrading works at Saltend inlet works should be completed shortly.

The problems at West Hull Pumping Station are primarily the result of a complex set of operating requirements. Some of these have been brought about by changes made to the operating regime at West Hull Pumping Station, following the emergence of performance issues with Humbercare.

The complex, and sometimes competing, set of requirements is dealt with through the combined use of an emergency operating procedure and manual intervention by experienced operators. The system appears to be working reasonably well, as demonstrated by the relatively successful operation of West and East Hull Pumping Stations on the 15th and 25th June 2007.

Clearly a complex operating system that relies on significant manual intervention would not be the operating regime of choice. It has been brought about by the need to modify the operation of Humbercare. In the long term it may be necessary to significantly upgrade the facilities, for example, at West Hull Pumping Station as explained in Section 6.2.2. The opportunity should then be taken to alter the operating regime, to simplify and automate wherever possible.

9. WHAT CONTRIBUTED TO THE 25TH JUNE FLOODING IN THE HULL CATCHMENT?

9.1 Exceptional weather – a 1 in 150 year storm falling onto saturated ground

Exception rainfall occurred on and around Hull on the 25th June 2007. This has been estimated as being of a return period of 1 in 150 years or greater.

Also heavy rain fell on the 15th June and over the following days. This is likely to have resulted in the chalk aquifer being full with groundwater at or about ground level at the start of the 25th June rainfall.

Further details are given in Section 7.1 of this report.

The combined effect of exceptional rainfall and a saturated ground/high water table will have been the main cause of the flooding. No urban drainage system in the UK will have been able to cope with those conditions.

9.2 Land drainage flows

The Hull drainage system is unusual in that a significant number of land drainage systems and watercourses are connected to the sewer system.

Furthermore, as stated in the IRB Interim Report ⁽¹⁾, many of the old land drainage and watercourse systems were culverted or filled in following the construction of a modern trunk sewer system in the post war years. As a consequence there are few alternative drainage routes for the storm runoff once the piped drainage system becomes overwhelmed.

Also, being in a bowl and with many areas below high tide level, groundwater can be a significant influence.

A combination of the above factors will have had a serious impact upon the catchments' drainage during the extreme conditions on the 25th June 2007.

9.3 Overland flows from adjacent rural areas and areas a higher ground

Many of the areas that flooded on the 25th June were relatively modern housing estates on the urban fringe. Some were relatively low lying and may have been the obvious places to flood following such an exception rainfall. However, not all the low lying areas flooded and some of the slightly higher areas were just as badly affected.

A comparison of the areas in the West Hull catchment with property flooding on the 25th June 2007 (see Figure 1.4, IRB Interim Report) ⁽¹⁾, the higher outlying areas and adjacent rural areas (also Figure 1.4) indicates that most of the areas that flooded were adjacent to either:

- Large areas of rural land,
- Higher ground, or
- Close to where a rural land drainage system(s) connected into the piped drainage system

or a combination of two or all three factors.

Thus, overland flows from outlying rural areas or adjacent higher ground running into the urban areas could be an explanation for some of the flooding.

9.4 Problems with road gullies

A possible source of flooding could have been the inability of storm water to drain into the piped system because of blocked or poorly operating road gullies. The IRB, in their Interim Report ⁽¹⁾, comment that the aim of Hull City Council is to visit all gullies on major routes twice a year and gullies in residential roads once a year. However, in the areas that flooded, in the 12 months prior to 14th June 2007, only slightly over one-third of the gullies had been cleaned and jetted.

The requirement to visit gullies on an annual or six monthly basis is to ensure that gullies are maintained in good working order. It is possible that this lack of visits resulted in drainage problems in some areas. To illustrate this, a Yorkshire Water report of a meeting with councillors on the 22nd April 2004 ⁽¹⁹⁾ mentions a problem at the corner of Trenton Avenue. It continues to explain that this could be caused by a blocked road gully.

The IRB ⁽¹⁾ go on to explain that just 0.57% gullies were reported as being blocked or slow running at the point of cleaning during the 12 months preceding the floods. This is very low given the frequency of gully visits and seems to suggest that there are very few problems with gullies.

However, this conflicts with other experiences that indicate blocked gullies can be a significant problem during exceptionally heavy rainfall. Examples of such problems are given in a paper written by Professor David Crichton (University College, London) ⁽²⁾. It specifically refers to the Hull flooding and gives examples of gullies where leaves and recent grass cuttings have partially obscured the gully. Smaller than the current standard covers in older parts of Hull are also mentioned. (<http://www.benfieldhrc.org/activities/publications.htm#tech>)

Reference to Figure 1.1 in the IRB Interim Report ⁽¹⁾ shows the roads that flooded. Some of these are isolated from the main areas of flooding and some are in areas that are not on particularly low ground. It may be that 'local' problems with gullies were the reason why these areas flooded and adjacent areas did not.

The condition of gullies on the private drainage systems around houses is also uncertain. A lack of maintenance/poor state of repair could have impeded the removal of water.

9.5 'Local' problems in the sewer system

Reference to Figures 1.1 and 1.4 in the IRB Interim Report ⁽¹⁾ shows the roads that flooded and the properties that flooded. Some of these areas are some distance away from the main areas of flooding and are not in particularly low areas. It is possible that 'local' problems in the sewer system contributed to the flooding.

The issues regarding surge in the transfer tunnel may indicate that the sewers arriving at West Hull Pumping Station were not always running full. In the Arup report into the June flooding ⁽⁷⁾ it is suggested that the surge problems were caused by a reduced pressure from a reduction in flows being presented to the transfer tunnel. Assuming that the pumps remained pumping at a constant rate, the reason for the reduced flows to the tunnel may have been a reduced flow arriving at the pumping station.

The significance, or not, that 'local' sewer network capacity problems played in the flooding should be explained by Yorkshire Water.

9.6 **Problems relating to the revised Humbercare system**

In MWH report **West Hull SPS, Options Report**, October 2004 ⁽¹⁰⁾, it is suggested that the Humbercare scheme resulted in a significant reduction in flooding protection in Hull, especially so in West Hull catchment. However, as explained in Chapter 5 of this report, this deterioration in flooding protection may be somewhat misleading. This is because the Humbercare predictions include higher future flows, a 2015 planning horizon and no pumping from West and East Hull Pumping Stations. This was not the case on the 25th June 2007.

Nevertheless, the predicted areas of flooding, as illustrated on the maps in the appendices of the above mentioned report ⁽¹⁰⁾ show a similarity with some of the areas that flooded. This does not necessarily mean that the Humbercare scheme is the reason for, or contributed to, the severity of flooding. It may be that other factors such as the low lying ground, local sewer capacity issues and land drainage inputs are significant. However the impact of changes inherent in the Humbercare scheme (the initial scheme plus the subsequent modifications prior to June 2007) should be explained by Yorkshire Water.

Further modelling would be necessary to more accurately compare the predicted flooding with the areas that flooded on the 25th June, for example, as suggested in Section 5.2.6 of this report.

The unavailability of all the recently restored pumping capacity at West Hull Pumping Station will have impacted upon the ability to remove flow from the sewer system. However, as explained in Section 7.6 of this report, it is uncertain if Yorkshire Water had intended all 20m³/s capacity to be available at all times or whether this capacity included some redundancy for maintenance downtime.

9.7 **Summary**

There are many factors that contributed to the 25th June 2007 floods. The combination of exceptional rainfall falling onto what was probably saturated ground with a very high water table is the main reason. No amount of drainage improvements will have been sufficient to avoid much of that flooding.

The 'special' aspects of the Hull drainage system will not have helped during such a very heavy and prolonged storm. In particular:

- Land drainage and watercourse inputs into the piped sewer system will have been a significant reason for the sewers becoming full in some areas.
- Overland flows from outlying rural areas and higher ground may have contributed to some of the problems on the urban fringes.

Issues with blocked gullies and/or local drainage capacity issues may well have caused some of the more isolated and local area flooding. These problems may well have been an additional factor in the main areas of flooding.

Performance issues were identified with the Humbercare scheme in 2004 and actions were being and had been taken to mitigate these problems when the 25th June 2007 storm occurred. It is uncertain how significant these issues will have been in contributing to the flooding because much of the modelling work provided either looks at a future scenario situation and/or does not take into account the post Humbercare improvements already in place. Yorkshire Water should clarify their view of the level of service delivered on 25th June.

10. BRANSHOLME/KINGSWOOD CATCHMENT

10.1 Introduction

The Bransholme/Kingswood catchment is hydraulically isolated from the remainder of the Hull sewer system. This is because both the surface water (SW) and foul water (FW) drainage systems terminate at local pumping stations. The surface water flows are pumped up to the River Hull and the foul water flows are pumped up into the East Hull sewer catchment.

Local flooding occurred in the Bransholme/Kingswood catchment on the 25th/26th June 2007. Given the hydraulically 'isolated' nature of the catchment, any drainage related shortcomings would have been associated with 'local' issues, not the Humbercare scheme.

The foul pumping station worked continuously throughout the flooding and the following days with no reported problems. The surface water pumping station worked continuously on the 25th June but succumbed to thrust bearing failure when it became inundated on the 26th June.

10.2 The catchment

The Bransholme development commenced in the 1950s and is on very low lying land. Unlike the remainder of Hull, drainage is to separate surface water and foul systems. The foul system originally terminated at a sewage treatment works, this was closed in recent years and flows are now transferred, via a new pumping station, to the East Hull sewer catchment.

The surface water pumping station was constructed in the 1950s and has continued to operate since then. Yorkshire Water state that some upgrading has taken place in recent years.

The catchment is still being developed, in particular the Kingswood area to the north of the original Bransholme development. This will generate additional surface water and foul flows which, eventually, will require additional pumping capacity.

With regard to the flooding, the main issues appear to be:

- 1) The reliability of the surface water pumping station
- 2) The capacity required at the surface water pumping station.

These issues are examined in the remainder of this chapter.

10.3 Performance issues at the surface water pumping station

10.3.1 IRB comments

The IRB state ⁽³⁾ that Yorkshire Water were warned as long ago as 1996 about the poor condition of the pumping station and, had the recommendations of the 1996 report been actioned, the "*Bransholme flooding would have been less serious*".

The IRB concerns regarding M&E serviceability ⁽³⁾ may have been fed by a number of 'loose' comments in various engineering reports/documents. Taken out of context these could be somewhat alarming and suggest that the M&E equipment was in poor condition.

10.3.2 1996 recommendations

Yorkshire Water, in their reply (pages 22 to 24) to the IRB Final Report ⁽⁵⁾, refer to 8 recommendations and state that:

- 4 have been actioned.
- 3 are no longer required (other events have taken place, resulting in their need no longer being necessary).
- 1 not carried out, due to technical difficulties.

The 1996 report ⁽²⁰⁾ refers to:

2.9 Surface water system recommendations.

2.9.1 Reinstatement level sensing equipment

2.9.2 Option B – A second pumping station, to take the proposed Kingswood development.

2.9.3 Review of existing pumping station, to determine:

- Actual discharge capacity;
- Reliability of M&E equipment; and
- Structural integrity of building.

2.9.4 Monitor progress of proposal to construct a barrage to make River Hull navigable.

3.10 Foul water system recommendations.

3.10.1 Provide actuated penstock on Kingswood system upstream of new connection point.

3.10.2 Provide storm storage at Bransholme sewage treatment works.

Yorkshire Water, in their response ⁽⁵⁾ explain that:

- Recommendation 2.9.1 has been actioned.
- Recommendation 2.9.2 has been superseded – Option B has been abandoned in favour of redeveloping the existing pumping station by reconfiguring the wet well and replacing the pumps with pumps of greater capacity.
- Recommendation 2.9.3 (first bullet point - actual discharge capacity) has not been possible for technical reasons. However, Yorkshire water state that they have subsequently confirmed the capacity as 5.4 m³/s through the use of pump discharge curves. For the avoidance of doubt it would be useful for Yorkshire Water to make this information available.
- Recommendation 2.9.3 (second bullet point -reliability of M&E equipment). Yorkshire Water explain that they are undertaking a programme of pump refurbishment.

- Recommendation 2.9.3 (third bullet point - structural integrity of building). Yorkshire Water state in September 2001 that they re-clad the building.
- Recommendation 2.9.4 – monitor proposals for River Hull. This is being done in conjunction with the other stakeholders.
- Recommendations 3.10.1 and 3.10.2. These have been superseded by the closure of the sewage treatment works and transfer, via a new pumping station, of raw sewage to the main Hull system.

It may be that, for the avoidance of doubt, a more detailed explanation needs to be given by Yorkshire Water of their actions to the IRB.

Also, in the September 2001 Arup Workshop Brief ⁽²¹⁾ and October 2001 Brown and Root Project Review reports ⁽²²⁾ it is explained that the previous recommendation for constructing a new pumping station (to take the proposed development areas in Kingwood) is replaced by a preference to redevelop the existing surface water pumping station by re-configuring the wet well and replacing the existing pumps. This approach has the advantage of both satisfying the additional pumping demand and addressing the issues identified in recommendation 2.9.3 of the 1996 report.

In the November 2007 Arup report ⁽⁷⁾ it is stated that the Bransholme Foul Water Pumping Station, which was built in the late 1990s, was refurbished early in 2007. This refurbishment included the replacement of all the pumps and would be in line with good practice for the maintenance/refurbishment of small foul pumping stations.

10.3.3 Pumping station maintenance

Yorkshire Water make the point, in their response to one of the IRB comments (page 23) ⁽⁵⁾, that the number of reactive visits to the pumping station was not excessive when compared with the number of planned visits. It is understood that, between 2001 and 2007 (exact dates not known), there were 95 maintenance jobs, 61 of these were planned cyclical work and 54 were of a reactive nature.

It should be noted that the above two classifications do not add up to 95 (61 plus 54 is 119).. However, assuming the number of reactive visits is correct, this suggests that about half the visits are reactive (just under one per month).

This level of reactive visits would not appear to be excessive and is in line with a pumping station that is reasonably well maintained. However, it would be beneficial to see a detailed breakdown of the visit log to confirm (or otherwise) this view. It would also be useful to see details of telemetry alarms and subsequent actions, to see how many of these alarms were related to heavy rainfall and how many were associated with M&E serviceability issues.

10.4 Perceived need for a larger pumping station

The IRB, in their Final Report ⁽³⁾ (Sections 5.2.1 to 5.2.3) make reference to the 1996 and 2001 reports and various pumping capacities. However, these references to the capacity required to service the whole Kingswood development once constructed, not the situation as in June 2007.

There are also suggestions in the IRB report ⁽³⁾ that the pumping capacity should be in excess of actual 5.4 m³/s. This may be based upon confusion between:

a) Future pumping capacity (once the Kingswood area is developed) and the situation as in June 2007.

and

b) The **total installed capacity** and **capacity of the pumping station**, which are not the same, (see Section 2.2.3 of this report for an explanation). It is normal and good practice to install pumps that, in total, have a greater capacity than the rising main receiving the flows. This is because a degree of redundancy is often built into a pumping station, thereby allowing a pump(s) to be out of commission (being serviced etc) whilst not reducing the capacity required for pumping.

Therefore many of the comments made by the IRB may be based on incorrect assumptions. Yorkshire Water explain these issues in some detail in their Initial Review of the IRB Report ⁽⁵⁾. However, for the avoidance of further misunderstandings, it would be useful if Yorkshire Water could collate these different pump capacity requirements, as referred to in the 1996 and 2001 reports, into a simple short report and table. Furthermore, it would be helpful if Yorkshire Water could explain what capacity was/is required, both as of June 2007 and at the various stages in the future development of Kingswood.

10.5 Yorkshire Water's response on the 25th/26th June 2007

It is understood that the surface water pumps worked continuously throughout the 25th June and failed on the morning of the 26th, when the thrust bearings ceased. The bearings failed because the station had become inundated with flood water, thus the bearings could no longer be accessed for maintenance ^(5, 7). This is not a normal M&E failure; it was caused by a combination of the pumps running continuously and not being able to be serviced due to the flooding.

Yorkshire Water comment that it is the first time in 50 years that this failure has occurred at the station. It is understood (YW initial review to IRB report, page 30) ⁽⁵⁾ that work is now being carried out to protect the thrust bearings from water ingress.

Yorkshire Water, in a reply to OFWAT, state the failure of the surface water pumps did not cause the flooding – It was the inundation with flood water that caused the pumps to fail. Yorkshire Water admit that the failure reduced the ability to pump away the excess surface water, at least until replacement pumps could be brought to site 12 hours later. The IRB, on the other hand, suggest that the failure did contribute to the flooding. We have not seen any evidence to support this view, though there may be information that has not been brought to our attention.

10.6 Contingency plans

The IRB state in both their Interim ⁽¹⁾ and Final Reports ⁽³⁾ that there was no contingency plan for Bransholme, should the M&E equipment fail.

Yorkshire Water disagrees with the IRB and, in a letter to OFWAT dated 6 November 2007, clearly state that there is a contingency plan. Furthermore, this involves the hire of standby pumps and generators from contractors. Yorkshire Water, in their Initial Review of the IRB Final Report ⁽⁵⁾, explain that the delay on the 26th June was caused by the contractors pumps already been used at the emergency at Ulley. This emergency had been elevated to Gold Command status and, in doing so, had a greater priority than the Hull flooding, which was a

Silver Command status. Yorkshire Water state that alternative pumps were sourced and pumping commenced 12 hours after the bearing failure.

We would expect all pumping stations to have a contingency plan and for this to be available on the company intranet/operations system. For the avoidance of doubt, it would be helpful if Yorkshire Water provide a copy of the generic plan together with a plan giving specific details for the Bransholme Surface Water Pumping Station. These specific details should include the number of pumps, pump sizes (volume), pumping heads, hose sizes, coupling details, power supply/sockets, access to the compound, key holders etc.

10.7 What contributed to the catchment flooding

10.7.1 Ability of the catchment to accept heavy rainfall

The Bransholme development, which commenced in the mid 1950s, is sited on very low-lying land. There are very few natural watercourses remaining. Most surface water drainage is via the piped system; this terminates at the pumping station, which pumps flows up to the River Hull. The catchment would therefore be more susceptible to flooding than most in the event of extremely heavy rainfall.

Yorkshire Water, in the various reports explain that the surface water drainage is designed to cope with a 30-year storm. This 30-year requirement comes from a publication called Sewers for Adoption. The document is primarily aimed at developers; sewerage undertakers (including Yorkshire Water) commonly use the standard for surface water/combined drainage systems.

Reference to the ability of the existing Bransholme catchment and future Bransholme/Kingswood catchments to accept storm runoff is made in the 1996 Ouse Technical Unit ⁽²⁰⁾ and 2001 reports ^(21,22). The critical storm duration is between 45 minutes and 90 minutes depending upon the storm profile and time of year – 45 minutes for a summer event and 90 minutes for a winter event. Some flooding is predicted in the existing catchment in a 30-year event; however, this is relatively minor and is unlikely to cause serious or widespread flooding.

Given the susceptibility of the catchment to flooding, and the almost lack of natural gravity watercourse drainage, it is debatable if a 30 year standard is sufficient. This is a national issue and should be addressed as such. It will be necessary to involve all stakeholders in such a debate; these include the Environment Agency (normally responsible for watercourses) and the local authority (responsible for highway drainage).

It is encouraging to see that both Yorkshire Water and the IRB recognise the somewhat special surface water/watercourse/land drainage issues in Hull and are supporting a more integrated approach to addressing the issues.

10.7.2 25th June rainfall

110 mm of rainfall was recorded at the University on the 25th June ⁽¹⁾. This was an extremely large volume of rainfall and has been quoted as being between a 1 in 144 and 1 in 200 year event in the various reports supplied. The actual return period is somewhat academic, what is important is the extreme nature of the rainfall.

It is also worth bearing in mind that the rainfall was of a far longer duration than the critical 45 or 90 minutes considered in the modelling, as discussed in the 1996 ⁽²⁰⁾ and 2001 ^(21,22) reports. Given the limited amount of information that we have been able to examine, and the

influence of a saturated catchment on runoff, we are unable to comment on the likely influence of this longer duration event on the increased likelihood (or not) of flooding.

Heavy rainfall occurred earlier in June, in particular during a heavy storm on the 15th June. This would have had the effect of saturating the ground, making the runoff from the 25th rainfall that much greater than would otherwise have been the case. Thus, whilst the 25th June storm may have been an event of between once in 144 and once in 200 years, the ground conditions (i.e. saturated nature) were also somewhat extreme. The combination of these factors would have made the reaction to the storm, in terms of runoff from unpaved areas, extremely rare in terms of return period.

With the above factors in mind it is not surprising that flooding occurred in such a low lying and susceptible catchment. Given that the pump failure did not occur until some 12 hours after the main rainfall had ceased and the relatively compact nature of the catchment, it is likely that the vast majority of flooding would already have occurred before the pumps failed. However, we have not seen any information regarding the extent and times of property flooding in the catchment. Such information, if it exists, would be helpful in determining the effect that the pump failure had on the flooding.

10.7.3 Land drainage and illicit connections

The unusual Hull situation

The Hull catchment is different to most urban drainage catchments because the surface water pipe drainage system is, to a large extent, the only surface water drainage system.

In most urban catchments the piped surface water system would be expected to take runoff from paved areas such as roads, roofs etc. It would not, however, be expected to take extensive land drainage systems, watercourses etc. Furthermore, when the piped system becomes full, excess water would be expected to find its own way to natural watercourses and, in doing so, limit the flooding caused by the piped system being overwhelmed. In Hull there are very few natural watercourses, the first and second lines of defence are both the piped drainage system.

Bransholme Surface Water System

Whilst the Bransholme surface water system is relatively modern, the special circumstances mentioned above are likely to result in some land drainage being connected to the surface water system. However, it is unclear from the 1996⁽²⁰⁾ and 2001^(21, 22) reports just how much allowance was made for these connections in the hydraulic modelling. There are two issues in particular:

- Mention is made in the 1996 OTU report⁽²⁰⁾ of Engine Drain being connected to the piped system and the benefits of this in shorter duration storms because it can be used as surcharge relief. However, it is uncertain what influence the Engine Drain would have on the piped system in the event of a very heavy and long duration storm, such as that of the 25th June 2007. This is an issue that needs to be investigated.
- The IRB interim report⁽¹⁾ mentions opening up watercourses and linking these to the Holderness Drain.

Reference is made in the 1996 OTU report⁽²⁰⁾ (Section 3.6) to a 1993 report in which infiltration arose from land drains. Also, reference is made to a 1994 ERTU report, which mentions some infiltration coming from wrongly connected land drains.

Thus, the implication is that some land drains have been culverted and linked to the piped drainage system. If this is the case these systems could have a significant impact on the piped drainage system in a heavy prolonged storm, especially when the ground was saturated, such as on the 25th June 2007. The existence, or not, of these piped watercourses requires further investigation.

Bransholme Foul System

Section 3 of the 1996 OTU report ⁽²⁰⁾ refers to the foul system suffering significant ingress during rainfall events. Parts of the Capstan Road and Wawne village sub catchments are known to be combined and other areas are thought to have wrongly connected land drainage, cross-connected paved areas and minor infiltration. It is suggested that the cross connections are from a few properties throughout the catchment and not worthy of investigating because elimination of this flow is impractical.

Given that the foul pumping station continued working throughout the 26th June flooding and the main problem was caused by surface water, chasing the majority of this extraneous water may be of a low priority. One exception may be connected land drainage, which during periods of long rainfall/saturated ground, could add significantly to the flows in the foul system.

11. CONCLUSIONS AND OUTSTANDING QUESTIONS

The issues surrounding the June flooding have been reviewed, in particular the following key questions:

- 1) Was the initial Humbercare design robust?

It is clear that the original initial Humbercare scheme commissioned in 2001 did not deliver the level of service expected (in terms of flood protection). It is also clear that Yorkshire Water subsequently carried out works to address this, though uncertainty remains around the level of service provided in June 2007.

- 2) Is the 1:30 year flooding standard appropriate for Hull/Humbercare urban drainage system?

It is our opinion that a 1 in 30 year standard is not appropriate for the Hull catchment.

- 3) Following commissioning of Humbercare, and the emergence of performance issues, was Yorkshire Water's response timely and robust enough?

It is uncertain if Yorkshire water's response was timely and robust. Yorkshire Water should take actions to demonstrate the adequacy of their response in the light of the the 2007 floods.

- 4) Do operational problems inhibit the performance of the system as operated on the 25th June 2007?

Operational problems make the system difficult to operate. However, it is uncertain if the operational problems inhibit the performance of the system. There is a need for Yorkshire Water to demonstrate how they will handle operational issues in future.

Additionally, other relevant sewerage related issues raised by the IRB have been considered.

The review took the form of an investigation based upon already available documentation/information. Some of this was produced as a direct result of the June 2007 flooding, other information pre-dates the flooding and was essential background reading. It came from the following sources:

- The documentation that Yorkshire Water provided to the IRB before the publication of their final report;
- The IRB's Interim and Final Reports;
- Yorkshire Water's Initial Response to the IRB Final Report, dated 21st November 2007; and
- Yorkshire Water's Initial Review to the IRB Final Report, dated 17th December 2007.

It is our opinion that some of the concerns raised are due to misunderstandings or a lack of obvious/relevant information.

An example of this would be the difference between the pumping capacity available at Bransholme Pumping Station in June 2007 and the capacity suggested in a number of engineering/consultants reports. The reports refer to future requirements once the Kingswood area has been developed, not the capacity required in June 2007. This reference to a 'future' flow is not necessarily clear and may have been the source of some confusion.

However, there are a number of concerns raised by the IRB that cannot simply be explained as a misunderstanding. Many of these are complex and have their roots in actions that were taken many years ago. An example was the decision to fill in or culvert many of the open watercourses and drainage systems, this may have reduced flood storage capacity if lagoons/swales were not constructed to compensate for the reduction in flood storage.

Whilst considerable information has been made available to this review, much of the relevant information is spread between various reports provided by Yorkshire Water and the connection between this information is not necessarily obvious or easy to follow. A number of specific issues have been detailed in this report where explanations from Yorkshire Water may deal with these concerns.

There remains a need for Yorkshire Water to provide explanations for its response to the concerns raised by the IRB.

REFERENCES

- 1) The June 2007 Floods in Hull. Interim Report by the IRB, 24th August 2007.
- 2) Professor David Crichton. "The Hull floods of June 2007. Some insurance industry implications". (www.benfieldhrc.org/floods/Chrichton_Hull_2007.pdf).
- 3) The June 2007 Floods in Hull. Final Report by the IRB, 21st November 2007.
- 4) Yorkshire Water. Initial Response to the IRB Final Report, 21st November 2007.
- 5) Yorkshire Water. Initial Review of the IRB Final Report, 17th December 2007.
- 6) Yorkshire Water. Hull Maintenance Scheme, Feasibility Study to Investigate Increased Flooding Risks, Issue 1. Ove Arup & Partners Ltd, January 2006.
- 7) Yorkshire Water. June Floods in Hull and Haltemprice. Ove Arup & Partners Ltd, November 2007.
- 8) Yorkshire Water. Hull Catchment Modelling Report. Ove Arup & Partners and MWH, January 2006.
- 9) Yorkshire Water. Hull UWWTD Capital scheme PF 940. Re-examination of Flow Transfer Options, 20th March 1997.
- 10) Yorkshire Water Services. West Hull SPS, Options Report. MWH, October 2004.
- 11) Yorkshire Water, A4435 – Hull West PS – Executive Summary of MWH Findings. (Not dated).
- 12) WaPUG/WRc. Code of Practice for the Hydraulic Modelling of Sewer Systems. First Edition, November 1993. ISBN 0 902156 92 6.
- 13) WRc. Guide to Short Term Flow Surveys of Sewer Systems, 1987.
- 14) WRc. Sewerage Rehabilitation Manual, 1st Edition, 1983.
- 15) BSi. BS 8005: Part 1, 1987. Sewerage, Part 1. Guide to new sewerage construction.
- 16) BSi. BS EN 752-4: 1997. Drain and Sewer Systems Outside Buildings. Part 4, Hydraulic Design and Environmental Considerations.
- 17) Water Services Association. Sewers for Adoption, 4th edition, May 1995. ISBN 1 8989920 02 8.
- 18) Water UK/WRc. Sewers for Adoption, 5th edition, July 2001. ISBN 1 898920 43 5.
- 19) Yorkshire Water. Report of public meeting/meeting with councillors, 22 April, 2004.

- 20) Yorkshire Water, Ouse Technical Unit. Kingswood Development Hull, Sewer Requisition. June 1996.
- 21) Yorkshire Water. Kingswood Sewer Requisition, Pumping Station, Notional to Outline Study 4. Ove Arup & Partners Ltd. September 2001.
- 22) Kingswood Developments, Surface Water Requisition. Brown and Root/Scott Wilson. October, 2001.