Effects of flood plain management on river hydraulics – a case study

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Abstract

Anthropogenic activities on rivers and flood plains can have significant impacts on the subsequent responses of the river to various flood events. Historically, many developments were carried out across rivers and along flood plains without regard to consideration of potential changes to the river – flood plain system. In some instances these developments have had positive impacts, such as improved flood control when a dam was employed to impound water. However, in other cases developments have led to increased and unplanned flooding. This paper presents details of a case study which considers the impacts of siting an unplanned landfill on the floodplain of a river. In particular, the paper presents results of a hydraulic model study, using DAMBRK, that was carried out to assess the impacts on the river hydraulics due to the development on the flood plain. A discussion of the results follows.

Introduction

The main waste disposal facility for County Clare, Ireland, is located at the Doora refuse tip. This landfill is sited on the floodplain of the lower Fergus River southeast of the town of Ennis, see Figure 1. These waste disposal activities have been continuing since the late 1960’s and occupy approximately 30ha of the floodplain. In 1943 the Irish Government passed an act of Dail Eireann entitled ‘District of Fergus Drainage Act, 1943’, as part of this Act it is stated that the land on which landfill is located ‘... shall form part of the
drainage works of the Fergus District and may be used by the Councils as an overflow reservoir or for any other purposes connected with the working or maintenance of the said drainage works'. In order to ensure protection against flooding the Act specified that '... the most suitable means of effecting this solution is ... To abandon the area north of the Ennis-Quinn road on the east bank ... thereby providing a reservoir for the flood waters.' The landfill was sited in the land mentioned in Act and hence has implications for flood control along the Fergus River. The waste disposal activities have reduced the volume of storage available for flood waters and the position of the landfill has
significantly reduced ease of access of flood waters to the storage area. Such activities have raised the water levels in the flood plain but, more importantly, as a result of the restricted access caused an increase in water levels in the channel of the Fergus River itself increasing the risk for further problems elsewhere along the river.

The study of the Fergus River which was carried out by the authors considered a number of different aspects of the river - flood plain systems. This paper is concerned primarily with the application of DAMBRK to consider the impacts on water levels in the River due to management decisions to reduce flood plain storage during the years 1982 – 1997 as described in the next section.

Description of the downstream river channel and flood plain

The river valley downstream of Ennis Bridge to the tidal sluice gates at Clarecastle Barrage, Figure 1, is approximately five kilometres long. A single tributary, the Gaurus River, flows into the Fergus along this stretch just north of the landfill site at Doora. No flow records for the Gaurus exist and since its catchment area of 64 km² is relatively small compared to the Fergus catchment of 684 km², its contribution to the total flow in the Fergus has been assumed to be negligible for the purposes of this study.

There are four bridges over the river along the reach under study: Ennis Bridge in the town which forms the upstream boundary of the model, Clonroad Bridge just outside the town, a rail bridge approximately 250 metres further downstream, Doora Bridge adjacent to the landfill site and the Fergus rail bridge approximately 600 metres upstream of Clarecastle Barrage. All bridges are either single or double span bridges and as such do not provide significant constriction of the flow.

For the first 800 metres of the channel downstream of Ennis Bridge the river is contained by vertical walls as it flows through the centre of the town and the surrounding urban area. Further downstream the channel is relatively straight and of constant width and is flanked on either side by man-made levees to prevent flooding of the surrounding farmlands. Breaches in the levees occur regularly along the reach allowing flood waters to inundate the flood plain.

The flood plain as shown in Figure 2 is made up of three separate zones: the embanked channel of the Fergus (A), the area either side of the Gaurus owned by Clare County Council (B) and the privately owned area north of the Gaurus and east of the Fergus (C). In 1982 the landfill was contained in a 5ha section of the Gaurus flood plain and the areas and volumes associated with the three flood plain compartments were as shown in Table 1.

Since 1982 significant changes have taken place to these areas and volumes. The privately owned area of the flood plain, C, has been reclaimed by constructing an embankment along the Fergus river boundary and installing non-return sluices for drainage from the area into the river and is thus considered unavailable for flood water storage. Some housing has subsequently
been built on this land. Landfilling operations on Zone B removed another 25ha from the available flood plain by 1997. The storage represented by the completed landfilled operations in 1997 is approximately 250,000m³. Thus the total volume removed is 383,600 or 36% of the original total volume available. The increased landfilling alone represents 22% of the original volume removed.
Table 1: 1982 Flood plain areas and volumes

<table>
<thead>
<tr>
<th>Zone</th>
<th>Name</th>
<th>Area (ha)</th>
<th>Volume (m³)</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Fergus Channel</td>
<td>34</td>
<td>269,830</td>
</tr>
<tr>
<td>B</td>
<td>Gaurus</td>
<td>110</td>
<td>722,530</td>
</tr>
<tr>
<td>C</td>
<td>Private</td>
<td>27</td>
<td>133,600</td>
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<tr>
<td></td>
<td>TOTALS</td>
<td>171</td>
<td>1,125,960</td>
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Description of the Fergus River Model

An hydraulic model was constructed using DAMBRK to analyse the changes on water levels in the main river channel due to the above reductions in flood storage volume. DAMBRK is a computerised mathematical hydraulic model that has been developed to dynamically route a flood through a downstream river valley. The model was developed over many years at the US National Weather Service, Fread [1]. The governing equations of the model are the complete one-dimensional Saint-Venant equations of unsteady flow which are coupled with internal boundary conditions representing the rapidly varied flow through downstream hydraulic structures such as dams, bridges or embankments which may develop a time dependent breach.

Bridge or embankment flow constrictions, tributary inflows, river sinuosity, flood plain inundation, levees located along the downstream river and tidal effects can be realistically incorporated during the simulated downstream propagation of a flood. High water profiles along the valley, flood arrival times and hydrographs at user selected locations are standard model output. The model is used by, inter alia, the U.S. Army Corps of Engineers when assessing dam failure and river flood routing and is considered to be one of the most reliable and generally most applicable model for use in this type of analysis. The following are the main assumptions that are made in DAMBRK:

- flow is one-dimensional.
- flow is assumed to vary gradually along the channel so that hydrostatic pressure prevails.
- the longitudinal axis of the channel is approximated as a straight line.
- the channel bed is fixed, neglecting the effects of scour and deposition.
- the fluid is incompressible and of constant density throughout.

Following a topographic and hydrographic survey of the study domain, a model of the river – flood plain system from Ennis Bridge to Clarecastle Barrage
was developed using DAMBRK. The main features of the model used in this study were:

- The embanked river channel is approximately 5 kilometres long with an average top width of 40 metres.
- The embankments on both sides of the channel were assumed to be intact over the entire reach except at the confluence of the Gaurus and the Fergus. The average height of these embankments was specified as 6 metres o.d. Thus, overtopping of the embankments by river flood waters was not permitted in any of the model simulations.
- The volume of storage available between the embankments for a water level of 5 metres o.d. in the channel is approximately 283,000 m$^3$. This value is within 5% of that estimated in the AFF report at 269,830 m$^3$.
- Although flooding is known to occur along both sides of the river, the model assumes that only the Gaurus flood plain is available for flood water storage and that entrance to this flood plain is restricted to a 125 metre stretch where the Gaurus joins the Fergus.
- Because the model does not take into account the contribution of storage in the Gaurus flood plain and the storage volume within the embanked channel is overestimated by approximately 5%, the model is considered to be conservative with respect to calculating water levels.

One of the main purposes of the study was to assess the impacts of the increased landfilling on water levels. Thus the model was developed to simulate two scenarios for the above system:

(i) Scenario I - 1997 conditions with 472,530 m$^3$ of flood storage
(ii) Scenario II - 1982 conditions with 722,530 m$^3$ of flood storage

DAMBRK simulates flood plains as storage compartments and requires storage–elevation rating curves to determine the interactions between main channel and flood plain. The storage–elevation relations for the flood plain for water levels between 4 and 5 metres o.d. specified to the model are shown in Figure 3 for the two scenarios modelled.

**Calibration of the Fergus River Model**

The hydraulic model was calibrated against estimated water levels on the flood plain given in the An Foras Forbartha (AFF) [2] report for a flood which occurred on 30 January 1975. The report gives the changes in water levels on the flood plain and corresponding flows in the river over a period of four hours and ten minutes, which is the estimated maximum time of gate closure at Clarecastle Barrage. This maximum time of gate closure provides the worst case condition for water levels upstream due to the backwater effects caused by the closed gates. For this period the report also gives recorded water levels upstream of the Barrage which provided the downstream boundary condition for the model. This downstream boundary condition is shown below in Figure 4. The
upstream boundary condition, river inflow, was specified as a constant flow of 53m$^3$/s. During model tuning a Manning's coefficient of 0.04 was found to produce best results, Chow [3] and Cowan [4].

Figure 3: Gaurus flood plain storage-elevation

Figure 4: Downstream boundary condition at Clarecastle Barrage
The model predictions are compared with the AFF [2] estimated levels in Table 2 below. The model predictions are within 3 centimetres of the levels estimated by AFF which indicates very good agreement between the two sets of results. These results are presented in graphical form in Figure 5. The close agreement with the AFF estimates indicated that the model was reproducing the depth-storage relation in the flood plain with sufficient accuracy.

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>AFF Analysis</th>
<th>DAMBRK Predictions</th>
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<td>Scenario II</td>
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<td>9.40</td>
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</table>

Model simulation and results

The calibrated model was used to dynamically route two large floods through the downstream valley and compares the computed water levels on the Gaurus flood plain for the cases with and without the landfill extension of 25 ha. In the AFF report the 20-year return period flood is estimated as having a mean daily flow of 77.8 m$^3$/s. This flow was specified to the model as a constant discharge for the maximum gate closure time of 4 hours and ten minutes. The results from these simulations are presented graphically in Figure 6 below. It can be seen from the above figure that the extended landfill results in an increase in water levels on the flood plain of approximately 0.2 m. The largest flood event on record occurred in 1995 and gave an extrapolated discharge at Clarecastle of 93 m$^3$/s. Again, this flow was also specified to the model as a constant discharge for the maximum gate closure time. The results from these simulations are presented graphically below in Figure 7. As with the previous flood case, the extension to the landfill results in an increase of 0.19 metres in the water level on the flood plain. Again, the calibration flood downstream boundary condition was used and it is likely that the above maximum water levels are underestimated.

Discussions and conclusions

The flood plain across the Gaurus River was designed to be abandoned for the purposes of flood control under the 1943 Act. The construction of a landfill has resulted in the loss of some 25% of available storage in the flood plain. The application of the model DAMBRK to the above system shows that water level
Figure 5: Comparison of DAMBRK & AFF results for 1975 flood

Figure 6: DAMBRK Predicted water levels for 20-year return period flood
rises in the order of 0.2m are likely due to the increased landfilling activities since 1982. Moreover, analysis of the water level records from gauging stations along the river indicate that the hydrological flood regime is also changing in the river as a result of upstream activities. A design flood of a given magnitude in 1982 appears to have increased in frequency of occurrence by approximately a factor of three. These increased flood flows and levels are, in part, due to the loss of flood storage caused by landfilling. From this study it is obvious that the hydrological regime of the system has been significantly altered by the presence of the landfill and that the net ability of the flood plain to contain a given extreme event is reduced. It is imperative that developments along river courses be planned and managed in an integrated manner to avoid the types of problems encountered here. The use of widely available models such as DAMBRK allows such an integrated approach and should be used where possible.

References