PAPER 10

1 an 2-d Modelling for the Afon Adda Flood Alleviation Scheme

Presented by

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Modelling of the Afon Adda, Bangor

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1 Introduction

The city of Bangor is situated on the North coast of Wales, in Gwynedd, on the southern edge of the Menai Straits (NGR SH576720) as shown in Figure 1.1. It occupies the floodplain of the Afon Adda, a culverted watercourse running from south west to north east for approximately 4km and outfalling into Bangor Harbour at SH586729. Over the last 250 years the watercourse has been gradually culverted in order to facilitate the development of the city. It now conveys storm drainage from urban areas together with two rural inflows that join the right bank close to the upstream end.

The gradual and unplanned confinement of the Afon Adda into a culvert has resulted in a system of a variety of sizes and materials and often of inadequate capacity. As a consequence of this and a steady accumulation of silt over time, parts of Bangor have become prone to flooding, which has been recorded at various locations from 1957 to the current day. In addition, many parts of the culvert were in a poor structural condition, which increased the likelihood of a collapse in the future. As a result, over 400 residential and other properties were at risk of flooding.

In 2004 Halcrow were appointed by the Environment Agency to develop a flood alleviation scheme to protect the city of Bangor against flooding from the Afon Adda. The scheme completed in 2008 comprised the following elements:

- Replacement/refurbishment of large sections of the 4km length of the Afon Adda culvert to improve the level of protection against flooding up to a 1 in 100 year event, and restore the culvert to an acceptable structural condition.
- The construction of a flood storage area, upstream of the main Rural Inflow.
- Upsizing of the two piped sections conveying the two rural inflows to join the main Adda culvert.
- The installation of debris screens and silt traps at both rural inflow inlets to reduce the risk of future blockages.

This £9m scheme was constructed over a three year period, divided into three distinct phases. Some changes in pipe diameter, alignment and method of construction occurred during the detail design phase of the project as new information was obtained, which was incorporated into the hydraulic model. However, the main elements of the scheme remained unchanged.

The aim of this paper is to describe the methodology and the criteria followed in the hydraulic modelling used in the design of the flood alleviation scheme. .

2 Catchment Description

The Afon Adda is a culverted main watercourse (designated as Main River) conveying two rural inflows together with storm drainage from urban areas. It commences at an elevation of 41.59m AOD near Penrhos Garnedd and discharges into Bangor Harbour at a height of approximately 5.73m AOD. The Afon Adda has a small elongated catchment running in a north-easterly direction parallel to the coast, with an estimated area of 3.36km^2, of which 1.0km^2 comprises the two rural inflows.

The only parts of the catchment that are undeveloped are the two rural inflows to the south of the watercourse. The rest is fully developed, the most recent being the Tesco's superstore at the head of the catchment. The steep-sided valley is now occupied by a mixture of newer retail developments, residential areas and Bangor town centre. The course of the Afon Adda is described in the following sections.

Although the Afon Adda has been completely culverted, it is still possible to locate the former line of the watercourse by the mature trees and vegetation along its length, particularly in its lower lengths prior to discharging into the harbour. This latter area remained an open watercourse until approximately 50 years ago, when it was culverted to prevent flooding problems in the adjacent housing areas. The rest of the watercourse had been culverted in a piecemeal way over the previous hundred years, which has resulted in the extremely variable nature of culvert size and material in existence today.

3 Data Collection

The previous modelling completed by JBA in 2000 was based on a hydraulic model built with the WALLRUS sewer modelling software which dates from 1989 and is now obsolete. However the manhole numbering scheme, and the data assigned to each manhole was retained for use in developing an up-to-date model using the Infoworks software.

Further data was obtained from the existing Welsh Water sewer records, which provided some information on manhole locations and catchment areas draining to the culvert. However information from this source was limited.

Only limited information was available on culvert condition, consisting of some Closed Circuit Television (CCTV) information and a historic inspection report. However some improvement work had been undertaken since then which made accurate assessment of the present day internal condition difficult.

In order to remedy the data deficiencies identified above, the following information was obtained:

- Updated CCTV and walk through inspections
- Flow survey information
- Topographic survey

The available information regarding the location and condition of the culvert was initially scarce. In order to obtain an understanding of the structural condition of the Afon Adda culvert, Halcrow had to procure a Close Circuit Television (CCTV) survey of the culvert. The CCTV survey was commenced in March 2004 but problems were encountered due to the presence of silt and debris. The CCTV survey progressed until the end of August 2004, at which time four sections of culvert remained unsurveyed.

Only limited information was available about the areas which contributed to the flow of the Afon Adda. Therefore a flow monitoring survey was carried out by Enviromontel Ltd to help assess the areas draining into the culvert. Although this is a standard technique used to calibrate sewer models which has been developed and refined over the past twenty five years, it was very unusual to utilise such a survey on Environment Agency projects.

Three rain gauges and a total of ten flow monitors situated at strategic locations throughout the culvert were commissioned. Flow and level was recorded on the Afon Adda for a period of 6 weeks from 23rd September 2004 to 2nd November 2004. Ideally up to five events should be used to calibrate a model, but due to the short period of record only two events were suitable for the rural flows. For the urban catchment where flows are higher, other events were able to be used to calibrate the urban model as described in Section 5. Three rain gauges were also installed in the catchment, the nearest rain gauge to each rural inflow being used for the calibration exercise.

Topographical surveys to supplement existing information were undertaken at various stages during the planning and design phases. However a specific survey was carried out in April 2004 to determine thresholds levels of properties considered to be at risk of flooding. These levels, in conjunction with the LIDAR data were then used for the cost/benefit appraisal.

4 Hydrological Analysis

The flow survey undertaken in 2004 comfirmed that a significant proportion of the flow in the Afon Adda came from two rural inflows on the right bank of the culvert. However, the survey also revealed many connections from urban areas along the length of the culvert.

Whilst the rural contributions were accounted for in the form of flow hydrographs applied on the right bank of the Afon Adda, the urban contribution was accounted for by defining the areas of the urban sub-catchments draining into the culvert. A design rainfall was then applied to the Infoworks model.

The short data record inhibited full event analysis to be carried out to improve estimates of Time to Peak (Tp) and Standard Percentage Runoff (SPR) values. Catchment descriptor values extracted from the CDROM were therefore used to define the shape and peak of the design hydrographs for the rural areas. However information from the two most upstream flow monitors enabled the rural catchment areas to be verified

Following calibration, the FEH boundaries are used for the design flood events. A critical storm duration was derived by running the boundaries for a 100 year event with a variety of durations. The duration generating the highest peak is then adopted for the design runs. The critical storm duration for both boundaries is 1.25 hours.

The methodology used to determine the design rainfall events for the urban inflows is as described in details on page 35 of *The Wallingford Procedure*, Volume 1. This is the standard method incorporated within Infoworks to generate a representative rainfall event for any location in the UK from and for any duration and return period.

The areas of the urban catchments were estimated during the calibration process of the whole Infoworks model (see Section 5), where notional sub-catchments were added to side connections until measured and modelled flow agreed at a particular gauge station.

5 Hydraulic Modelling

The Infoworks model representing the original network has been derived from the model built by JBA with the modelling software package WALLRUS Version 1.1 Once transferred into Infoworks CS (Version 6.0), the model of the original network was thoroughly revised in the light of the culvert survey undertaken in 2004 and calibrated on the basis of the flow survey of the same year.

Where data was missing, for instance due to manholes being buried or otherwise inaccessible, linear interpolation was used to create estimates of invert and ground level. Where different surveys were contradictory, the most recent information was used in the model and where data from within the same survey was inconsistent, the more conservative option was carried forward.

The two rural inflows draining into the culvert from the south are thought to constitute the majority of the flow entering via the culvert. However, the recent survey revealed many connections along the length of the culvert and although the source of a small number of these has been established from Welsh Water records, the majority remain unidentified. Therefore information from the flow survey was used in an attempt to verify the extent of the connected areas.

This period of flow survey included six storm events, which fulfilled the survey criteria and a period of dry weather flow. Of these six events, the first four were chosen for the purposes of calibration since the magnitude of flow during the fifth event caused irreparable damage to many of the flow monitors.

Site visits revealed important details about the areas where the two streams enter the culvert system. In high flow situations it is clear that most of the flow would bypass the existing inlet structures and flow overland. When applying the hydrographs, representing the two streams, in the calibration process this was taken into account by applying a condition whereby any water unable to enter each inlet is lost from the model. A blockage was also applied to the inlet pipes, since a significant amount of debris was seen to be entering them.

The calibration process was undertaken in the downstream direction, where sub-catchments were added to side connections until measured and modelled flow agreed at the gauge in question. These sub-catchments were identified from Welsh Water records as areas without storm drainage connections to the main combined sewer system. These sub-catchments were therefore drawn, where possible, to coincide with gaps in the provision of surface water drainage as shown on the Welsh Water records.

Provision was made within the model to take account of infiltration from soil and groundwater into the culvert. This was achieved by applying constant inflows at three points along the length of the culvert, representing the accumulation of flow which in reality enters the culvert diffusely. These base flows were derived from the flow survey records of dry weather flow.

In summary, the comparison of modelled and gauged flows in the main culvert suggested that whilst the model tends to over-predict peak flows, the response of the model is a reasonable representation of that of the real catchment and this over-prediction can be considered as giving a degree of conservatism to any culvert designs based around the modelled flood scenarios

The hydrological boundaries applied to the Infoworks model were:

- 1 in 100 year event plus climate change rainfall event (to take into account the urban contribution).
- Two hydrographs representing the rural inflows generated by the design event
- Three constant inflows at points along the length of the culvert to represent infiltration from ground water.

A tidal boundary was assessed using a harmonic (astronomical) tidal time series for Menai Bridge, calculated using tidal prediction software for a period encompassing Mean Spring Tide, where high water approximately coincided with Mean High Water Spring (MHWS).

In accordance with the UK Climate Impacts Programme 2002 (UKCIP02), the effects that the climate changes would have over a 50 year period were accounted for during the hydraulic modelling by increasing the inflows and the rainfall intensities by 20%.

To properly assess the benefits of the proposed scheme it was necessary to represent overland flow occurring as a result of flooding from the system, and in particular the scenario assuming the culvert blockage or collapse. Therefore, a dynamically linked 2D/1D hydrodynamic model using TUFLOW was constructed for the entire catchment of Afon Adda from its upstream source to its outfall to the Harbour using filtered LIDAR data for the ground model. Overland flow was represented by the 2D model, and culverted flow was represented by the 1D model.

The multiple domain facility of TUFLOW was used to build the present 2D model. As such the model was built on two domains: one in the South Western side (South domain) and the other in the North-Eastern side (North domain) of the railway stations. Each domain was aligned in a way that it follows the culvert alignment and the street network, and as result it provided benefit of having minimum active computational cells, and thus savings on model run time. It also provided benefits on pre and post processing of data and model results.

The dimension of the South domain is 2000m along and 540m across the culvert. The dimension of the North domain is 1770m along, and 850m across the culvert. Both domains were built on 2m cell size.

The Adda culvert was represented by 1D model using ESTRY, a component of the TUFLOW software. Data from the Infoworks model was used as the basis of this ESTRY 1D model and the culvert has mostly been represented by circular type, with a few of rectangular type. The length of the culvert represented by the ESTRY model is 4146m. Boundary conditions are as taken from the Infoworks model.

Roughness in both the 1D and 2D model was represented using Manning's n value. All objects offering resistance to flow have been digitised to represent the roughness more accurately. Table 5.3 shows the range of roughness values used to calibrate the 2D/1D model. The culvert network has a range of roughness values depending on the condition of the culvert which ranged form 0.15 to 3.0

6 Model Results

The Infoworks model of the existing watercourse described in Section 5 was used to assess the capacity of the system and the associated standard of service. The sections with the lowest standard of service were the lengths of pipe conveying flows from the two rural inflows. The capacity of the Rural Inflow one outflow pipe was estimated being exceeded during a 1 in 5 year return period event, whilst flooding commenced from Rural Inflow two during a 1 in 2 year return period event.

In this situation, where most of the flow from the two rural catchments bypassed the culvert completely, the hydraulic modelling showed that the main culvert did not flood until the 1 in 75 year return period event. However, if the rural inflows were modified to allow all of the inflows to enter the main culvert, this caused the main culvert to flood at a return period between 1 in 10 and 1 in 25 years.

The 1D/2D model was important to assess the future situation whereby a lack of maintenance or repairs to the culvert would cause collapse or blockages. This showed the 469 properties (422 residential properties and 7 other properties) would have been at risk of flooding from a rainfall event with a return period of 1% (1 in 100) chance of occurring in any given year. For a 0.5% (1 in 200) chance of occurring in any given year event 426 residential properties and 49 other properties would have been at risk of flooding. The extent of flooding resulting from culvert collapse would have varied depending on the location of the collapse, the flows in the culvert at the time of collapse and the time taken for repair works to be completed.

The works undertaken within the Afon Adda Flood Alleviation Scheme have increased the standard of protection both along the main culvert and the two rural inflows to a 1% (1 in 100 years) chance of flooding. This will improve the level of service from fluvial flooding for a total of some 110 residential and commercial properties. The scheme has been designed so that further works can be incorporated at two locations to fully account for future climate change.

7 Conclusions and Recommendations

- The Afon Adda Flood Alleviation Scheme has been completed to provide protection to a 1 in 100 year (1%) level of service throughout the length of the catchment.
- Use of the Infoworks software was invaluable to correctly represent the performance of the culverted watercourse.
- Traditional sewer flow surveys can provide improved accuracy to models of EA watercourses that are largely underground.
- ESRY and TUFLOW provide an accurate means of assessing overland flow and flood depths for culverted watercourses such as the Afon Adda.
- Use of these techniques are therefore recommended for study of similar watercourses elsewhere.

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