FLOOD RISK ASSESSMENT FOR DEVELOPMENT PROPOSALS

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ABSTRACT

Inappropriate development within flood plains can lead to an increase in flood risk, both to the proposed development and to existing developments up and down stream of the proposed development. This paper describes the processes that should be followed when assessing the potential impact of a new development on flood risk. It provides a brief introduction to the need for, requirements of, and methods to be used during the preparation of a flood risk assessment.

1. INTRODUCTION

Ireland has experienced a number of significant flood events in recent years, and given the expected effects of climate change (Sweeney *et al.*, 2003) more severe and more frequent flooding can be expected in the future. It is also likely that pressure for further development in floodplain areas will occur in the future, as flood plain areas often make attractive development sites for a number of reasons. These include the fact that flood plain areas are typically flat, which reduces the amount of engineering works required to construct developments, they may be the only space left in or around a town which has not previously been developed and because riverside properties can often be sold at a premium. However, for development to be sustainable it must be ensured that developments are planned and designed with appropriate consideration of flood risk, to avoid an increase in the risk of economic, social and health impacts associated with flooding within Ireland.

Whilst options for dealing with existing properties subject to flooding are limited and are a legacy of past decisions, opportunities for planning and designing new developments such that flood risk is not increased are (or should be) much greater. If such opportunities are to be exploited to the full, it is important that the potential change in flood risk due to a proposed development is understood, and that mitigation measures are designed to prevent any such increase in flood risk. This process is known as flood risk assessment, and this paper will suggest when such studies should be carried out, what should be investigated and how this may be achieved.

2. SOURCES OF FLOODING

A development may be flooded by a variety of mechanisms from a range of sources. These include:

- Fluvial flooding: flows within a river/stream/drain are greater than the channel capacity, such that water spills onto the flood plain. Fluvial floods may be exacerbated by man-made restrictions in watercourses such as bridges, culverts and weirs.
- Coastal flooding: sea water encroaching onto land due to high tides, waves, low pressure-induced storm surges, or a combination of these causal factors;
- Sewer flooding: caused by high rainfall intensities, blockage of sewer systems or "tidelocking" of outfalls by high river levels. Flooding from sewers can result in significant water quality problems.
- Overland flow flooding: caused by surface runoff following heavy rainfall. The risk of flooding due to surface runoff can be increased by changes to land use and land management practices (e.g. urbanisation, some agricultural practices);
- Groundwater: flooding due to high water tables and increased river flows following long periods of wet weather. Groundwater flooding typically occurs in areas underlain by limestone or other aquifers. May lead to prolonged inundation;
- Infrastructure failure: such as burst water mains, flood defence failure, reservoir collapse, pumping station failure. Floods due to this can be sudden and may occur with no warning.

Whilst all potential flooding mechanisms/sources should be considered during a flood risk assessment this paper refers only to fluvial flooding problems.

3. FLOOD RISK

Flood risk can be described as a measure of the potential for flooding to cause damage, which is a combination of the likelihood of flooding occurring and the consequences of flooding.

The likelihood of flooding occurring can be expressed in terms of the annual probability of exceedence (or, alternatively, as a return period) of a flood event of a certain magnitude. The consequences of a flood must be assessed by considering the hazard posed by the flood (e.g. flood depth, velocity, water quality etc.) and the scale and vulnerability of the development (e.g. a hospital is more sensitive to flooding than an allotment). Both the likelihood and consequences of flooding should be considered in a flood risk assesssment.

4. SCALES OF FLOOD RISK ASSESSMENT

Flood risk assessment may be carried out at a range of scales. In England and Wales, the Environment Agency has undertaken extensive broad-scale modelling studies to map flood plains on a national scale. A similar process is underway in Ireland (Adamson, 2001), which aims to provide nationwide coverage to assist in the identification of areas that are likely to be subject to flood risk. More detailed catchment or sub-catchment scale flood risk assessment studies may also be carried out by public bodies, such as Councils, to develop a strategic understanding of river and catchment management needs (DTLR,2001).

This paper will concentrate on flood risk assessments for development proposals, which are to be submitted in support of planning applications. Such assessments are commissioned by developers to enable the planning authority to assess the suitability of a proposed development in relation to flood risk.

5. POTENTIAL IMPACTS OF NEW DEVELOPMENTS ON FLOOD RISK

New developments within flood plains may lead to an increase in flood risk for a number of reasons:

- new development in flood plains increases the sensitivity to flooding by increasing the number of people/properties/infrastructure exposed to the flood hazard;
- new development can increase upstream flood risk if it restricts the conveyance capacity of the flood plain, leading to increased upstream water levels;
- new development can increase downstream flood risk if it causes a reduction in the volume available for the storage of flood water on the flood plain, displacing water downstream;
- new development can increase downstream flood risk by causing an increase in the rate and volume of runoff entering the watercourse (this effect can be caused by any development, including those outside of the flood plain).

All of these effects should be considered when undertaking a flood risk assessment, although this paper only provides an introduction to the steps needed to assess the first three flood risk issues.

6. POTENTIAL MITIGATION MEASURES FOR NEW DEVELOPMENTS

The flood risk assessment process should allow identification and outline design of whatever mitigation measures are appropriate to avoid an increase in flood risk due to a proposed development, and should demonstrate their effectiveness. A range of mitigation measures are available to protect new developments from flooding, and to avoid an increase in flood risk elsewhere.

New developments may be protected by new flood defences, although a better option is to raise the land on which the development is to be constructed to above flood level. This is preferable as flood defences are associated with a residual risk of failure, and significant flood depths may be experienced behind flood defences that are overtopped during a flood event that is in excess of the design flood event. The ideal situation is to design the development such that vulnerable developments are located outside of the floodplain altogether.

Several measures may be used to offset the potential effect of a development on upstream flood risk. These include channel/floodplain modification works (channel straightening, widening, deepening,

two-stage channels, improvements to channel roughness, flood relief channels etc.) and replacement and/or modification of existing bridges and culverts. The long-term environmental impacts and maintenance requirements of such works should be considered carefully, and proposed mitigation measures should be modelled to demonstrate their effectiveness.

If the development could lead to a significant loss in floodplain storage then compensatory floodplain storage works should be designed to ensure that no net loss of floodplain storage occurs due to a development. It should be ensured that the water stored on the floodplain at any point in time during a flood event is the same following a development as under existing conditions. This means that the volume lost at a certain level should be replaced at the same level. This "level for level" storage provision (Pinkett, 1995) ensures that flood risk is not increased at any point in time through the flood hydrograph.

Level for level compensatory floodplain storage is achieved by regrading land to a lower level in order to replace the volume lost due to the development (Figure 1). This allows provision of replacement storage at the same level at which it is to be lost. Compensatory storage should be provided at or near to the development site, and its feasibility will depend upon a number of factors, including the required volume of compensatory storage, existing topography, land ownership, land use and environmental issues.

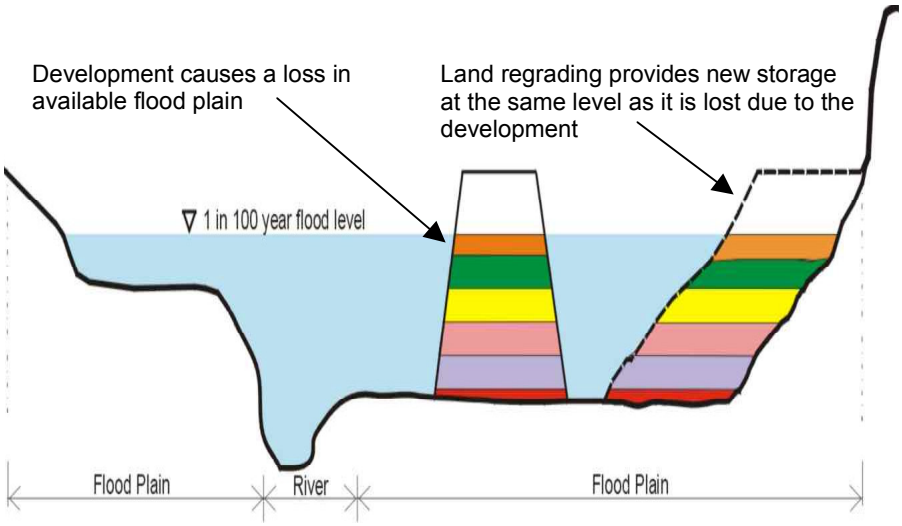

Figure 1: Level for level compensatory flood plain storage.

7. PLANNING REQUIREMENTS FOR FLOOD RISK ASSESSMENT

The Department of Environment, Heritage and Local Government assumes overall responsibility for the planning system in Ireland, although the local authorities are responsible for determining planning applications in the first instance. In Ireland there is currently no national planning guidance on development and flood risk that provides guidance on when (or how) a flood risk assessment should be undertaken, although all watercourse crossings require approval from OPW under Section 50 of the Arterial Drainage Act (1945). Currently, the onus is on local development planning authorities to request that flood risk assessments be carried out when they are aware that a proposed development may lead to an increase in flood risk. It is anticipated that this situation will be strengthened within the next few years (Adamson & Cussen, 2003).

In the United Kingdom (UK), major developments have taken place in the last few years in national planning policy guidance on development and flood risk. In England, PPG25 (DTLR,2001) was published in 2001, and is to be reviewed in 2003. The Scottish Executive have recently circulated a draft version of SPP7 (Scottish Executive, 2003) for comment, which will supersede NPPG7 (Scottish Executive, 1995). The Welsh Assembly have recently issued a draft update to TAN15 (Planning Policy Wales, 2003) and draft PPS15 is being prepared for Northern Ireland, which is expected to be

available for consultation by the end of 2003. The available planning policy guidance documents for the UK all require flood risk assessments to be undertaken in areas at significant risk of flooding (i.e. in areas with an annual probability of exceedence of 1 in 1000 or greater). They include guidance on the circumstances in which these assessments should be undertaken, and what these assessments should investigate.

8. IDENTIFYING THE NEED FOR FLOOD RISK ASSESSMENT

The UK guidance notes rely heavily upon the availability of flood plain maps in their sequential approach to determining the need for flood risk assessments, as the trigger for requesting a flood risk assessment relies on a preliminary assessment of whether a proposed development lies within the flood plain.

Given the current absence of a national database of such maps for Ireland, such an approach may not be possible. However, a flood risk assessment should be carried out wherever it is thought that a proposed development may be at risk of flooding and/or may lead to an increase in flood risk elsewhere. As noted in PPG25 and SPP7, a range of indicators may be used to suggest that a site may be at risk of flooding, including:

- areas defined as being at risk of flooding in local development plans;
- areas which are known to have flooded in the past, or are at a level which is close to a previously recorded flood level;
- areas in or around a watercourse, particularly where there is steeply rising ground on the opposite bank, or the land use is such that it may be expected that previous development has not occurred due to flood risk (e.g. public parks or sports fields);
- areas in flat, low lying land, especially where developments at similar levels/locations have experienced flooding or are protected by flood defences;
- areas adjacent to, near to, around or behind any flood defence or flood control structure;
- developments upstream of a restriction in the watercourse, either natural (e.g. rock outcrop) or man-made (e.g. culvert, weir).
- developments which may involve culverting or realigning a watercourse (OPW, 2001);
- developments overlying alluvium (Planning Policy Wales, 2003).

If a proposed development site lies in such an area then a flood risk assessment is likely to be required. Even if the proposed development site is located behind existing flood defences, it is advisable to carry out a flood risk assessment to ensure that the development could withstand flooding in the event of the flood defence breaching or being overtopped.

It is recommended that a flood risk assessment is carried out as early as possible in the development planning process. This is because flood risk issues may have a major impact on the viability, end use, masterplanning and design of a development site. If a site is found to be subject to flood risk then ideally it should be left in its undeveloped state and an alternative location found for the development site. If this is not possible because of other factors, then the development must be designed carefully to address the flood risk issues.

Ideally, flood risk assessments should be carried out before land is purchased for development, and the materplan of the proposed development only be created once the site constraints due to flood risk issues are fully understood. Consultation should be undertaken with the local development planning authority at as early a stage as possible to ascertain the requirements in relation to flood risk issues.

9. OBJECTIVES OF FLOOD RISK ASSESSMENT

A flood risk assessment should be prepared to allow the planning authority to make an informed decision as to the acceptability of a proposed development in flood risk terms. In broad terms, a flood risk assessment should be undertaken with the purpose of (DTLR, 2001):

- providing an assessment of whether any proposed development is likely to be affected by flooding and whether it will increase flood risk elsewhere and of the measures proposed to deal with these effects and risks; and
- satisfying the local development planning authority that any flood risk to the development or additional risks arising from the proposal will be successfully managed with the minimum environmental effect, to ensure that the site can be developed and occupied safely.

The flood risk assessment should be undertaken to assess these factors for a range of flood events up to and including the design flood event. The local planning authority should provide advice as to the appropriate annual probability of exceedence for the design flood event. OPW (2001) recommend that the 1 in 100 design flood be used when considering new watercourse crossings associated with new development. The local development planning authority should also provide advice as to the acceptable limit of increase in upstream water levels due to the development (afflux) so that the proposed development does not cause a significant increase in upstream water levels, and on requirements for compensatory flood plain storage.

It is likely that in order to produce a flood risk assessment that will satisfy the local development planning authority it will be necessary to undertake sufficient work such that the following issues can be identified:

- flooding mechanisms, hydraulic structures and flood routes affecting the site;
- the likely rate of onset of flooding, and the availability of flood warning times;
- flood flows and levels for a range of event likelihoods, up to and including the design event;
- flood durations, extents, depths and velocities;
- the presence, standard of protection and condition of any flood defences in place;
- the impact of the development on upstream flood risk;
- the impact of the development on downstream flood risk;
- if the river is sensitive to such changes and the development may have a significant impact, the impact of the development on fluvial geomorphology;
- the residual risk associated with events in excess of the design event.

It is important that the development is designed such that it will remain at an acceptable level of flood risk for its lifetime, and as such account should be taken of potential climate change effects on flood flows.

10. METHODS OF ASSESSING FLOOD RISK

In order to meet the objectives of a FRA, as listed above, it is usually necessary to undertake hydrological and hydraulic calculations. When beginning a FRA, two issues should be taken into consideration:

- flood estimation can be time consuming and can require significant survey work, and as such can be associated with significant costs. For some small developments, the costs associated with a full modelling study may be a significant proportion of the potential economic benefit of a development (this is not to say that such studies should not be undertaken). The flood risk assessment should be appropriate to the scale, sensitivity and potential impacts of the proposed development.
- no matter how skilled the practitioner, the results of river modelling studies are associated with a significant level of uncertainty, and any information on past flood events can be very valuable in constraining the uncertainty associated with such events. The amount of existing information about a site can have a significant influence on the amount of modelling work required to assess flood risk at a site, and on the accuracy of the resulting models.

For these reasons, it is often best to carry out flood risk assessments as a two-stage process. The first stage is to undertake a scoping study, followed by a detailed modelling study.

10.1 Scoping Studies for Flood Risk Assessment

A scoping study is used to develop an understanding of the flood conditions at the site, to identify available information about flood risk and to assess the likely suitability of the site in flood risk terms. A scoping report will typically include:

- Identification of possible flooding sources and mechanisms;
- Identification and review of existing information relating to previous flood events;
- Identification and review of any previous modelling studies;
- Qualitative assessment of the risk of flooding to the development;
- Qualitative assessment of the potential impact of the development on flood risk elsewhere;
- Assessment of the likely applicability and success of mitigation measures;
- Recommendation as to whether the development is likely to be acceptable;
- Recommendations for further work to produce hydrological estimates of flood flows;
- Recommendations for further hydraulic modelling to produce estimates of flood levels, velocities etc.;
- Recommendations for further hydraulic modelling to assess the potential impact of the development,
- Recommendations for further work required to design mitigation measures.

A key element of a scoping study is to identify and review existing information which may provide an indication of the existing flood risk at a proposed development site, and which may be of use in more detailed modelling studies. Local authorities are often a good source of information on past flooding problems, and may hold recorded flood levels from past flood events. Local libraries and local history groups may also provide useful data. Level recorders and flow gauging stations are run by a variety of organisations, including the OPW and local authorities, but the overall responsibility for hydrometric data collection and collation lies with the Environmental Protection Agency (EPA). The location of hydrometric stations may be located using the EPA's "Register of Hydrometric Gauging Stations" and information on the quantity and reliability of available information at each station can be obtained from the EPA. It is essential that the reliability of rating curves for each gauging is determined before flow data is used in hydrological analysis. Met Éireann hold rainfall and other meteorological data.

In some cases a scoping study may provide sufficient information to allow a decision to be made about the likely viability of a proposed development site. Following the scoping study a second stage may be undertaken, where the necessary modelling studies can be completed.

10.2 Modelling Studies for Flood Risk Assessment

Modelling work is likely to be required as part of a flood risk assessment to assess any or all of:

- the existing flood risk (flood levels etc.) for a site;
- the potential impact of a proposed development;
- the effectiveness of proposed mitigation measures.

Procedures for undertaking these assessments are described below.

10.2.1 Assessment of existing conditions

The first step in assessing flood risk is to develop an understanding of the flood frequency curve for a watercourse. In order to do this it is necessary to estimate flood flows, and the standard method for doing this in most watercourses in Ireland is to make use of the techniques described in the Flood Studies Report (NERC(1975); Cunnane & Lynn (1975)) and its supplementary reports (O'Donaill,2001).

For most catchments it is usually best to apply both statistical and rainfall-runoff methods and to compare the results. Whilst FSR methods may be applicable for most catchments, the characteristics of each catchment should be considered carefully before estimating flood flows. Special techniques may be required to model very small catchments (<0.5 km^2), heavily urbanised catchments and permeable catchments. The Flood Estimation Handbook (Institute of Hydrology, 1999) provides

guidance on situations in which the various methods are most appropriate, and recommends methods of reconciling estimates produced by statistical and rainfall-runoff methods. O'Donaill (2001) summarises some techniques that may be applicable for flood flow estimation.

If loss of flood plain storage is likely to be an issue in the flood risk assessment, a method should be chosen which will produce estimates of both the peak flow and the design flood hydrograph.

Wherever possible, use should be made of recorded flow data on the watercourse under study, either close to the site itself or even at sites further up/downstream (referred to as "Donor" catchments in the Flood Estimation Handbook).

Once estimates of flood flow have been calculated hydraulic modelling is required to convert flood flows into flood levels (and to provide additional information such as velocities). Typically, this will require the use of a commercial hydraulic modelling package, such as HEC-RAS, ISIS or MIKE-11, to simulate hydraulic conditions along a river reach. The latest versions of these packages can simulate steady-state backwater conditions and unsteady state (hydrodynamic conditions). These packages can simulate a variety of key hydraulic features (bridges, culverts, weirs etc.), although the methods used to model these features can vary, and the applicability of the model used should be considered carefully for each situation. For the majority of river reaches these models all require the following input parameters:

- Upstream boundary conditions: design flood flows
- Downstream boundary conditions: downstream flood level (can be estimated from a rating curve, known flood level or previously modelled level). If this is based on an estimated rating equation (e.g. normal depth assumption) the downstream boundary should be located far enough downstream such that the assumed downstream flood level does not influence water levels at the site of interest.
- Model geometry: survey data is required to represent key elements of the river channel, floodplain and key hydraulic structures. The number and spacing of cross-sections required will depend upon the geometry of the situation.
- Hydraulic coefficients: estimates of the roughness of the channel and floodplain, and loss coefficients associated with each hydraulic structure are required.

The availability of downstream boundary data, spatial extent of the hydraulic model, survey requirements and available flood level data for calibration should be identified during the scoping study. As such modelling requires a number of approximations, assumptions and estimates, calibration of the model should be undertaken wherever possible. Scenario testing should be undertaken to assess the sensitivity of flood hazard variables to assumed parameters.

In some situations, where the sensitivity to flood risk is low, and calibration data is available, it may be possible to use the single-section method (Highways Agency , 1995) to estimate hydraulic conditions.

10.2.2 Prediction of conditions with proposed development

Once existing conditions have been defined, the hydraulic model should be modified to simulate the conditions that would be expected to occur if the proposed development were in place. The development should be modelled with the mitigation measures in place that would be used to protect the development from flooding, and modelling should be undertaken to demonstrate the benefit of any mitigation measures designed to avoid an increase in up or downstream flood risk.

Steady-state simulations can usually be used to assess the impact that the proposed development may have on upstream water levels, although in some cases the use of hydrodynamic modelling may be advantageous. Predicted water levels for the existing and proposed case can then be compared and the increase in water levels due to the proposed development calculated. This result can then be compared to the afflux limit provided by the local development planning authority, to assess whether mitigation measures will be required to offset this increase in water levels.

Assessment of the potential impact of the proposed development on downstream flood flows can be achieved using either the method described by the Highways Agency (1995) or by comparing the results of hydrodynamic modelling of the situation before and after the development. The results of individual developments on downstream flood risk can often to be shown to be small. However, the potential cumulative effects of floodplain storage loss can become significant. Therefore, for watercourses where it is expected that such cumulative losses may be significant, it is desirable that no net loss of flood plain storage occurs for any development. Requirements for compensatory flood plain storage should be discussed with the local development planning authority for each development site.

It is important that the flood risk assessment demonstrates the effectiveness of any proposed mitigation measures. The assessment should indicate the position and anticipated level of any works proposed to protect the development from flooding and to avoid off-site impacts.

11. FLOOD RISK ASSESSMENT REPORTS

A report on the methodologies used, and findings of, the flood risk assessment should be submitted to the local development planning authority. This should provide sufficient information that the local development planning authority can make an informed decision about the appropriateness of the proposed development in flood risk terms.

As a guide, Appendix F of PPG25 (DTLR, 2001) and Appendix 1 of TAN15 (Planning Policy Wales, 2003) summarise the information that should typically be included in a flood risk assessment report for England and Wales, respectively. SEPA (1998) provide recommendations on information that should be included when submitting a report based on hydrological/hydraulic modelling in Scotland. OPW (2001) provide guidance on information that should be included with a submission for a Section 50 consent.

12. FURTHER ADVICE

Arup are currently working on the production of guidance for undertaking flood risk assessment for development proposals within the United Kingdom, on behalf of CIRIA. Whilst this guidance is focused on flood risk assessment within the UK, much of the advice within it is also likely to be relevant to Ireland, and will provide more information on flood risk, flooding mechanisms, assessment methodologies/techniques and mitigation measures than is possible within this paper. It is expected that this guidance will be published in the Spring of 2004. Further details about this project can be found by contacting CIRIA (www.ciria.org).

CONCLUSIONS

In order to ensure future development is sustainable, it is essential that the flood risks to, and caused by, development are assessed and managed in an appropriate manner. As the greatest opportunity for managing such risks lies with the planning and design of new developments before they are constructed, it is vital that the flood risk assessment process is an integral part of planning applications for any development that has the potential to increase flood risk.

New developments may increase flood risk in a number of ways, but use of appropriate scientific tools to aid planning and design of development sites may enable the engineer to avoid unacceptable increases in flood risk. This paper provides a brief overview of the flood risk assessment process, although a CIRIA report that is to be published next year will provide more detailed guidance.

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