Study to Identify Practical Measures to Address Flooding on the Clare River

VOLUME 1 - REPORT

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The Office of Public Works
Oifig na nOibreacha Poiblí

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EXECUTIVE SUMMARY

This report has been prepared with the objective of identifying practical measures to address flooding on the Clare River and on its main tributary, the Abbert River, within a study area from Lough Corrib to Corofin in County Galway. The study was commissioned as result of severe damage and disruption caused by flooding in the area in November 2009.

The brief from the Office of Public Works (OPW) required the study to include the following;

- A hydrographic survey from Lough Corrib to Claregalway to establish whether the presence of siltation significantly reduces the conveyance capacity of the channel.
- An examination of existing data on the Clare and Abbert Rivers to compare the Arterial Drainage Scheme design with the existing channel at critical locations.
- An examination of the available Hydrometric Stations data in the area with particular reference to the recent flood event.
- The development of a numeric hydraulic model of the study area, using available data augmented with a series of cross sections taken at selected locations.
- Calibration of the hydraulic model using data gathered from the recent flood.
- The development of an outline flood damage (improvement works benefit) analysis.
- Recommendation of a number of engineering measures to form the basis of a proposed alleviation option to eliminate or reduce flooding in the study area from a similar sized event to the November 2009 flood.

In order to fulfil the brief, the study comprised the following elements;

- A review of the Clare River catchment including description of the various Arterial Drainage Scheme works, physical characteristics of the Clare and Abbert Rivers, the control of water levels in Lough Corrib, catchment geology and hydrogeology, ecology, meteorology, urbanisation and land use zoning and cultural heritage.
- An analysis of historical floods in the study area.
- An analysis of the various parameters pertaining to the November 2009 flood event including analysis of rainfall events and return periods.
- The collection and assessment of extensive datasets from the Environmental Protection Agency, the Office of Public Works and Met Eireann relating to Clare River flows and water levels, Abbert River flows and water levels, Lough Corrib levels, rainfall intensities and operational data relating to the Salmon Weir sluice barrage in Galway city on the Corrib River.
- Surveying of cross-sections of the Clare and Abbert River channels and flood plains.
- Surveying of all of the bridges and other hydraulic features along the study area river reaches.
- The comparison of existing bed levels and cross sectional areas to design levels and cross sectional area in both the Clare and the Abbert Rivers.
- The collection of anecdotal evidence relating to peak flood levels and other pertinent information
- The estimation of flood flows relating to November 2009, the 100 year flood and the 100 year flood incorporating a climate change allowance.
- An hydraulic analysis of the Clare and Abbert River channels including the development of a HEC-RAS 1D model.
- Calibration of the hydraulic model using the anecdotal evidence collected for the November 2009 flood event.
- The use of the hydraulic model to analyse potential flood risk management measures to eliminate or reduce the impact of a flood of similar magnitude to that of November 2009.

- The preparation of an outline flood damage analysis for the November 2009 flood event in order to calculate the economic damages consequent to this flood.
- Extrapolation of the November 2009 flood damage analysis for events of other magnitudes in order to calculate the economic risk posed by various flood events and to calculate the benefit accruing from putting various flood risk management measures in place.
- The evaluation of various alleviation options made up of a number of flood risk management measure, by carrying out initial viability screening on technical, economic, environmental and social acceptability grounds.
- For flood risk management measures deemed to be potentially viable, a more detailed viability assessment was carried out which included cost benefit analysis, an assessment of upstream or downstream flood risk, an assessment of environmental impact, climate change impact and future maintenance requirements.
- The drawing up of a programme of flood risk management measures satisfying the detailed viability assessment.

The main outcome of the elements of works listed above is a recommended programme of measures to deal with identified flood risk locations complete with cost estimates, estimates of economic benefits accruing as a result of the implementation of the measures and the calculation of benefit to cost ratios. Another outcome of the study is that it is not possible to provide viable flood risk management measures for the areas at risk of flooding adjacent to the Abbert River and for one particular area in Miontach North adjacent to the Clare River.

The full description of the study is divided into eight chapters contained in Volume 1. Volume 2 contains Appendices pertinent to the study.

Chapter 1 is an introduction to the report and sets out the aims of the study.

Chapter 2 discusses the general catchment characteristics of the Clare River catchment as well as the study area. It also discusses the Lough Corrib catchment and the operation of the sluice gates at the Salmon Weir in Galway city in relation to levels on Lough Corrib. The final section of the chapter describes significant flood events in the study area including a description of the flood of November 2009.

Chapter 3 describes the various datasets collected in order to carry out the study including a description of the survey of the rivers as well as the collection of anecdotal evidence from residents and public representatives from the study area.

Chapters 4 and 5 analyse the hydrology and the hydraulics of the Clare and Abbert River. The hydrological element focuses on estimating pertinent flood flows at the various hydrometric gauges. In Chapter 5, relating to the hydraulic analysis, the development of the hydraulic model is described as well as an analysis of various model runs both for calibration purposes and to test various flood risk management measures.

An outline damage analysis is provided in Chapter 6 for the November 2009 flood events, for the Design Flood event and for the Design Flood Event with a Climate Change allowance factored in. It also describes the results of the preliminary Flood Risk Assessment.

Chapter 7 provides detail on the various flood risk management measures proposed and an initial and more detailed viability assessment process, based on which the measures were assessed. The outcome of

this chapter is a programme of viable flood risk management measures, complete with cost estimates as set out in the table below;

PROGRAMME OF MEASURES STANDARD OF PROTECTION - DESIGN FLOOD					
Area	**Location**	**Proposed Measure**	**Capital Cost**	**Benefit**	**Benefit to Cost Ratio**
CLARE RIVER					
2	Miontach South	2a. Raise access road 2b. Increase size of culvert in conjunction with road works 2c. Clean drain ED @ Miontagh (OPW) and other drains in vicinity	€ 114,856	€ -	0.0
3	Miontach North	3a. Raise access road 3b. Raise access road	€ 120,969	€ -	0.0
4	Claregalway	4a. Install additional flood eye at Claregalway Bridge 4b. Regrade channel upstream of and under bridge 4c. Fill gap in wall at An Mhainistir housing estate 4d. Provide local embankment at old Nine Arches bridge	€ 917,353	€ 13,064,033	14.2
5	Kinishka	5a. Increase capacity of at two culverts on stream OPW C3/5 5b. Clean stream C3/5	€ 6,210	€ 87,990	14.2
6	Lakeview	6a. Provide surface water outlet through fields and along N17 to downstream of Claregalway Bridge	€ 301,542	€ 2,061,562	6.8
8	Caherlea/Lisheenavalla	8a. Install additional flood eyes at Crusheen Bridge 8b. Channel widening from 900m upstream of Crusheen Bridge to Claregalway 8c. Cleaning and regrading of Islandmore drain OPW C3/7 & F.799/1 8d. Raise local road in Caherlea/Lisheenavalla	€ 4,352,274	€ 992,665	0.2
TOTAL - CLARE RIVER			€ 5,813,203	€16,206,250	2.8

The conclusions of the report and the main recommendation of the report are presented in Chapter 8.

1. INTRODUCTION

RYAN HANLEY

1.1. Background

RYAN HANLEY was commissioned by the Office of Public Works (OPW) in March 2010 to carry out a study of the Clare River from Lough Corrib to Corofin and on the Abbert River from its outfall to the Clare River to Ballyglunin.

The aim of the study is to identify practical measures to prevent or alleviate damage and disruption due to floods from the River Clare and Abbert River, as was caused by the flooding encountered in the catchment in November 2009. The flooding of Lough Corrib and the Clare River which followed the extreme rainfall events of October and November 2009 caused severe and prolonged hardship to businesses, residents within the catchments of the Lower Lough Corrib and the river and to commuters using the N17 and other minor roads in the vicinity.

A number of practical measures to alleviate and reduce the impact of a flood event of this magnitude, including the provision of an additional flood eye in Claregalway, have been developed by the OPW. One of the main objectives of this study is to build a calibrated hydraulic model to test and assess the efficacy of these proposed measures and as a means of scoping and sizing these OPW flood mitigation measures. Over the course of the study, alternative measures were also developed, tested and their viability assessed with the aim of producing a programme of remedial measures to modify the river channel and improve the discharge of flood waters through bridge structures, complete with outline designs and cost estimates.

The brief from the OPW requires the study to include the following;

- A hydrographic survey from Lough Corrib to Claregalway to establish whether the presence of siltation significantly reduces the conveyance capacity of the channel.
- An examination of existing data on the Clare and Abbert Rivers to compare the Arterial Drainage Scheme design with the existing channel at critical locations.
- An examination of the available Hydrometric Stations data in the area with particular reference to the recent flood event.
- The development of a numeric hydraulic model of the study area, using available data augmented with a series of cross sections taken at selected locations.
- Calibration of the hydraulic model using data gathered from the recent flood.
- The development of an outline flood damage (improvement works benefit) analysis.
- Using the information derived from above, a number of engineering measures are to be developed to form the basis of a proposed alleviation option to eliminate or reduce flooding in the study area from a similar sized event to the November 2009 flood. A number of engineering measures including those set out in the brief were to be examined using the hydraulic model.

1.2 Methodology

The study involved the following elements;

- A bathymetric survey of the river channel from Lough Corrib to Claregalway Bridge to determine the bed level of the channel between bridge and the lake confluence
- Collection and examination of existing OPW data on lake levels, river hydrometric station ,Salmon Weir gate operation in Galway City together with photographic and video records of historical flood events including the November 2009 flooding
- Collection and examination of relevant hydrometric and meteorological data relating to the November 2009 flood and previous historical flood events
- Cross-sectional river bed and bank surveys along the Clare River and Abbert River as baseline information for the construction of the hydraulic model of the River Clare upstream of the its confluence with Lough Corrib
- Hydrological analysis of collated meteorological and hydrometric data on historical flood events including the November 2009 flood
- Hydraulic modelling of the river Clare and Abbert river channels together with model calibration using meteorological and hydrometric data
- Outline flood damage analysis including outline flood risk assessment based on the examination of recorded data, photographic and video evidence and interviews conducted with stakeholders affected by the floods of November 2009
- Flood alleviation option analysis and recommendations together with consideration of cost benefit analysis prepared in accordance with guidelines prepared and/or advised by the OPW

It should be noted that all levels referred to in this report have been converted to Malin Head Ordnance Datum.

2. Catchment Characteristics

2.1 The Clare River Catchment

The Clare River forms part of the Corrib-Mask catchment which covers an area of 3,056km^2.

The Corrib-Mask catchment is bounded on the north by the Moy catchment, on the east by the Suck catchment, on the south by the catchments of the Craughwell and Kilcolgan Rivers and on the west by the catchments of a number of small rivers which discharge to the Atlantic on the western seaboard. The River Corrib is the main river channel discharging waters from the Corrib-Mask catchment via Lower Lough Corrib and the Corrib river channel which flows from the lower lake to the sea at Galway City.

The Clare River catchment is approximately 1,036km^2 or approximately 30% of the Corrib catchment.

The Clare River, with a reach of approximately 93 kilometres from its confluence with Lough Corrib Lower, rises approximately 8km above the town of Ballyhaunis, County Mayo. Its principal tributaries working in a southerly direction from its source in County Mayo are the sinking River, the Nanny River, the Grange River and the Abbert River. For the greater part of it's length the Clare flows north south passing through Ballyhaunis, Milltown, the outskirts of Tuam, through the villages of Corofin and Claregalway to it's confluence with Lough Corrib, approximately 8km west of Claregalway. The confluence of the river with the lake is located at the Lough Corrib Lower which ultimately drains to the sea via the Corrib River channel to Galway City.

The present day drainage network has been significantly influenced by arterial drainage schemes carried out since the early nineteenth century to reduce winter flooding.

Figure 2.1 overleaf shows the drainage pattern of the catchment prior to arterial drainage in the early nineteenth century. Prior to drainage, many streams within the present Clare catchment flowed underground or terminated in permanent or temporary lakes (turloughs) due to the karst limestone geology of east County Galway. These surface waters discharged underground emerged later as groundwater further down the catchment.

A large permanent lake existed north of Corofin at the confluence of the Grange River and the River Clare. The Abbert River ended in a turlough at Ballyglunin and was not linked by a surface channel to the River Clare. Water in these turloughs flowed into swallow holes and from there via underground conduits until it emerged at large springs.

An extensive turlough was also located between Corofin and Turloughmore. Water flowed underground through swallow holes in this turlough and re-emerged in springs such as at Loughgeorge. There was no surface water channel from this turlough to Lough Corrib.

Generally, extensive flooding would have occurred at Ballyglunin, north of Corofin at Clonkeen, south of Corofin and at Turloughmore. Arterial drainage works in the Clare catchment initially involved removing the water from the upper and middle parts of the catchment, and the reduction of flooding at Ballyglunin and Corofin.

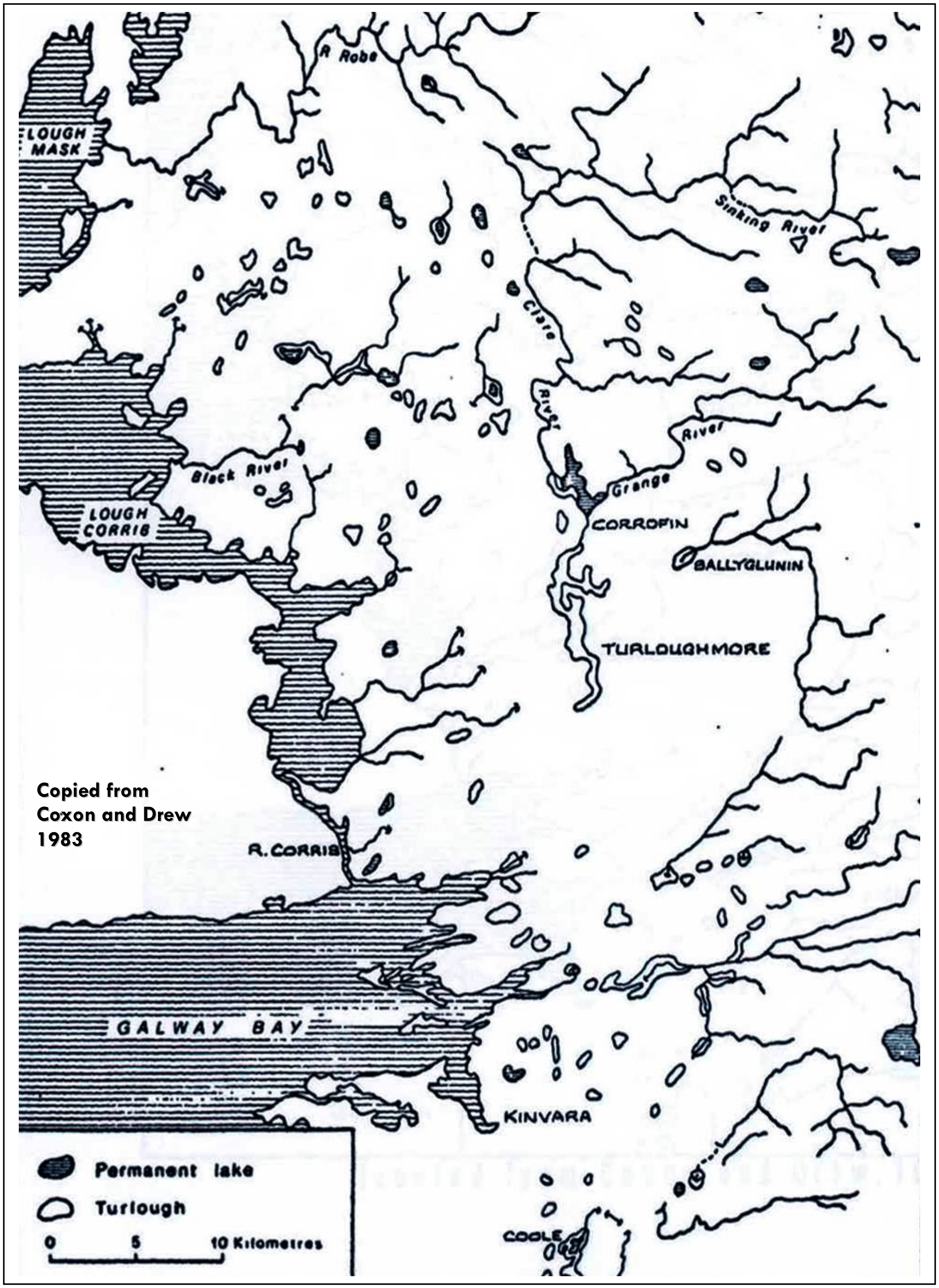


Figure 2.1 Drainage pattern within the present Clare Catchment – Late 18th Century

A further Arterial Drainage Scheme was carried out by the OPW in the 1950's and 1960's on the Clare River in order to further drain agricultural land in the catchment. The scheme involved continuous channel excavation along the whole length of the Clare River. Key features of this drainage scheme was extensive deepening or widening or both included the deep rock cut at Lackagh and further deep rock cuts at

Corofin and at Conagher above Milltown. Approximately 1.7million m^3 of material was excavated in total from the river channel, 350,000m^3 of which was rock. Similar works were also undertaken on the tributaries and smaller watercourses.

The scheme was designed as a deep drainage project whose basic objective was to provide the basic conditions for increased crop production and the improvement of stock by the relief of 135,000km^2 of agricultural lands from flooding and waterlogging.

2.2. The section of the Clare River catchment pertinent to this Study

The portion of the catchment of interest for this particular study extends from Corofin in the north to its confluence with the Lough Corrib Lower. The reach of river pertinent to this study is approximately 27.5km in length and drains a catchment of approximately 1073km^2.

There are a number of tributaries along this reach, the largest being the Abbert River with a length of approximately 33.4km From Claregalway downstream, extensive systems of land drains have been excavated which discharge to the river at various points.

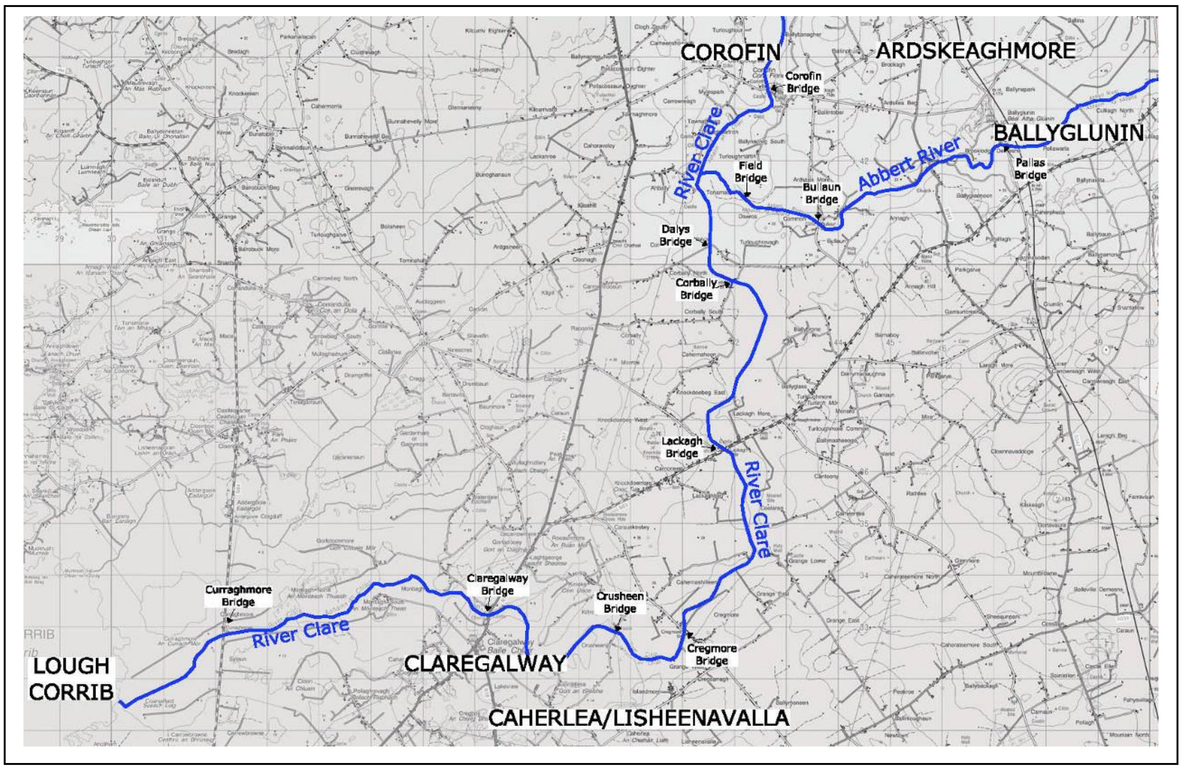


Figure 2.2 Extent of the Clare catchment pertinent to the Study

The width of the Clare River along the river channel of interest to this study varies from approximately 9 metres at Anabally field bridge, just upstream of the Abbert River confluence, to 32 metres, just downstream of the Curraghmore Bridge on the N84 road.

The corresponding range of river channel depths (ie depths from bank to lowest point of riverbed) within the study catchment area, varies from a minimum depth of 2.5m at Section 162 at Turloughcartron (halfway between Corofin and the Abbert River confluence) to a maximum of 7.7 metres at the most upstream section of the study area at Corofin and 7metres at the most downstream section of the study area just upstream of the confluence with Lough Corrib Lower. Channel depth typically range from 3 to 4m with the exception of a 1,800m stretch of river channel in the vicinity of Lackagh Bridge where the

channel depth is up to 10m. The overall gradient of the river over the section of river channel from Corofin to Lough Corrib is in the region of 1/1240 with a minimum bed level at Corofin of approximately 22.2metres OD (Malin) to a minimum bed level of -0.5m OD (Malin) at the river's confluence with Lough Corrib Lower. The gradients over critical sections of the river channel within the study area will be discussed in more detail later in the report.

The catchment is generally rural, apart from the urban settlements of Claregalway and Corofin through which it flows. The main villages and agglomerations of houses, located along this reach of the river include Corofin, Turloughcartron, Turloughmartin, Dawros, Corbally North, Corbally South, Ballybrone, Cahernahoon, Knockdoebeg East, Ballyglass, Knockdoemore, Lackagh More, Lackagh Beg, Cahernashilleeny, Cregmore, Cregcarragh, Grange West, Lisheenavalla, Caherlea, Islandmore, Crusheen, Kiltroge, Gortatleva, Lakeview, Miontach North, Miontach South, Cahergowan and Curraghmore. Although classified as rural, there is substantial ribbon development in all of the above areas, much of which has been developed in the recent past.

The nature of the catchment is generally gently undulating pastureland with highest elevations generally in the region of 30 metres OD (Malin), with the exception of the area around Knockdoe Hill which rises to approximately 70 metres OD (Malin). Portions of the river channel banks throughout the study area are in a high vegetative state most notably from Corofin to the Abbert River outfall, in the vicinity of Lackagh Bridge and Cregmore Bridge as well as from Crusheen Bridge to approximately 1km upstream of Claregalway.

2.3. The section of the Abbert River catchment pertinent to this Study

The width of the Abbert River along the reach of interest (outfall upstream to Ballyglunin) varies from a minimum of 5 metres at the confluence with the Clare River up to 30 metres wide upstream of Brooklodge. The Abbert River catchment area is in the region of 240km^2.

The depth of the channel varies from a minimum depth of 1.3m in the vicinity of Brooklodge to a maximum of 4.0m at Bullaun Bridge. Typically, the channel depth is of the order of 3m. The overall gradient of the section of Abbert channel within the study area from Ballyglunin to its confluence with the Clare River is in the region of 1/696 with a minimum bed level at Ballyglunin of approximately 30.84 metres OD (Malin) to a minimum bed level of 20.0 metres OD (Malin) at the river's confluence with the Clare River. The gradients over critical sections of the river channel within the study area will be discussed in more detail later in the report.

The Abbert River catchment is rural, although there is substantial residential ribbon development in parts of the catchment. The main agglomerations of houses along the river channel are located in the townlands of Tonamace, Turloughmartin, Ardskeghmore, Bullaun, Annagh, Brooklodge and Ballyglunin. The nature of the catchment is gently undulating pastureland with highest elevations generally in the region of 35 metres O.D. Portions of the channel bank are in a high vegetative state.

2.4 Control of water levels in Lough Corrib Lower and the Corrib River channel

Lough Corrib discharges into Galway Bay at Galway City via the Corrib River channel between Menlo and the Salmon Weir barrage.

The discharge in the Corrib River is controlled by a sluice barrage on the main river channel just upstream of the Salmon Weir Bridge in Galway. The barrage was completed in 1959 and consists of fourteen hinged steel gates and two wooden drop gates.

In a report entitled "Hydraulic and Hydrologic Investigation of Lough Corrib Flow Regime and of Gate Manipulation Policy at Galway Sluice Barrage", carried out by the OPW Hydrology Unit in May 1987 the stated purpose of the sluice barrage is to regulate the flow in the Corrib River so as to maintain the design water level in Lough Corrib

- at or above 28 ft or 8.53 metres OD (Poolbeg) (i.e 5.83 metres OD Malin) in time of low flow and
- at or below 30 ft or 9.14 metres OD (Poolbeg) (i.e 6.44 metres OD Malin) at times of high flow.

The maintenance of the low water level at a minimum of 5.83 metres OD (Malin) is required for several reasons including the prevention of excessively low levels on Lough Corrib Lower, to ensure

- sufficient draft for the launching and navigation of boats,
- salmon and eel fishing at the Salmon Weir bridge,
- abstraction of water from the River Corrib via the Galway City Water Supply intake structure located on the Terryland River,
- sufficient supplies of water to the head races of mills within the city's canal network in the past, for which rights may still exist.

A low river level at 5.83 metres OD Malin at the Weir barrage was also deemed necessary to provide sufficient outfall for the discharge of inflowing streams in the lower reaches of the Corrib River

The maintenance of the high water level at or below 6.44 metres OD (Malin) in the lower lake was adopted as a desired guideline value by the OPW "to prevent flooding along the lake margins and along the lower reaches of inflowing streams".

The sluice gates at the Salmon Weir are currently operated by the Office of Public Works based on the following considerations:

- Water level gauge readings transmitted using telemetry to the Salmon Weir from level recorders:
  - on the lake at Anglinham, Annaghdown, Barrusheen, and Cong Pier,
  - on the Clare River at Corofin
  - on the Corrib River at Woodquay and the Weir
- Long term weather forecast,
- Time of year,
- Wind direction,
- The requirements of the various stakeholders set out above i.e., the WRFB (fish stock management) , Galway City Council (water extraction) and boat users (draft for launching)

The decision is then made to open more gates or close back more gates based on experience.

2.5 The operation of the Weir Barrage and its effect on high lake levels

2.5.1 Historical compliance of lake levels with the desired level range

Among other things, the aforementioned 1987 Report examined recorded level data from autographic level recording gauges on Lough Corrib from 1960 to 1986 and compared them with the desired range in lake level envisaged by sluice gate operation at the Salmon Weir Barrage. This Report concluded that

- the design minimum level of 5.83 metres OD Malin on Lough Corrib Lower was maintained above or close to the desired low level,
- the desired high guideline level of 6.44 metres OD (Malin) had been exceeded on all but four of the years recorded.

This trend can be extrapolated forward to the present by examining more recent maximum lake levels. An analysis of the gauge at Annaghdown Pier (Station 30083, upstream of Clare River confluence), reveals that the only years, in which the desired maximum level of 6.44m OD (Malin) was not exceeded, were 1995 and 2005. It is noted that this guideline maximum level was exceeded in 2009 on 26 January 2009 and again from 18 November and to the end of the currently available records on 11 December 2009.

2.5.2 The routing of Lough Corrib outflows though the River Corrib channel

Based on the maximum lake levels recorded up to 1986, the 1987 OPW Report sets out to examine and report on the flow regime in Lough Corrib and the benefits, if any, to be gained by adoption of new gate manipulation policies at the sluice barrage.

To facilitate this analysis, a series of rating curves were developed for River Corrib discharge at different water levels through the Salmon Weir Barrage for all combinations of sluice gate openings. Fig 2.3 sets out the above rating curves for the various sluice gate openings included in the 1987 report.

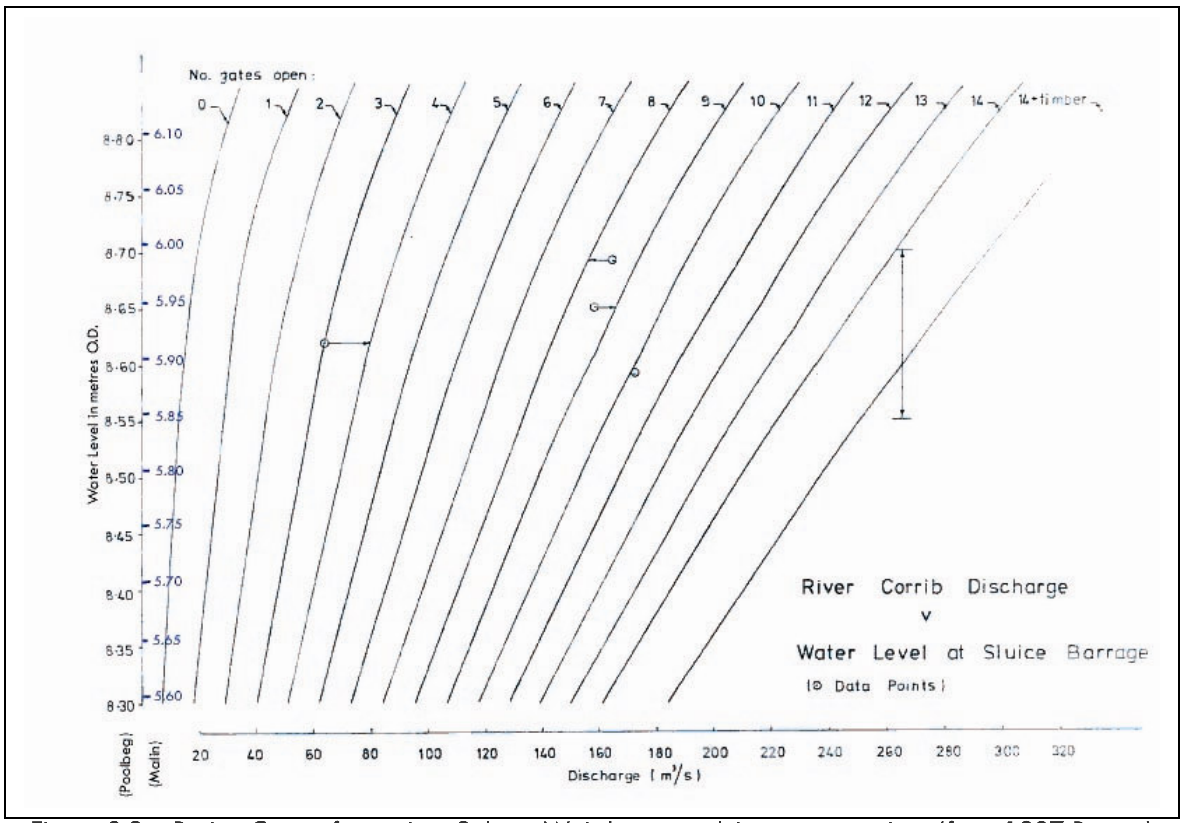


Figure 2.3 Rating Curves for various Salmon Weir barrage sluice gate openings (from 1987 Report)

The 1987 Report states that

"these rating curves show that when the "design flow" of 311.5m³/sec occurs in the Corrib River with all sluice gates open, the water level in Lower Lough Corrib is about 9.6m O.D" (Poolbeg) i.e. 6.88m OD (Malin).

Design conditions envisaged that this discharge of 311.5m^3/sec would occur at a Lough Corrib level of 9.14 metres OD (Poolbeg)" i.e. 6.42m OD (Malin), the maximum desired high level in the lake.

The Report goes on to conclude that
"*the Corrib River channel is not performing as designed. The reason for this is that actual energy losses due to friction along the channel being higher than assumed in the design calculations. This problem is not localised but occurs over the whole length of the Corrib River channel*" (approximately 8km).

The Report further determined that
"channel enlargement involving the excavation of approximately 700,000m^3 of material would be required to discharge the design flow of 311.5m^3/sec at a Lough Corrib level of 6.42m OD (Malin). Although the discharge of 311.5m^3/sec was used as the design flow in the original design of the Corrib/Clare Arterial Drainage Scheme, the data measured since the completion of the scheme show that this design discharge has a return period of about 20 years. The discharge with a 3 year return period, the normal standard used for Arterial Drainage Schemes is approximately 265m^3/sec and occurs at a lake level of 6.63m OD (Malin), over 0.21m over the desired maximum lake level. Channel enlargement involving the excavation of about 300,000m^3 of material would be required to discharge the 3 year flood at a Lough Corrib level of 6.42m OD (Malin)".

2.5.3 The effect of wind induced effects on lake level

Another feature of Lough Corrib, examined by the Hydrology Unit of the OPW in the 1987 Report is that of wind effects on Lower Lake levels. The Report states that
"When a wind blows over a lake it exerts a shear stress on the water surface. This causes the surface water to tilt upwards in the direction of the wind so that the water level is raised on the leeward (downwind) shore and lowered on the windward shore. The rise above still water level is known as wind set up. When the wind abates the lake surface returns to horizontal".

The 1987 Report analysed the gauges around Lough Corrib which showed
"numerous occasions where the water levels rose temporarily at some gauges and fell temporarily at others. Differences of 0.4m were recorded".

The Report goes on to conclude that
"Wind set up can exacerbate flooding by piling water up on the leeward shore. Furthermore, by reducing the water level at the lake outfall, wind set up can reduce discharge so that high lake levels persist longer."

2.5.4 The analysis of different gate manipulation policies by OPW and their effect on lake flood levels

Four gate manipulation policies were analysed as part of the 1987 Report by the OPW's Hydrology Unit using historical data of sluice gate opening, weir level data and the established rating curves for the weir to back route six years of outflows (1981-1986) from Lough Corrib. The predicted water levels for the different gate manipulation policies were then compared with the historical record of actual gate operation during these six years.

The four gate manipulation scenarios examined are set out as follows;

A. <u>All gates open all year</u>

Maintaining the gates in an open position all year round should result in the maximum (if any) achievable reduction in high levels in Lough Corrib.

B. <u>Narrow band gate control</u>

This exercise involved examining the effect of all the gates opening when lake level reaches 5.98m OD (Malin) and all gates closing when the lake level reaches 5.88m OD (Malin).

C. <u>Lower limit gate control</u>

With this policy, the gates are manipulated to give the largest discharge possible under the condition that the water level at the barrage must not fall below 5.81m OD (Malin). The gates would be progressively opened as the lake level rises with the final gate being opened at a lake level of 6.52m OD (Malin). .

D. <u>All gates closed all year</u>

The scenario was analysed as a matter of interest and demonstrated as expected that in this case Lough Corrib would reach very high levels, up to approximately 7.98m OD (Malin), an increase in the order of 1.0m.

The 1987 Report concluded the following in respect of Scenario A (all gates open all year)

"…summer levels would be exceptionally low. However, the effect on winter levels is less extreme. This was illustrated using data from 1981 and 1986 which illustrate two extremes of behaviour. In 1981 where levels and flows were moderate in the winter months, the water levels in the lake were reduced by about 0.4m by leaving the gates open all year. In 1986, with its large flows, there is zero reduction in flood level at the highest level. This pattern appears to a greater or lesser degree in other years also. The behaviour of the water level at the end of 1986 illustrates dramatically that in periods of high flow, the initial summer level has little effect on the resulting high levels in December. The level in December is determined entirely by the large inflows and is independent of the lake level at the time the large inflows start (provided that the lake level is not unrealistically low)".

Fig 2.4, taken from the 1987 report, plots the lake levels achieved by the existing gate manipulation policy in 1986 vis-à-vis the simulated lake levels that would have been achieved by alternative gate manipulation Scenarios A, B and C above. The 2009 recorded lake flood level is added to contextualise the 1986 analysis vis-à-vis the recent lake level recorded during the 2009 flooding event.

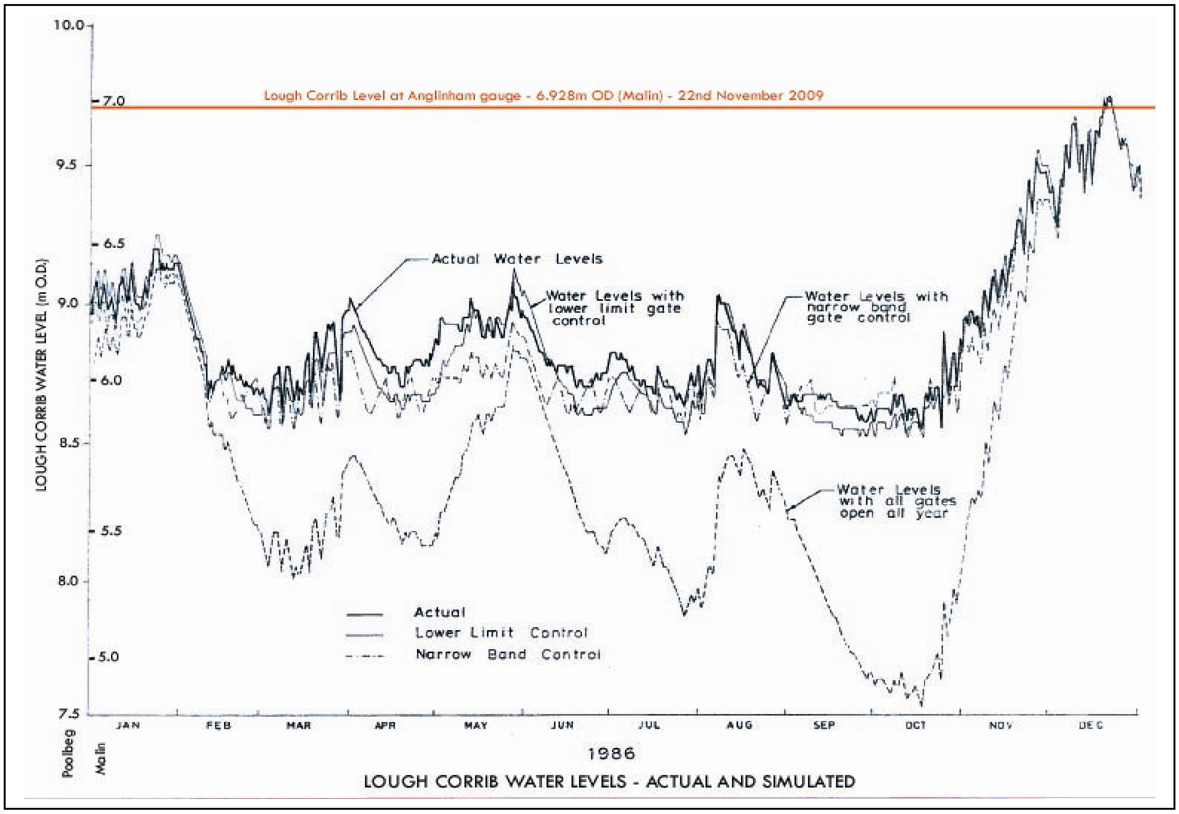


Figure 2.4 Comparison of Lough Corrib levels in 1986 for different Weir gate manipulation policies

The routing exercise results from the 1987 Report show that Scenario A (all gates open all year) does not reduce the high lake levels at all. It is clear the lake water level following runoff consequent to extensive rainfall from the Corrib-Mask and Clare catchment is clearly dependent on the ability of the Corrib channel to discharge lake outflows rather than on the manipulation of sluice gates, some 8 kilometres downstream.

The failure of Scenario A to mitigate high water levels in the lower lake is further explained in a Geological Survey of Ireland (GSI) report relating to flooding in the Claregalway area in 1990 and 1991. This GSI report explains the effect on the high water levels of keeping all gates open all year by way of an example. For instance, if at the start of wet weather in October, the lake levels would be considerably lower than when the sluice gates are in operation. Consequently, exceptionally high rainfall at this time would have less impact due to the greater amount of available storage in the lake and would be less likely to cause flooding. Heavy rainfall of long duration occurring later in the year when Lough Corrib is no longer exceptionally low would have the same effect on flood levels as at present. This is due to the inability of the Corrib River channel to discharge water sufficiently at the appropriate level.

The failure of the best case Scenario A to control high lake levels when runoff into the lake is high means that the other gate manipulation policies set out in Scenarios B and C will not achieve the level reduction either.

The routing exercise for Scenario B (Narrow band gate control) again shows that at intermediate flows (flows corresponding to lake levels around 6.3m OD) some reduction is achieved, in the order of 0.1m, but at high flows there is little reduction in level.

Again, the water level pattern generated by routing using Scenario C (Lower limit gate control) is very similar to the existing water level pattern recorded during the six year period 1981-1986 though in some intermediate floods (eg September-October 1985), there is a slight worsening of conditions

The conclusion of this 1987 OPW study was that the flow routing studies demonstrate that the gates in the sluice barrage are well manipulated at that time. Gate manipulation policy has not changed since then.

The report concluded that there is no new gate manipulation policy that can be recommended that will yield any significant reduction in Lough Corrib high levels following heavy prolonged rainfall events.

This conclusion from the1987 report is still valid today.

2.6 Catchment Geology and Hydrogeology

A brief desk study was carried out of the catchment to assess the significance of the aquifer system in the catchment region and to quantify the winter rainfall acceptance potential of the overlying soils and sub-soils ie. the ability for rainwater to infiltrate the soil.

The Geological Survey of Ireland (GSI) quaternary map indicates bedrock and shallow till as the overburden cover for the entire region east of the Corrib to Athenry including the study catchment. This quaternary is generally referred to as free draining. The Flood Studies Report (NERC, 1975) winter rainfall acceptance potential map, 1:625,000, was also consulted and this shows very high infiltration capacity for the catchment (SOIL type 1).

The catchment area is underlain by a pale to medium grey, bedded, fossiliferous, medium grained limestone called the Burren limestone (Daly, 1985). This limestone is generally pure with low clay content. It is often present at or close to the ground surface with only a thin cover of free draining sandy till (boulder clay).

Pure limestones such as the Burren Limestone are susceptible to solution by groundwater moving through cracks in the rocks. The acid in rainwater reacts with the calcium carbonate in the limestone to form calcium bicarbonate. This is soluble and so is removed in solution thus enlarging the cracks in the rocks and causing the formation of widened conduits and caves. This solution of limestone, creating distinctive features of relief, hydrology and hydrogeology, is called karstification.

The whole catchment forms part of a Regionally Important Karstified (conduit) Aquifer. Karst features are located throughout the catchment, most notably there are at least seven turloughs and a swallow hole in the vicinity of Corbally North and South over a river reach of 3 to 4km. There are two turloughs, three springs and two swallow holes in the Abbert River catchment. There is also a spring located halfway between Lackagh Bridge and Cregmore Bridge, a turlough in Caherlea/Lisheenavalla and an estevelle in the vicinity of Crusheen Bridge.

The type of flooding experienced in karstified catchments can include the backing up of sinking streams with inadequate underground channel capacity or the flooding of closed depressions by rising groundwater.

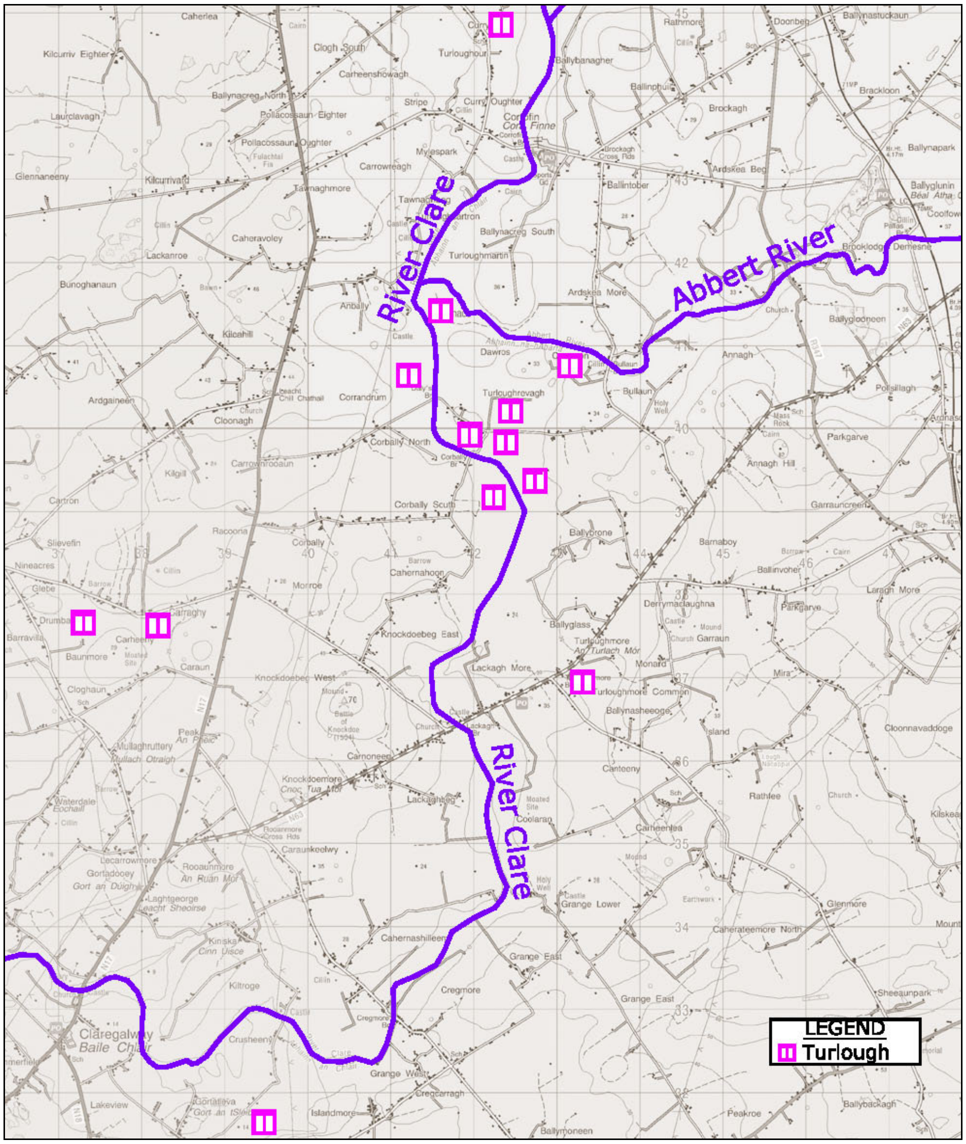


Figure 2.5 Location of Karst Features

2.7 Ecology

The River Clare catchment forms a key component of the Lough Corrib candidate Special Area of Conservation (cSAC) which is selected for the numerous aquatic habitats and water-dependent species occurring there that are listed in Annex I and II of the EU Habitats Directive, including hard water lakes, lowland oligotrophic lakes, Atlantic salmon, White-clawed crayfish, Otter, Pearl mussel, Sea lamprey, Brook lamprey and Slender naiad.

The River Clare catchment is considered to be one of the most important salmon spawning tributaries of the Corrib system. Any work to be carried out on the river will most likely require an Appropriate Assessment. No work will be permitted in the river during the spawning season of October to March inclusive.

2.8 Meteorology

The mean annual rainfall at Galway (National University of Ireland, Galway) is 1147mm and at Athenry it is 1164mm. Rainfall duration, intensity and frequency tables for Galway are presented below in Table 2.1.

The rainfall data relating to specific flood events will be discussed in more detail in Section 2.11 of the report.

STATION NAME: GALWAY
RP5 60 min = 15.3mm
RP5 2d = 57.0mm
Annual Rainfall = 1147

Rainfall in mm for a Range of Duration and Return Period

	Return Period (Years)						
Duration	**½**	**1**	**2**	**5**	**10**	**20**	**50**
15 min	4.4	5.5	6.2	8.3	10.2	12.2	15.4
30 min	6.0	7.4	8.3	11.2	13.7	16.4	20.8
60 min	8.3	10.3	11.5	15.3	18.4	21.9	27.4
2 hr	11.0	13.6	14.9	19.4	22.9	26.7	32.6
4 hr	15.1	18.2	20.0	25.6	30.0	34.6	41.8
6 hr	18.8	22.5	24.3	30.8	35.7	40.6	48.6
12 hr	24.3	29.1	31.5	39.9	46.3	52.7	63.0
24 hr	30.9	36.3	39.7	49.0	55.9	63.7	74.5
48 hr	38.1	44.7	48.9	60.4	68.9	78.5	91.8

Table 2.1 Rainfall duration, intensity and frequency tables at Galway (NUIG)

2.9 Urbanisation and Land Use Zoning

The Claregalway area and surroundings have seen considerable residential and commercial development in recent years. The remainder of the study catchment can be considered rural; however, it should be noted that there is extensive residential development throughout the rural fraction. Galway County Council's Local Area Plan (LAP) for Claregalway 2005-2011 sets out a strategy for the development of Claregalway. A copy of the proposed land zoning for Claregalway is shown below in Figure 2.6.

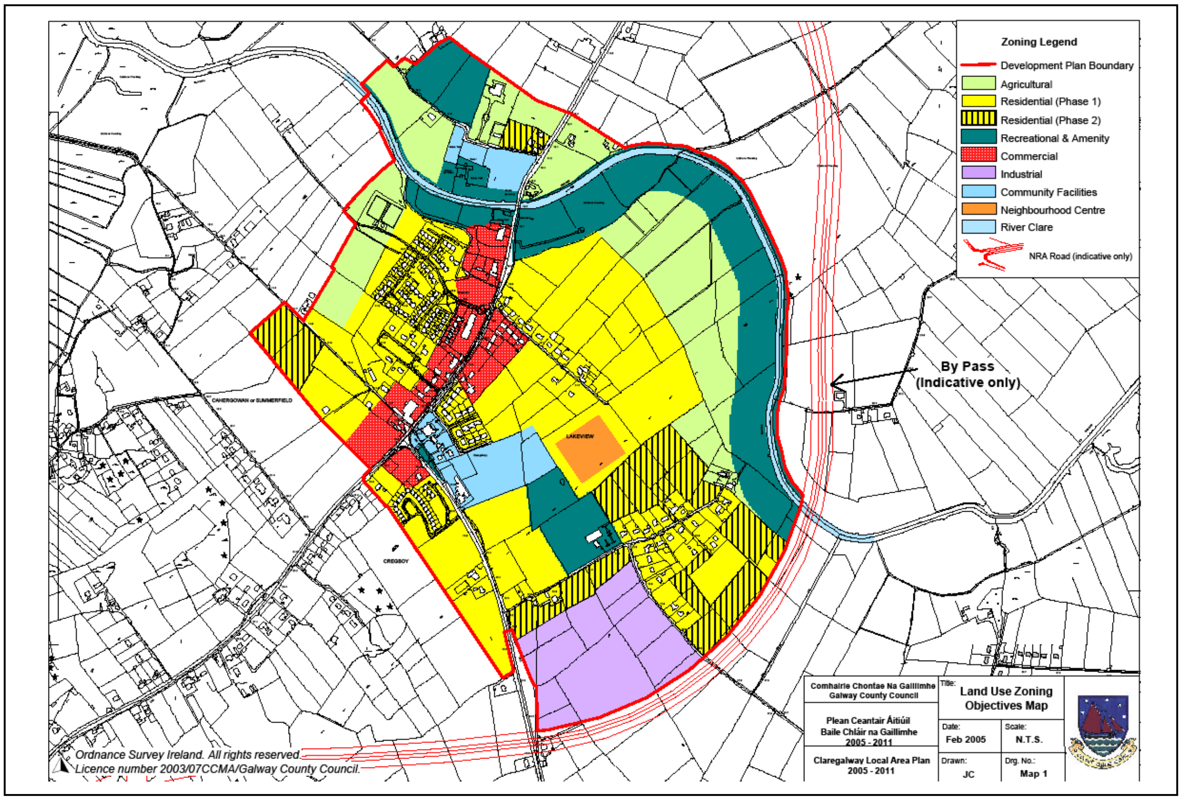


Figure 2.6 Land zoning for Claregalway – taken from the Claregalway Local Area Plan 2005-2011

The proposed average housing density within residential zones is assumed to be 25 houses per hectare. In total there is approximately 148 hectares zoned for commercial, industrial, residential and community facililities. The urban fraction of the Clare River catchment relevant to this study is therefore taken to be 148 hectares having an assumed impervious area of 40%. It is noted that this urban fraction is located towards the downstream end of the study catchment.

It is recognised that urbanisation can have the following effects on river systems: -

(a) The generation of larger volumes of runoff due to greater impervious areas.

(b) An increased response to rainfall resulting in a shorter time to peak and a flashier/peakier flood hydrograph.

(c) The canalisation/culverting of streams leading to faster conveyance of stormwater to watercourses.

(d) Land use changes in the floodplain resulting in obstructions to overbank flood flow.

(e) Obstructions to the river channel due to the construction of bridge/culvert crossings.

(f) Encroachment of the river's natural flood plain by development.

In addition to the size of the urban fraction, the location of the urban development is also of significance. An urban fraction which is largely located at the downstream end of the catchment, will respond faster in terms of flood peak to a storm event than the main/rural catchment and consequently their extreme flood peaks generally do not coincide. Notable floods usually occur in the summer period for urban areas due to the more intense rainfall patterns associated with summer storms and the impervious nature of urban catchments (runoff rate not significantly influenced by the soil moisture deficit), whereas with rural catchments the notable floods are generally winter floods when the antecedent conditions ensures a saturated catchment.

Another item of note relating to the Claregalway Local Area Plan is the proposed provision of a bypass of the town to the east. This would involve an additional bridge across the Clare River upstream of the existing Claregalway Bridge on the N17.

2.10 Heritage

There are a number of recorded monuments in Claregalway which provide evidence of early settlement in the area. They are afforded special protection under Section 12 of the National Monuments (Amendments) Act 1994. The monuments include two examples of ecclesiastical remains (GA070-012 and GA070-035), as well as a tower house (GA070-036) and a settlement (GA070-109). Galway County Council's strategy approach in relation to archaeological heritage in Claregalway is to ensure the protection and sympathetic enhancement of the Recorded Monuments in consultation with the Department of Environment, Heritage and Local Government (DEHLG). The Local Area Plan sets out that all planning applications for new development, redevelopment, any ground works, refurbishment, restoration etc within and in close proximity (30m) to the Zone of Archaeological Potential and within close proximity (30m) to the other recorded monuments shall take account of the archaeological heritage of the area and the need for archaeological mitigation.

2.11 Historical Flooding

There is a history of flooding in the catchment including the most notable flood events of recent times in November 2009, December 2006, January 2005, December 1999 and the winter of 1990.

Flooding in the catchment below Claregalway Bridge is largely influenced by high lake levels which occur frequently. When high lake levels occur in combination with large fluvial flood flows in the River Clare, extreme flood events such as those in 2006 and 2009 occur in areas west of Claregalway town.

By contrast flooding in Claregalway Town and in the Clare catchment above Claregalway Bridge is caused exclusively by river floods, the characteristics of the river channel and their effect on the discharge of high runoff volumes from the river catchment through Claregalway Bridge.

Flooding due to rising groundwater levels in areas distant from the river above Claregalway such as Lisheenavalla, Caherlea and Ardskeaghmore are more complex. Although no doubt related to the adjacent level induced by the passage of river water through the Clare channel, the karst nature of the underlying fissured limestone geology and the role played by it in inducing and dissipating such local flood waters is complicated and beyond the scope of this study.

The main topic of this study is the flood event of November 2009; however the other recent significant flood events are described briefly below as background information.

2.11.1Flood Events of Winter 1990 and Winter 1991 and the GSI Report of 1992

The information relating to this flood event is taken from a report carried out by the Geological Survey of Ireland (GSI) in March 1992. Flood events in the winters of 1990 and of 1991 took place as a result of extreme rainfall in the months of January to February 1990 and December 1990 to January 1991. The main consequences of the 1990 and 1991 events was flooding of low lying ground along the Clare River between Turloughmore and Claregalway and downstream of Claregalway to Lough Corrib. The flooding lasted in some areas for six weeks in 1990 and went close to inundating a house as well as flooding a road in Lisheenavalla. However, the main issue was flooding of farm land, which according to local farmers at the time, occurred regularly but was exceptionally bad in February 1990.

The GSI report deduced that the rainfall event of January and February 1990 was the worst event since 1953 (the earliest year for which data was available). The February 1990 Monthly Bulletin produced by

Met Eireann has " Stormy February – Wettest Ever" as the headline and it reported "a seemingly unending series of vigorous Atlantic depressions …….bringing prolonged periods of heavy rain that caused widespread flooding at times"

The intensity and persistence of the rainfall event from 18 December 1990 to 11 January 1991 was greater than for any other corresponding event since 1953. Since 1953, the order of the statistical significance of rainfall events at that time was early 1990 (as described above), 1959/1960 and the third in January 1991. To conclude, the worst and the third worst rainfall events occurred in a 12 month period between February 1990 and January 1991.

The GSI report concluded that the height of the floods around Lough Corrib in 1990 and 1991 would not have been diminished if the sluice gates were kept open all year round. Consequently, it can be deduced that the present gate manipulation policy has no influence on the levels of of extreme lake floods.

2.11.2 Flood Event of December 1999

The Met Eireann monthly weather bulletin of December 1999 described the month as "a wet month everywhere with over twice the normal rainfall in places; this rain was often accompanied by strong winds. Flooding was widespread in the west and southwest over the Christmas period where the heaviest rain fell. It was the wettest December on record in many stations in the west and north including Belmullet and Malin Head, while it was the wettest of any month at a few stations with records stretching back over 40 years. Over most of the country, rain was measured on all but three or four days during the month, with heavy falls on several days, notably the 8th, 10th, and in the periods 16th to 18th and 20th to 24th.

There were 25 wet days in County Galway. Maam Valley measured the highest daily fall of the month, 59.3mm on the 16th December. Fig 2.7 below sets out recorded daily data for December 1999 recorded at the meteorological at NUIG Galway. 274mm or 195% of the average monthly rainfall fell during the month of December 1999. 35.9mm of rain was recorded on the 21st December alone.

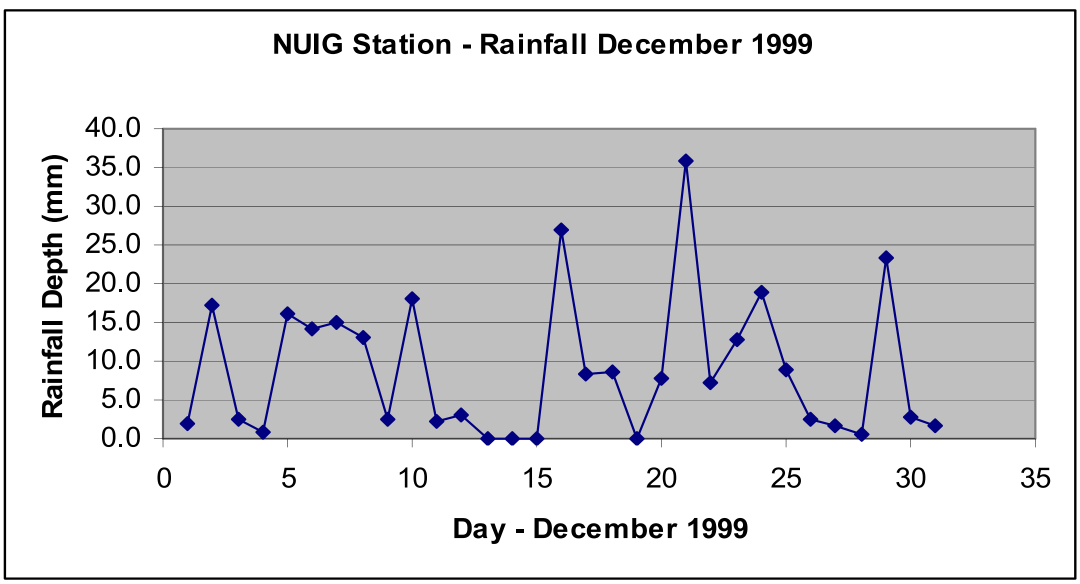


Figure 2.7 Daily recorded rainfall depths recorded at NUIG – December 1999

A peak water level of **8.907m** OD (Malin) was recorded in the River Clare at Claregalway (daily average value) on 25 December 1999.

Plate 2.1 Taken from downstream face of Claregalway Bridge during the 1999 flood event.

2.11.3 Flood Event of January 2005

The weather of the first three weeks of January was dominated by deep Atlantic depressions close to the country which resulted in a long spell of wet and stormy weather. Figure 2.8 below sets out the daily rainfall totals recorded for January 2005.

High wind and heavy rainfall brought widespread disruption throughout the country and floods to the west of the country starting on the 7th and 8th January. Three day totals of over 50mm were recorded in western areas around this time. 172.5mm of rain was recorded for the month at NUIG all of which took place in the first three weeks of the month. In total, 24 wet days were recorded in Galway in January 2005.

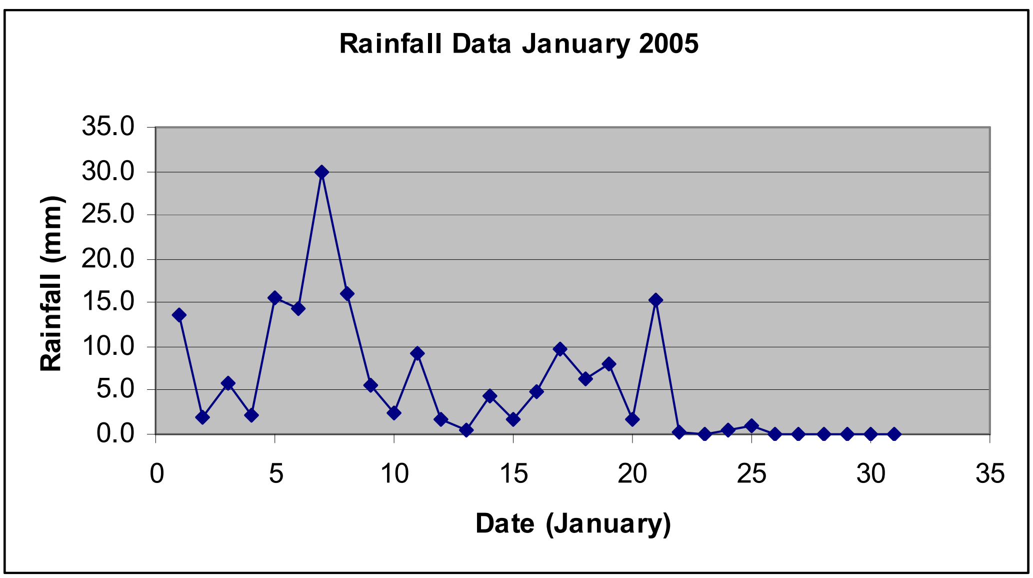


Figure 2.9 Daily recorded rainfall depths recorded at NUIG – January 2005

Extensive flooding occurred in the Clare River catchment as a result of this rainfall. The graphs below illustrate the corresponding levels in the Clare River at Claregalway for January. The peak of the flood occurred on 10th January (06:15 hrs) at a water level of **8.77m** OD (Malin). At this level, the river would have overflowed its banks at Claregalway and flooded surrounding fields. The N17 road would not have flooded at this level.

The corresponding level in Lough Corrib at the time at the Anglinham station was 6.54m OD (Malin), a difference in water level of 2.23m. All the sluice gates at the Salmon Weir were open from the 7th January 2005 with 14 out of 16 gates having been up until the 4th January 2005 and 12 open since 25th December 2004.

The recorded water levels of the lake at the Anglinham gauge and of the Clare River at Claregalway Bridge are plotted on Figure 2.9 relative to the severe rainfall event of January 2005

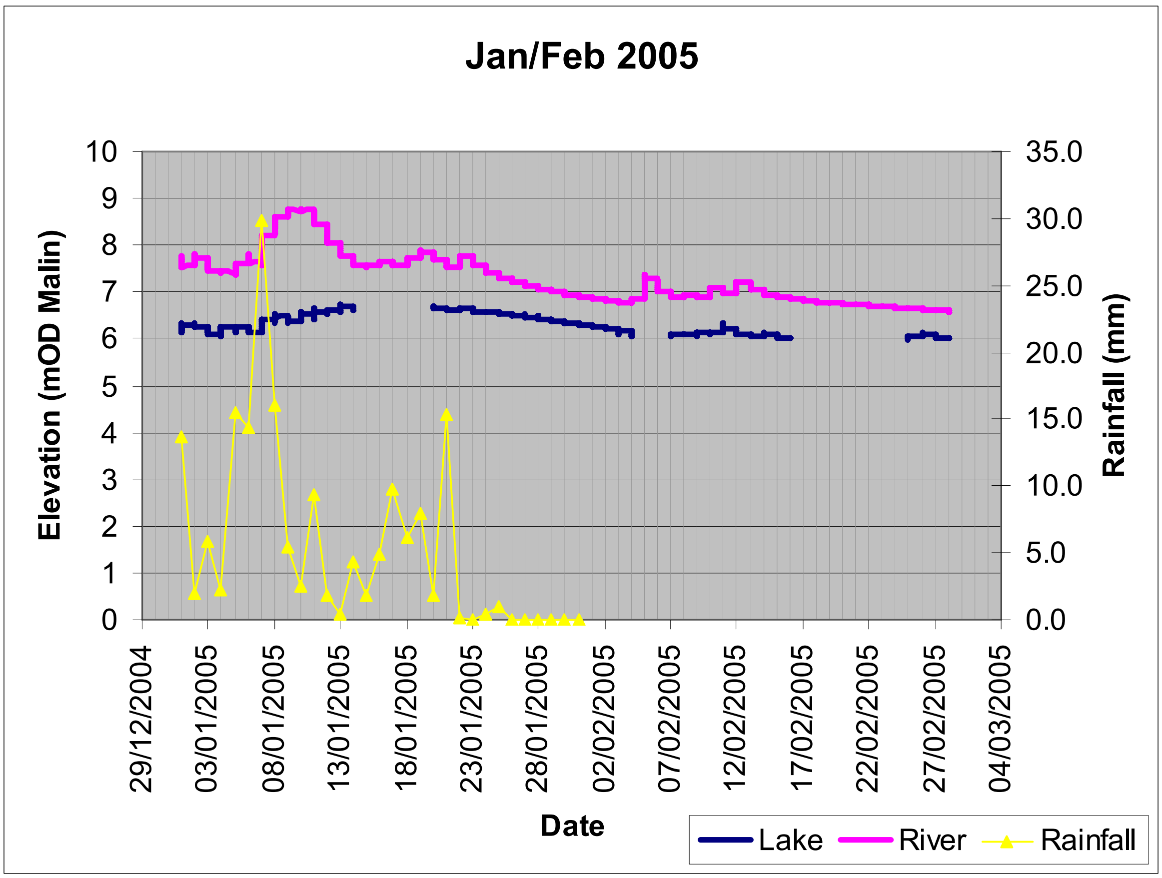


Figure 2.9 Recorded Lake and River levels Jan/Feb 2005 vis-à-vis daily rainfall records

The aerial photographs overleaf from the OPW illustrate the impact of the flooding in the Claregalway area in January 2005.

Plate 2.2 Looking south east from Claregalway towards Lakeview (Caherlea in background) – Jan 2005

Plate 2.3 Turloughs at Lakeview – Jan 2005

Plate 2.4 Flooding in Gortatleva and Caherlea/Lisheenavalla area – Jan 2005

Low lying land in the Miontach, Cahergowan and Curraghmore areas downstream of Claregalway were also extensively flooded during this flood event.

2.11.4 Flood Event of 2006

Meteorological data shows that the summer of 2006 was generally dry with below average rainfall from mid May to mid August with heavy rainfall commencing during the last weeks of August 2006. However rainfall recorded during each of the final four months of 2006 was considerably above average as set out in Table 2.2 below

Month	Recorded Rainfall 2006 (mm)	Average 1966-2006 (mm)	Maxima 1966-2006 (mm)
September	**232.8**	106.5	**232.8 (Sept 06)**
October	148.2	131.0	284.9 (Oct 67)
November	149.3	122.5	211.0 (Nov 02)
December	199.2	124.5	274.0 (Dec 67)
Sept to Dec (incl)	**729.5**	484.5	**729.5 (2006)**

Table 2.2 Monthly Recorded Rainfalls at Claremorris Station - September to December 2006

The level in Lough Corrib usually takes a number of months to peak following the Autumn – early Winter rainfall each year. The cumulative rainfall event during the months preceding December was an extreme occurrence and represents the highest cumulative rainfall for the four month period September to December within the 40 year record supplied by Met Eireann resulting in very high lake levels in early to mid December 2006. Recorded rainfall for September to December 2006 inclusive exceeded the cumulative rainfall recorded in previous maximum years i.e. 1967, 1999 and 2000 by 10 -11%.

Plate 2.5 Confluence of Clare River and Lough Corrib - Headford Road (Curraghmore) – 8 Dec 2006

Plate 2.6 Flooding downstream of Claregalway at Miontach townland – 8 December 2006

The December 2006 flood event on the Clare River upstream of Claregalway was caused by runoff from an extreme rainfall event in the Clare River catchment. 149mm of rainfall fell on the catchment over a 10 day period in early December 2006 resulting in a severe river flood which came to soffit of the Claregalway Bridge

Water levels recorded in the lake and on the Clare River at Claregalway in December 2006 are shown Figure 2.10 below in conjunction with daily rainfall record at the NUIG meteorological station;

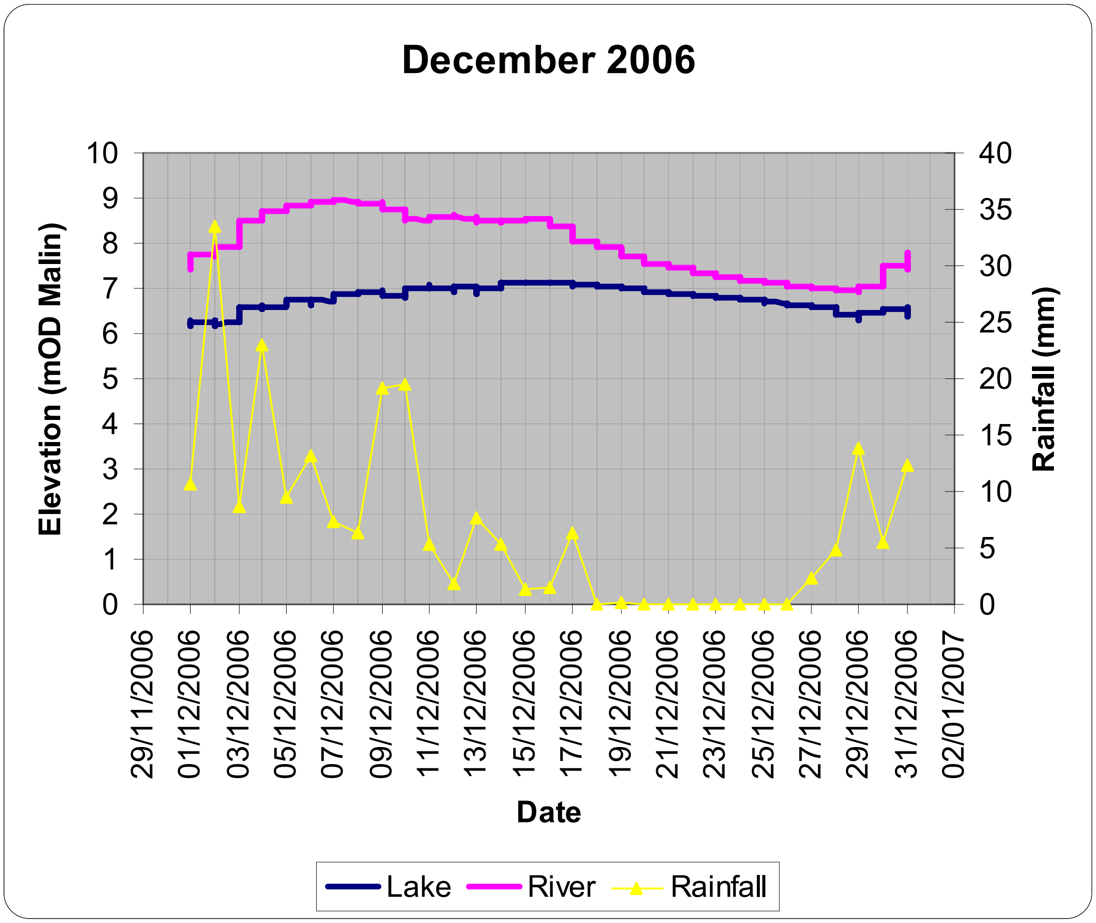


Figure 2.10 Recorded Lake and River levels December 2006 vis-à-vis daily rainfall records

A peak water level at the Claregalway Bridge river gauge of **8.944m OD (Malin)** was recorded on 7th December 2006.

The corresponding level on Lough Corrib at the time at the Anglinham gauge was **6.801m OD (Malin)**, a difference of approximately 2.14m in stage between the Claregalway gauge and Lough Corrib lake level on that day. The river gauging station at Claregalway is mounted on the downstream face of the bridge.

The water level upstream of the Bridge was higher, as described below for the November 2009 flood event.

Plates 2.7 to 2.10 overleaf show the extent of flooding in December in Claregalway and areas adjacent to the River Clare upstream of the town.

Plate 2.7 Looking towards Claregalway from the North – 8 December 2006

Plate 2.8 N18 road east of Claregalway (Lakeview in foreground, River in background) - 8 Dec 2006

Plate 2.9 Clare River in vicinity of Crusheen Bridge – 8 December 2006

Plate 2.10 Caherlea and Lisheenavalla – 8 December 2006

2.12 November 2009 Flood Event

A brief description of the November 2009 flood event and the extreme rainfall event that caused the flooding is provided here in the context of the other historical flooding described above. Further detail and description of the cause, mechanism of flooding and flood impact is provided in later sections of this report.

2.12.1 High rainfall recorded in the Corrib catchment prior to the November 2009 flood

It is worth noting that the extreme rainfall recorded in November 2009 was preceded by a notably wet summer. Rain or showers were recorded on every day during July 2009. It was the wettest July for over 50 years in many places and the wettest on record at a number of stations. By the end of July, Met Eireann soil moisture records show that the land was almost completely saturated. 161.1mm of rainfall was recorded for the month at NUI, Galway which represented 237% of the monthly average. Rain fell on 26 days of the month, with a peak daily rainfall of 23.7mm recorded on the 5th July.

After this very wet July, August was another month of very unsettled weather with rainfall totals well above normal. 215.7mm of rainfall was recorded for the month at NUI, Galway, representing 214% of the monthly average. Rain fell on 27 days of the month with 28.9mm recorded on 30 August alone. The wet weather of August extended into the first week of September when some heavy rainfalls were recorded which caused flooding in some parts of the country as soil conditions were saturated. Overall, the rainfall for the summer season (June, July, August) 2009 was up to 175% above average for the catchment.

It was therefore most likely that the catchment was above normal saturation levels by the end of summer 2009 prior to the commencement of the prolonged rainfall in October/November 2009.

October/November 2009 was notable for the high rainfall recorded and the consequent severe flooding experienced in many parts of the country. Atlantic depressions passing close to Ireland brought wet and windy conditions throughout almost all of November, continuing a pattern of very unsettled weather over Ireland which began in the middle of October.

The 18th to 31st October was a period of unsettled weather as a series of Atlantic depressions and their associated fronts moved across Ireland. The heaviest rain was measured on the 19th/20th, 24th and 30th, with widespread heavy showers also on the 21st and 22nd.

From November 1st to 26th, a series of fast moving deep Atlantic depressions brought active frontal systems across Ireland, bringing very wet and windy conditions. Spells of rain or showers gave falls of 10mm or more on many days across Connacht and Munster, while all areas received heavy falls on the 1st, 9th, in the period 16th to 19th and on the 21st. The **total monthly rainfall for November 2009** at NUI Galway was 465mm, approximately **300% of normal** November rainfall.

Daily rainfall amounts for November 2009 are shown on the graph below for NUI, Galway. The heaviest rain fell on the 17 November 2009 with 60.8mm of rain recorded on this day alone. This is the highest daily rainfall amount on record at this station. A further 28.7mm fell on the 18 November giving a two day rainfall total of 89.5mm. The next highest daily rainfall amount recorded during any of the historical flood events described above was 35.9mm recorded on 21 December 1999. Met Eireann agro-meteorological data shows that by the 10th of November, soil moisture deficit was zero, meaning that field capacity had been reached.

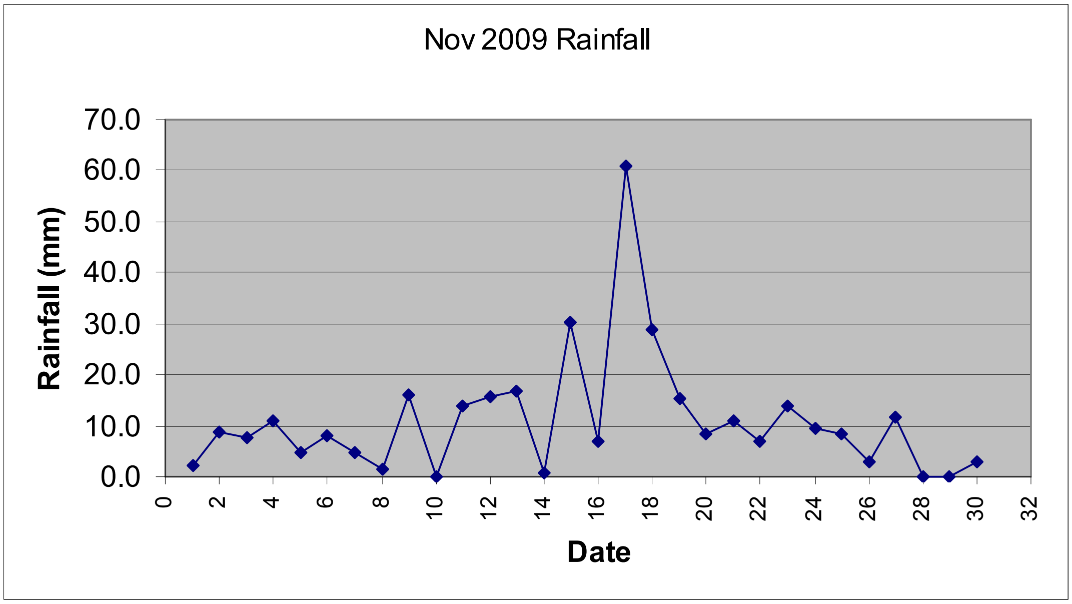


Figure 2.11 Daily recorded rainfall depths recorded at NUIG – November 2009

2.12.2 The Statistical significance of the extreme rainfall event that preceded the November 2009 floods

Met Eireann has carried out an analysis of the rainfall data in November and has estimated rainfall return periods for the study area ie Clare River catchment between Corofin and Lough Corrib.

The data in **Table 2.3** below is from Appendix 1 of Met Eireann's Climatological Note No. 12 "Report on Rainfall of November 2009" for the NUIG Meteorological station in Galway City.

Rainfall Event	Estimated Return Period of rainfall event
1 day duration - 17 Nov 09	**29** years
2 day duration - ending 18 Nov 09	**134** years
4 day duration - ending 18 Nov 09	**293** years
8 day duration - ending 19 Nov 09	**306** years
16 day duration - ending 24 Nov 09	**272** years
25 day duration - ending 26 Nov 09	**131** years

Table 2.3 Estimated Rainfalls Return Period – November 2009

In the case of flood events in the Clare and Abbert rivers, rainfall events in the order 4, 8 and 16 days duration are thought to be significant to the volumes of flood runoff particularly from a saturated catchment area. Figures 4(a) to 4 (f) of Climatological Note No. 12 are maps of Ireland which show the area of the country where rainfall of particular statistical significance in terms of return period was recorded during November 2009. The area of the country, where rainfall events of 4, 8, and 16 day duration was significant, extended in a north easterly direction from Galway City towards County Roscommon and included the upper Shannon Catchment. This area contains the portion of the Clare and Abbert river catchments which are contained within the study area of this report. The statistical significance with respect return period of 4, 8, and 16 day duration is seen to increase in a north easterly direction.

2.12.3 The effect of lake, river and turlough flooding in November and December 2009

Water levels at Lough Corrib and the Clare River at Claregalway from October to December 2009 are plotted on Figure 2.12 below in conjunction with the daily rainfall record for November 2009;

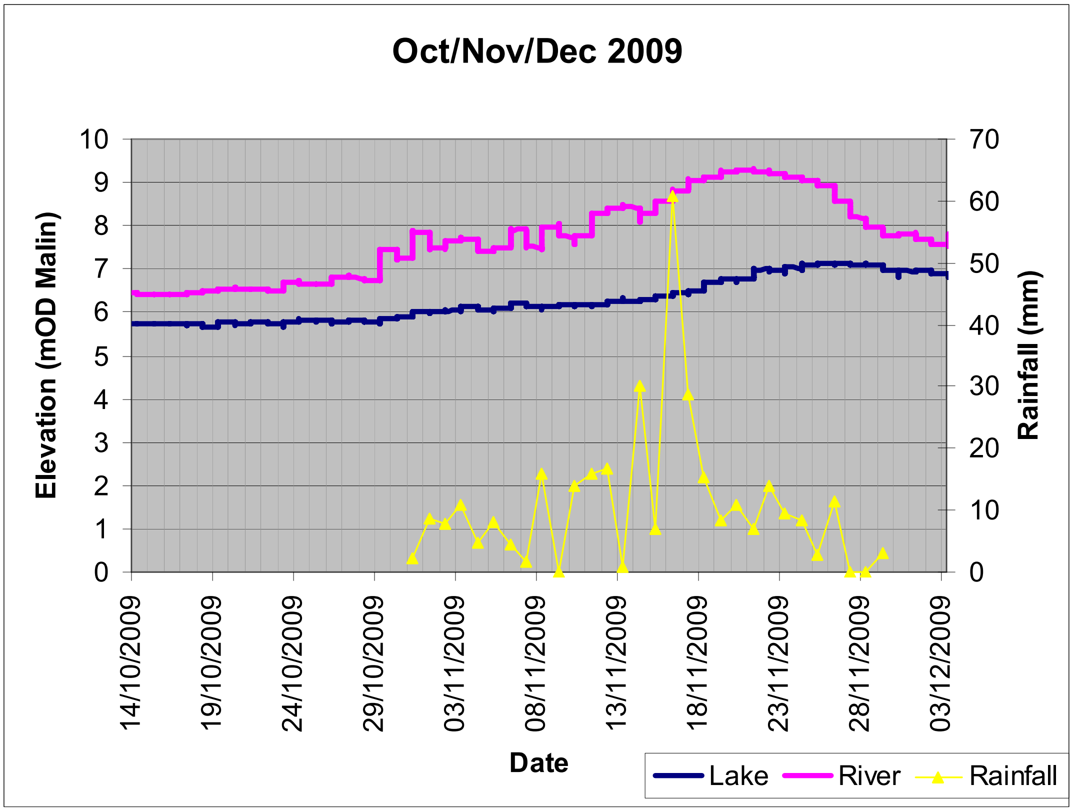


Figure 2.12 Recorded water levels at the Lake and at the River in Claregalway from Oct–Dec 2009 plotted vis-à-vis daily rainfall records for Nov 2009

The peak water level of 9.303m OD (Malin) at Claregalway Bridge was recorded on Sunday, 22nd November 2009. This level was 360mm higher than the previous highest water level recorded in December 2006.

Plate 2.12 Flooding of Clare at Claregalway - taken from upstream of bridge on 20 November 2009

The corresponding level on Lough Corrib at the time at the Anglinham gauge was **6.928m** OD (Malin), a difference of approximately 2.34m in stage between lake and the river at the Claregalway gauge on that day. Plate 2.13 shows the River Clare at the Headford Road (N84) crossing in Curraghmore on 20 November 2009.

Plate 2.13 River Clare Flooding on N84 at Curraghmore Bridge - 20 November 2009

It is noted that the hydrometric gauge is located on the downstream side of the Claregalway Bridge, meaning that the water levels logged by the data logger are not fully representative of the stage on the upstream face, particularly as the bridge acted as a hydraulic constraint. It has further been established by the EPA, the authority responsible for hydrometric gauge at Claregalway, that the water level as recorded at the datalogger was lower than the actual water level that occurred downstream of the gauge in calmer waters. This was as a result of the extreme conditions of high velocities in combination with turbulence at the datalogger housing, resulting in a hydraulic jump. Anecdotally we know that the water levels were higher than the soffit level of the bridge both upstream and downstream, which would have also caused much turbulence at the downstream side of the bridge where the logger is located. Therefore, the water levels recorded by at the gauging station need to be adjusted in order to establish the actual peak water level. By surveying the wrack mark downstream of the bridge following the peak of the flood, the EPA established that a correction factor of + 0.233m needs to be applied to the datalogger readings to give the true peak water level at the downstream face of the bridge.

Therefore, the correct peak water level downstream of the bridge is estimated as **9.536m OD (Malin).** The large difference in water level between the upstream and the downstream face of the bridge is most likely attributable to the bridge forming a choke resulting in higher water levels on the upstream side.

The water level was surveyed on the 21 November both upstream and downstream of the bridge and revealed a 0.800m difference. Therefore, the true peak water level at the upstream face of the bridge is **10.336m** OD (Malin). The level of the soffit of the bridge at Claregalway is 9.08m OD (Malin), 1.26m below the peak water level.

The following photos in Plates 2.14 and 2.15 taken by the EPA demonstrate this choke effect. Both photos show the upstream face of the bridge.

Plate 2.14 Upstream Face of Claregalway Bridge – 21st November 2009

The existing record of river levels at Claregalway Bridge 1996 - 2006 set out below in Figure 2.13 shows the magnitude of the water level in November 2009 compared to previous floods during the available period of record since 1996.

It should be noted that the depth W in the graph below refers to height at the staff gauge. 5.724m must be added to the W levels quoted to bring the level to Ordnance Datum Malin Head.

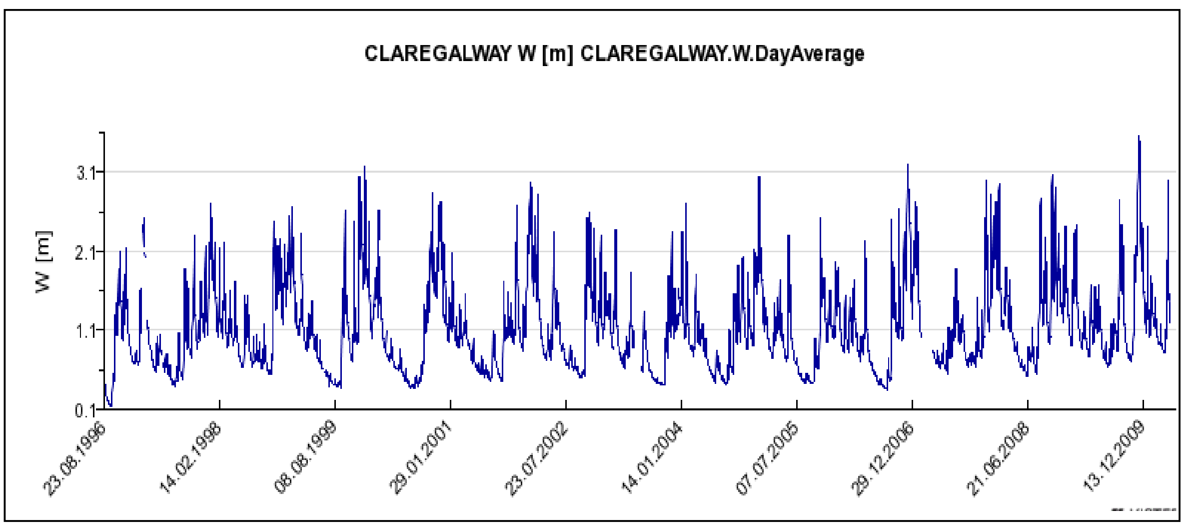


Figure 2.13 River Clare Water level at the Claregalway gauging station -1996-2006

Based on the rating curve for the river at Claregalway Bridge, the peak water level on the downstream face of the bridge would correspond to a peak flow of 162 cumec.

The road on the bridge was not flooded as it is a higher level that the approach roads both north and south of the bridge. However, on the N17 approach to the bridge outside the Arches Hotel, a flood depth of 0.635m has been established, making the road impassable for a number of days.

Plate 2.15 N17 at Claregalway flooded adjacent to replica stone arch bridge & Arches Hotel

Plate 2.15 Flooded of the N17 at Claregalway – south of the Bridge with Castle in background

The N17 from Galway City to Tuam and Sligo was closed through Claregalway from 20th to 26th November 2009.

Severe flooding occurred throughout the study catchment, both as a result of the Clare and the Abbert Rivers overflowing their banks, as well as overland flow from groundwater features such as turloughs and swallow holes becoming flooded.

The selection of photos included in Plates 2.16 to 2.20 below illustrates the impact of the flooding in various locations around the catchment, starting from Claregalway upstream along the Clare River to Corofin and the Abbert River.

The worst affected areas within the study area were in

- Miontach townland downstream of Claregalway Bridge(where one house was flooded (see Plate no 2.16)
- Claregalway village itself where access to national roads, housing estates and commercial developments was hampered by flood waters (see Plates no 2.17),
- Caherlea/Lisheenavalla townlands where thirteen houses were flooded and local road access was hampered by raised water levels in turlough areas (see Plates no 2.18, 2.19, and 2.20)
- Ardskeaghmore townland and Bullaun townland (on the Abbert River catchment upstream of its confluence with the River Clare) where 6 dwelling houses were flooded to a depth up to 1.2metres (see Plates no 2.21, 2.22, and 2.23)

Plate 2.16 Miontach Townland totally isolated by flooding adjacent to the River Clare downstream of Claregalway – November 2009

Plate 2.17 Flooded housing estate development in Claregalway – November 2009

Plate 2.18 House in Caherlea townland 21 November 2009

Plate 2.19 Flooding in Caherlea townland 22 November 2009

Plate 2.20 Flooding of roads and houses and dwelling at Lisheenavalla – 5km upstream of Claregalway – 21 November 2009

Plate 2.21 Flooding at the confluence of the Clare and Abbert Rivers 23 November 2009

Plate 2.22 Flooding on the Abbert River looking south to Bullaun Bridge on 20 November 2009

As would be expected due to the size of the Abbert catchment to Ardskeaghmore (211 km^2) relative to the Clare catchment upstream of Claregalway (1,073 km^2), the flood peak at Ardskeaghmore occurred ahead of the flood at Claregalway.

Runoff to the Abbert River from a number of persistent days rain from 15th to 18th November 2009 (see Figure 2.11) resulted in the overtopping of the river banks both upstream and downstream of Bullaun bridge on 19th November which caused the flooding of six dwelling houses. The larger Clare catchment to Claregalway peaked three days later on 22nd November 2009 following the extreme rainfall event of longer duration (see Figure 2.11 and Table 2.3 above).

It is noted that the flooding experienced in the Clare River catchment in December 2006, was not experienced to the same extent in the Abbert catchment. No property was flooded in this event. From an outline hydrological analysis of the Ballygaddy gauge north of Corofin, which is similar in catchment size and soil factor to the Abbert catchment, the return period for the December 2006 flood on the Abbert River is estimated at 16 years. The estimated return period for the November 2009 flood event on the Abbert is in the region of the 100 year event as detailed in Chapter 4.

From consultation with local residents, the Abbert does not appear to have overflowed in recent memory. However, it would appear from old staff gauge records from Bullaun Bridge that the peak water level of November 2009, may have been exceeded by up to 600mm in October of 1968.

Plate 2.23 House flooded in Ardskeaghmore townland (Abbert River)

Severe flooding including flooding of homes was also experienced outside of the study area in Cregboy (from turlough) and at Carnmore.

3. Data Collection

3.1. General

A substantial body of data has been collected as input to the hydrological and hydraulic model and to inform the findings of the study as described in the sections below.

3.2. Hydrometric Data

Active automatic dataloggers located in the study catchment are as follows (working upstream from lake);

Hydrometric Station	Waterbody	Location	Comment	Frequency of Level Recording
30083	Lough Corrib	Annaghdown Pier	Upstream of Clare River outfall	Every 15 minutes
30089	Lough Corrib	Anglinham	Downstream of Clare River outfall	Every 15 minutes
30012	Clare River	Claregalway	Downstream face of bridge	Every 15 minutes
30004	Clare River	Corofin	Downstream of bridge. Boundary of study area	Every 15 minutes
30004	Clare River	Ballygaddy	Upstream of study area	Every 15 minutes

Table 3.1 Location of automatic level recorders on Lower Lough Corrib/ Clare catchment

There are no active automatic dataloggers on the Abbert River.

All of the level data collected for this study has been converted to Malin Head Ordnance Datum.

A rating curve has been obtained from the EPA for the gauge at Claregalway and is shown in Figure 3.1 below;

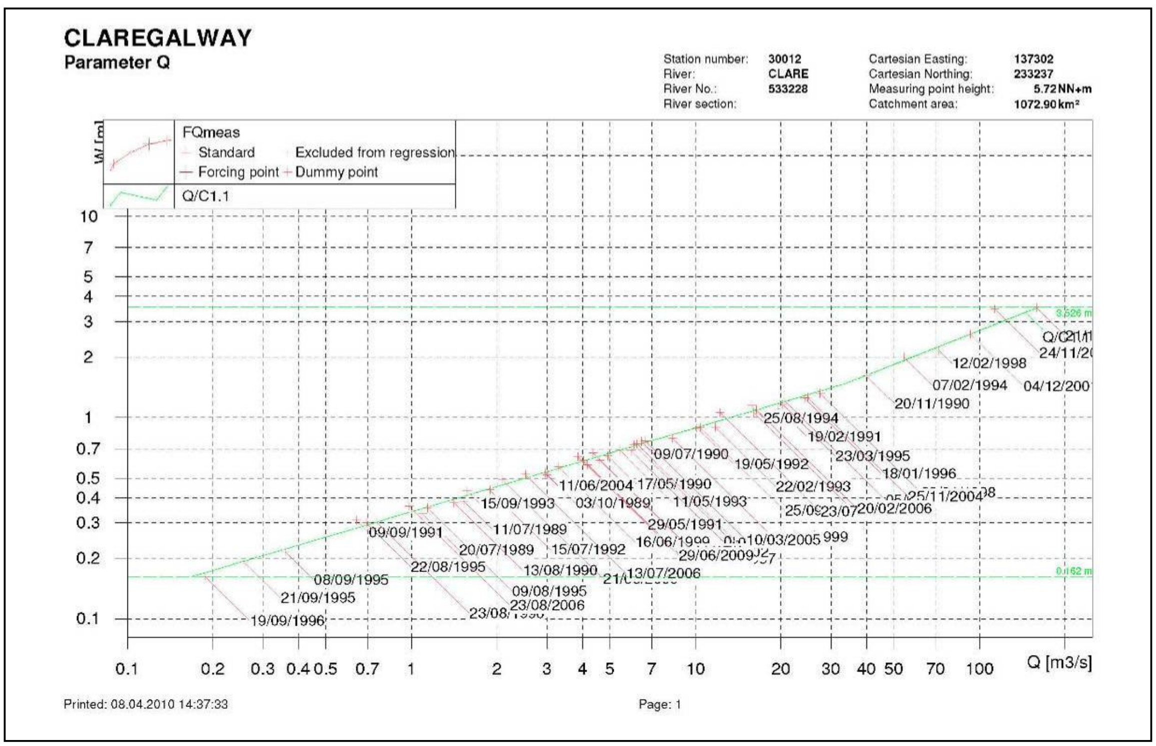


Figure 3.1 Rating Curve for River Clare at Claregalway

3.3. Meteorological Data

The nearest Met Eireann rainfall station to the catchment is at the National University of Ireland, Galway in Galway City, approximately 10 km away. Daily rainfall totals were obtained for this station for the significant flood events of recent years as well as for the November 2009 flood event. Daily rainfall records were also obtained for the rain gauge at the OPW offices in Headford, Co. Galway. The Met Eireann archive of monthly weather bulletins was also consulted particularly for the significant flood events.

3.4. Operational Data

As set out in Chapter 2, the discharge in the Corrib River is controlled by a sluice barrage on the main Corrib River channel just upstream of the Salmon Weir bridge in Galway.

The purpose of the sluice barrage is to regulate the flow in the Corrib River so as to maintain the design water level in Lough Corrib at or above 5.83m OD Malin in time of low flow and at or below 6.44m OD Malin at times of high flow. The OPW maintains a log relating to the operation of the sluice barrage including twice daily data for the number of gates open and closed, the water level at Woodquay and information relating to weather at the time.

As part of the study, the log books were obtained for the last number of years from the OPW and information pertinent to the significant recent flood events were transferred to an electronic database. In Chapter 2, a comment is provided in the description of each of the recent significant flood events as to the status of the Salmon Weir barrage at the time of the flood.

The study and modelling carried out by the OPW in 1987 with respect to discharge of flood waters from Lough Corrib via the Corrib River channel, provides conclusive evidence that the influence of the sluice gates does not extend upstream to Lough Corrib when water levels are high in Lough Corrib.

However, during the collection of anecdotal evidence, the issue of the sluice barrage was raised by all of the local residents consulted. This is the main reason for collecting this data. There is a strong perception locally that the water level in the vicinity of Claregalway and further upstream is affected by the operation of the sluice barrage. This theory will be tested later in this study using the hydraulic model by applying various lake levels at the downstream end of the study area and examining the effects upstream on the Clare River.

The local resident's accounts of perceptible falls in water levels as a result of the gates being opened may be as a result of the lowering of the groundwater level in the downstream end of the catchment. This theory assumes that some of the groundwater in the Clare River catchment discharges via underground channels to Lough Corrib or the Corrib River downstream of the Clare River channel confluence and thus the groundwater level is influenced more by Lough Corrib and Corrib River levels than the Clare River channel levels. A detailed hydrogeological study of lands between Claregalway and the Corrib River would be required to test this theory. However, ultimately such a study may prove inconclusive due to the karst nature of the geology underlying the study area catchment.

3.5. Surveys

In order to build the hydraulic models of the Clare and Abbert rivers, cross sectional surveys were carried out at approximately 150m intervals along the length of both rivers. Detailed cross sectional surveys were also undertaken at the upstream and downstream faces of all bridges and other structures along the channel.

As the river levels and flows were very high at the start of the survey following rainfall in early April, the survey of the banks and flood plains of both the Clare and Abbert rivers was carried out in advance of

the channel survey. These surveys were carried out using two GPS systems. Two members of the survey team marked out the locations of each cross section and surveyed one bank of the river using one GPS while two members surveyed the other bank of the river using the second GPS system.

Due to the width and depth of the Clare River, the channel survey was undertaken using a 12ft x 5ft flat-bottomed boat. As the current in the river was quite fast in certain sections, a 5 horse powered outboard motor was used to help stabilize the position of the boat at each cross section. A line with tags at 2 metre intervals was slung across the water. A member of the survey team was positioned on each bank holding the line taut in order to demarcate the line of the section. Using the GPS systems, the bank surveyors recorded the x, y and z co-ordinates of the start and end locations of the survey line. The remaining two surveyors were in the boat. The helmsman positioned the boat using the outboard motor, while the crewman surveyed and recorded the level of the river bed at each tag along the survey rope. The river bed levels were measured to the top water level (TWL) of each section using a staff. In order to tie in the bed levels, the z values of the TWLs were surveyed by one of the bank surveyors using the GPS equipment.

Plate 3.1 Vessel used for Clare River Channel Survey

A wading survey was carried out for the Abbert River channel as water levels had decreased significantly by the time of this survey. Levels were taken at 2 meter intervals along the bed of each cross section using the GPS equipment.

Detailed surveys were carried out for all bridges along both rivers using the GPS equipment. In total there were 21 bridges surveyed, 11 along the Clare River between Corofin and the outfall to Lough Corrib and 10 bridges along the Abbert River between Ballyglunin and the outfall to the Clare River.

The survey information was inputted to the model as boundary conditions. The data was also used to compare the Arterial Drainage design cross-sections to the current cross sections to assess whether any major changes have occurred in the channel since the scheme was completed in the 1960s.

Topographical surveys were also carried out of finished floor levels of properties, roads and land that were flooded or at risk of flood during the November 2009 flood event.

A bathymetric survey was also carried out to establish river bed levels from Claregalway downstream to the outfall at Lough Corrib and to establish if there is an issue with channel siltation in this reach of the

river. The bathymetric survey was sub-contracted to Aquafact International Services Ltd, who are specialists in this type of surveying. The survey was carried out on 1st April 2010. Weather conditions were good with a moderate south west wind blowing. The survey was undertaken using a SonarMite Portable Echo Sounder with Trimble GeoXT DGPS.

Prior to the survey being carried out, the sounder was calibrated by the bar test method and also against a 1.5m depth probe marked in centimetres and any difference was adjusted as necessary. This exercise was carried out at regular intervals during the survey to confirm that soundings were correct. Once the equipment was set up, the survey vessel followed predetermined transect lines at a speed of approximately three knots. Four transect lines were surveyed along the length of the river with a further 69 cross-section transects at regular intervals between Lough Corrib and Claregalway, at locations specified by Ryan Hanley. The sounder automatically recorded depths every second and DGPS positions every two seconds. It must be noted that although all soundings and contours of the survey are correct to datum, individual rocks/boulders are not portrayed unless the sounder passed directly over them.

In order to reference the recorded depth data to Ordinance Datum, the water surface level on the day of the survey was referenced to temporary benchmarks along the length of the survey area. These TBM's were then levelled to Malin OD by Ryan Hanley staff and all data was then reduced to Malin Head OD.

All data recorded during the survey was supplied in Excel files. Cross section levels at the prescribed locations (C1-C69) were extracted from the data and extrapolated separately as individual cross section data sets. In addition, all depth data recorded on the day of the survey was post processed to produce contour maps (0.5 m intervals) of the survey area. These contour maps are provided in Appendix A.

Following the bathymetric survey, the cross-sections as surveyed were compared with cross sections supplied by the OPW for the Arterial Drainage Scheme so that an assessment could be made of whether the channel has suffered from siltation over the past forty years.

The results of this exercise were surprising. When compared, the current cross-sections are in fact deeper than the channel depth shown on the Arterial Drainage Scheme drawings and not shallower as might have been expected. It must be noted that design cross sections were only available at approximately 2-3 kilometre intervals and thus there are few sections available for comparison. The table below shows the results of this comparison for the Clare River;

	Cross Section		Lowest Bed Level (m OD Malin)		∆ Elevation (m)*
	OPW Section No.	RH Section No.	Original Design (1950s)	Current (2010)	
c23 Curraghmore Br	19/0	c15	3.87	2.94	**-0.93**
c73 Claregalway Br	55/0	c42	4.14	2.45	**-1.69**
	96/0	c74	5.89	5.18	**-0.71**
	123/0	c86	6.8	5.91	**-0.89**
c103 Cregmore Br	143/0	c95	6.48	8.00	**1.52**
c123 Lackaghmore Br	174/0	c109	14.23	13.65	**-0.58**
	210/0	c127	17.21	16.09	**-1.12**
	245/0	c145	18.92	18.00	**-0.92**
c158 Clare – Abbert Confluence	269/0	c156	20.59	18.88	**-1.71**
	298/0	c170	23.5	21.77	**-1.73**

Note: (-) indicates a drop in bed levels since design stage; (+) represents a rise.

Table 3.2 Comparison of Arterial Drainage Design Cross Sections to Current Cross Sections

Of the ten cross sections for which original design data was available, there was only one location at which there the actual bed levels were higher than the bed levels envisaged in the original design. This occurs approximately halfway between Crusheen Bridge and Cregmore Bridge where the bed material changes from rock to blue clay.

Although the cross-section comparison above shows a fairly consistent difference in cross-sections along the length of the study area, when the longitudinal section is examined it is apparent that in general the largest changes in cross section occur downstream of Claregalway Bridge.

A longitudinal section of the river was developed in order to depict the levels as surveyed this year along the centreline of the channel compared to the levels along the centreline of the channel as designed for the Arterial Drainage Scheme. Again, the longitudinal section showed that the channel is now deeper, particularly downstream of Claregalway. In order to further examine the issue, the total cross sectional areas as designed were also compared to the current cross sectional areas. Again, it was found that the cross sectional area is larger today than the design cross sectional area. The results of the cross-sectional area comparison for the Clare River are shown in Table 3.3 below;

c23 Curraghmore Br
c73 Claregalway Br
c103 Cregmore Br
c123 Lackaghmore Br
c158 Clare – Abbert Confluence

Cross Section		Cross Sectional Area (m^2)		Difference (m^2)
OPW Section No.	RH Section No.	Original Design (1950s)	Current (2010)	
19/0	c14	65.94	116.07	50.13
40/0	c31	125.8	149.35	23.55
55/0	c42	61.29	84.3	23.01
96/0	c73	30.96	42.2	11.24
123/0	c86	39.5	41.55	2.05
143/0	c95	49.62	65.59	15.97
174/0	c109	20.74	21.93	1.19
210/0	c125	66.3	170.44	104.14
245/0	c141	42.76	81.52	38.76
269/0	c154	38.15	56	17.85
298/0	c187	45.63	84.35	38.72

Note: (+) indicates an increase in cross sectional area compared to design cross sectional area

Table 3.3 Comparison of cross sectional area of Arterial Drainage Design to Current Cross Sections

Again, the comparison above shows, that there has not been any deterioration in the available cross-sectional flow capacity since design stage of the Arterial Drainage Scheme.

This may be explained by the fact that the underlying bed material is generally marl from Lough Corrib to a couple of hundred metres downstream of the Claregalway bridge, whereas upstream of Claregalway, the bed of the river is more likely to consist of gravel, rock and/or boulder clay. It is possible that the marl has been scoured out over the intervening years particularly during high flows to create these deep pockets downstream of Claregalway.

There were only four sections available for comparison on the Abbert River. These were located at A3 (300m upstream of outfall to Clare River), A10 (in the vicinity of Ardskeaghmore), A25 (between Bullaun and Annagh) and A50 (at Ballyglunin).
Similarly to the Clare River, the comparison carried out for the Abbert River, showed that at two of the four cross sections, namely A3 and A25, the bed level surveyed was deeper than the original design

levels, in two cases by up to 700mm. The other two sections showed good correlation with the original design levels, however, it is difficult to draw a conclusion based on the limited information available.

Similarly when the cross sectional areas of the cross sections on the Abbert River were compared, the two sections at A3 and A25 appear to have a greater cross sectional area now than at design stage. There is a good correlation between design cross sectional area and present cross sectional area for the other two cross sections examined. However, it is difficult to draw any conclusion here, based on the limited number of cross sections available from the design stage.

3.6. Anecdotal Evidence

A significant volume of anecdotal evidence was collected relating to the November 2009 and other significant flood events. The evidence was collected in a number of ways including meeting the local actions group "The Claregalway Flood Taskforce", by knocking on doors of residents during the topographical survey, by phone and meeting with some of the residents whose homes were flooded on the November 2009 event. The internet was also a valuable source used to collect photos and video footage of flooding in November 2009. Aerial video footage of the catchment from the lake to upstream of Cregmore during the November 2009 event was supplied by the OPW. Aerial photography for the same event was provided by the Central Fisheries Board for the entire study catchment including the Abbert River. The OPW also supplied aerial photography of the study area taken during the 2005 and 2006 flood events. This video footage and photography as well as the survey data and witness accounts of residents were used to calibrate the model.

The table below provides a summary of the pertinent information collected from local residents, business owners and local representatives;

Name & Address	Method of Collection of Evidence	Impact of Nov 09 Flood Event	Other Comments
Pat Forde Lisheenavalla	Meeting - Caherlea 08/04/2010	One of numerous houses completely flooded in Lisheenavalla/Caherlea. Has not yet returned to house.	Concern regarding rapid rise in water levels following rain over Easter weekend 2010 when water levels rose very quickly to back of houses in Caherlea. This has not happened in the past. Concern expressed regarding the impact of the operation of Salmon Weir gates.
	Meeting - Arches Hotel 12/04/2010		All the members of the Claregalway Taskforce have concerns regarding the management of the catchment particularly in relation to the operation of the gates at the Salmon Weir. All members of the taskforce also enquired as to whether scope of study could be extended to cover flooding in Carnmore and Cregboy.
Cllr Malachy Noone Crusheen	Meeting - Caherlea 08/04/2010	Representing local residents whose homes were flooded.	Local Representative
	Meeting - Arches Hotel 12/04/2010		Concern re outfall to lake particularly with respect to alignment, siltation etc.
Jimmy Noone Crusheen	Meeting - Arches Hotel 12/04/2010	Road flooded. House at risk of flooding.	Member of Claregalway Flood Taskforce

Name & Address	Method of Collection of Evidence	Impact of Nov 09 Flood Event	Other Comments
Dorothy Regan Claregalway (estate opp Arches Hotel)	Meeting - Arches Hotel 12/04/2010	Access roads etc to estate flooded.	Major concern wrt operation of salmon weir gates. She provided photos of the gates taken on various dates.
Margaret & Ed Keogh Carnmore West	Meeting - Arches Hotel 12/04/2010 Email 08/06/2010	House flooded in Carnmore	Concern re impact of M6 motorway and local quarry. Provided photos by email following meeting. Subsequent email in June enquiring if Carnmore was included in study and whether she could move back into her home and a guarantee that flooding would not re-occur.
Gerard Loughnane Cregboy	Meeting - Arches Hotel 12/04/2010	His house and two other neighbouring houses flooded by turlough.	Concern re impact of motorway. The water rose more rapidly than ever before in the turlough and took 6 weeks to recede from houses. It appears that this turlough drains to Galway Bay via Renville Bay and is probably not part of Clare River catchment.
Sean Goram Ballyglass/Turlough more	Meeting - Arches Hotel 12/04/2010	Unknown	Member of Claregalway Flood Taskforce.
Liam Keogh Caherlea	Meeting - Arches Hotel 12/04/2010	House flooded in Caherlea.	Concern regarding drain flowing past house. Water came from all sides.
Jimmy Hughes Hughes Shop, Claregalway	Meeting - Claregalway (Hughes Supermarket) 20/04/2010	Access road to Miontach flooded. Access to houses by tractor only.	Local businessman. Concern re operation of Salmon Weir gates and impact on water levels at Claregalway. Also, expressed opinion that Miontach road needed to be raised and the capacity of a bridge along this road increased.
Padraig Duggan Miontach	Meeting - Miontach 20/04/2010	Access road to Miontach flooded. Access to houses by tractor only.	Concern re operation of Salmon Weir gates and impact on water levels at Claregalway.
Darby Greally Miontach	Meeting 20/04/2010	Access road to Miontach flooded. Access to houses by tractor only.	Has lived in area for 50+ years. He reports that when he was young, when water levels started to rise his father went to PO to ring into the Salmon Weir for it to be opened, following which the levels in the Clare would go down.
Gerry Dillon Miontach	Meeting 20/04/2010	Access road to Miontach flooded. Access to houses by tractor only.	Concern re operation of Salmon Weir gates and impact on water levels at Claregalway.
Maura Kilcommons Ardskeaghmore	Meeting in RH offices 22/04/2010	House and 4 neighbours (Johnny Coen, Mary Seward, Ann McGrath) completely flooded from Abbert River.	Houses are below river bank level. Water started to rise on Fri 21st. Receded quickly. No record of previous flooding. Photos provided.
Maureen O'Connor Ballybanagher, Corofin	Phonecall 21/04/2010	Basement of her house and neighbours house flooded (basement). Upstream of Corofin bridge.	Previous flooding in Dec 2006 and again April 2010. Levels taken by RH although outside of study area.

Name & Address	Method of Collection of Evidence	Impact of Nov 09 Flood Event	Other Comments
Mary Seward Ardskeaghmore	Phonecall 13/05/2010	Neighbour of Maura Kilcommons above	Houses are below river bank level. Water started to rise on Fri 21st. Receded quickly. No record of previous flooding.
Sean Flanagan (representing Lakeview Estate Residents Association) Lakeview, Claregalway	Letter and email 04/06/2010	Neighbouring land and roads flooded.	Residents of Lakeview estate are concerned at the impact of developments, particularly the Claregalway Corporate Park and Cuirt na hAbhainn housing estate on turlough water levels. Residents have recorded photographic evidence of water levels since 1990. Photos submitted showing water levels in the vicinity of Lakeview estate in 2005 and Nov 2009.
Name unknown Miontach North	Meeting 15/06/2010	House at risk of flooding – water came to within 100mm of FFL	
Mr Cunniffe Miontach North	Meeting 16/06/2010	House flooded to 6 inches above skirting board.	Flood water rose up through the floors of the house. Previously the flood has only come into garden. Family has not returned to house.
Name unknown Bullaun	Meeting 15/06/2010	House flooded to second step of stairs.	
Josette & Avril Farrell Cuirt na hAbhainn Housing Estate, Lakeview	Meeting 16/06/2010	Flood came to within 100mm of FFL	
Tom Conroy Gortatleva	Meeting 16/06/2010	House flooded to approx 50mm above FFL. Haybarn flooded up to approx 400mm above FFL.	Mr Conroy believes that the flooding in Nov 09 was caused by works being carried out on a canal in Galway city at the time of the flood. Mr Conroy has his own report on cause of flooding which he can give to OPW if required.

The main issues arising from our consultation with residents, public representatives and business owners within the Clare and Abbert River catchments are as follows;

- There is a widespread perception and strongly held views that the operation of the sluice barrage at the Salmon Weir and management of the catchment in general contributes significantly to elevated water levels within the catchment. This issue was raised by almost every person consulted.
- Several locals also expressed the view that there is a blockage at the confluence with Lough Corrib which causes the water to "back-up" and flood.
- Several of the consultees expressed concern that the scope of this study does not extend to areas close to the catchment in Carnmore and Cregboy were severe flooding was experienced in November 2009 including flooding of houses and roads. This flooding was not caused by overland flooding from the Clare River and was more likely caused by high water levels in turloughs in the area. Local residents have concerns that the construction of the new M6 motorway contributed to the level and volume of flooding.
- Residents in Caherlea and Lisheenavalla also expressed the opinion that water was pumped out of a quarry in Carnmore into their catchment which added to the flooding in the area. Witness accounts detail the flood water coming from the direction of the River Clare to the north of their houses as well as from the south from the Carnmore area via a drain.

- Residents of Miontach townland are of the opinion that if the road from Claregalway was raised by approximately a foot, access would have been maintained during the November 2009 flood event. There is also a view that the bridge over a significant land drain along this road caused a constriction to flow and that the capacity of this drain needs to be increased.
- The finished floor levels of four houses flooded by up to 1.2m in Ardskeaghmore in the Abbert River catchment are lower than the bank levels of the Abbert.
- The residents of Lakeview Estate in Claregalway expressed concern in writing regarding the impact of developments in the vicinity of their estate in Claregalway, in particular the construction of the Claregalway Business Park and Cuirt na hAbhainn housing estate on area which was historically a turlough.
- The majority of residents consulted during the study brought up the issue of the impact of the substantial residential and commercial development that has taken place in the catchment in recent years.

Some of the issues raised above cannot be dealt with in this study as they are outside the scope of this report including the flooding of areas in Carnmore, Cregboy and upstream of Corofin. The issues raised in relation to Carnmore and Cregboy would require a detailed hydrogeological study which may or may not prove conclusive.

The contribution of recent developments to flooding in the Lakeview area and throughout the catchment in general is also considered to be outside of the scope of the study. However, the catchment as it is currently will be examined and if necessary measures will be proposed to mitigate the effects of flooding to these residents in so far as possible.

The recurring local issue regarding the operation of the Salmon Weir gates is dealt with above in Section 3.4 and will be further considered during the sensitivity testing of the model by the application of various downstream lake levels to the model.

The other issues raised will be dealt examined using the calibrated hydraulic model; for example the potential requirement to raise the road in Miontach.

4. Flood Flow Estimation

RYAN HANLEY

4.1. Introduction

A design flood may be determined by either of two broad categories of methods, namely,

- Methods based on statistical analysis of flood peak data
- Methods based on a design rainstorm and a rainfall-runoff model which converts the design rainstorm into a design flood.

A further distinction arises between gauged and ungauged catchment methods. The latter use formulae which relate some key component of the method, such as the mean annual flood or unit hydrograph time to peak, to catchment descriptors such as area, slope and mean annual rainfall among others.

If catchments are gauged and there is a sufficiently long flow record (typically more than 20 years) then a relationship between peak flood flow and return period can be established by applying an Extreme Value distribution to the data series of "Annual Maximum" or "Peaks over Threshold" (POT) flow series. The theory of extreme values states that if Z is the maximum of a number of other random variables X_1, X_2, ……X_N then the distribution of Z converges towards one of the 3 types of Extreme Value distribution (EV1, EV2 or EV3) as N becomes infinitely large. Generally in Ireland the EV1 (2 parameter) distribution fits reasonably well the majority of gauged rivers.

If less data is available (e.g. typically less than 20years) then this can be used to give an approximation to the location parameter (i.e. mean Annual Maximum Flow) and a corresponding parameter for it's scale deduced from regional statistics or pooled station statistics.

The statistical method may be used on a single site basis or on a pooled basis. In respect to the latter, which is recommended by the UK flood estimation handbook, 1999, the flood data from several river sites are in effect pooled together to provide an improved estimate of the required flood value. Pooled analysis is regarded as providing a more reliable estimate of the required flood, providing that catchments included in the "pooling" group are sufficiently similar in area, annual rainfall and soil/geology conditions. The latter is expressed by the descriptor BFIHOST, a quantity which is not available for Irish catchments. An earlier pooling method, based on geographical proximity of catchments rather than physical and climatic similarity was used in the Flood Studies Report (FSR). An FSR dimensionless flood growth curve is available for Ireland and will be referenced later in this chapter.

In the absence of actual data, the most appropriate methods for estimating design floods on ungauged catchments in Ireland are presented in the Flood Studies Report 1975.

Two categories of ungauged flood estimation methods are available, namely;

- Mean Annual Flood by catchment characteristics plus Growth Curve Approach
- FSR Unit Hydrograph and Design Storm Method

In the case of the River Clare at Claregalway there is a sufficient number of reliable gauged stations to perform flood frequency analysis and extrapolate to ungauged sites based on catchment characteristics.

4.2 Statistical Flood Frequency Analysis

The following design criteria have been adopted by the design team in accordance with the FSR and the Flood Estimation Handbook (FEH). If a catchment is gauged and there is a sufficiently long historical flow record then the FSR recommends that flood flows should be estimated by statistical flood frequency

analysis methods such as Extreme Value Distribution to the data series of annual maximum flows or Peaks over Threshold (POT) flow series. Annual Maximum flow data can be obtained from the OPW or the EPA. In statistical flow estimation methods, an index flood (mean annual flood) is calculated and multiplied by a growth factor to obtain the required return period flow.

If a catchment is un-gauged the most appropriate methods for estimating design flows are described in the Flood Studies Report (1975). The method chosen should be appropriate to the size of the catchment. Methods include:

- Mean annual flood (Qbar) by catchment characteristics plus growth curve
- FSR Unit Hydrograph and Design Storm Method

The FSR and FEH recommend that estimates of the index flood from catchment characteristics at un-gauged sites be improved by the use of index flood values calculated from river flow data recorded at gauging stations, wherever possible. The FEH also recommend that use is made of donor and/or analogue catchments to improve estimates of the index flood at un-gauged sites.

A donor catchment is a catchment with a gauging station that is typically on the same river as the subject site. An analogue catchment is a catchment which is hydrologically similar to the subject site, but is not necessarily on the same river.

In this study, flood frequency analysis was carried out using the Extreme Value Type 1 (EV1) statistical probability distribution which has been found suitable for predicting extreme flood flows on Irish catchments. The EV1 distribution can be fitted to Annual Maxima Series (flood level and flow) using a variety of methods from Least Squares fit using gringorten plotting position to fitting by method of moments (ordinary, probability weighted and L-moments). The Least Square fit with gringorten plotting position provides a reasonable fit of the series to the data

The relevant gauges on the Clare River and the Corrib System used in the statistical analysis for this study are summarised in Table 4.1 below. It is noted that there are no gauges available on the Abbert River.

Station	Location	River	Area	Period	Rating Class
30012 (EPA)	Claregalway	Clare River	1,073 km^2	1996-2009	B
30004 (OPW)	Corofin	Clare River	699 km^2	1964 - 2009	A1
30007 (OPW)	Ballygaddy	Clare River	442 km^2	1974 - 2009	A2
30089 (OPW)	Angliham	Lough Corrib	3,100 km^2	1991 to 2009	N/A (water level only)
30061 (OPW)	Wolfe Tone Bridge Galway	Corrib River	3,111 km^2	1972 – 2002 Gauge relocated & new rating not established for 2003 to 2010	A2

Table 4.1 Summary of Gauging Stations used in the Flood Frequency Analysis

4.3 Statistical Analysis of Lower Lough Corrib Flood Levels at Anglinham Gauge (30089)

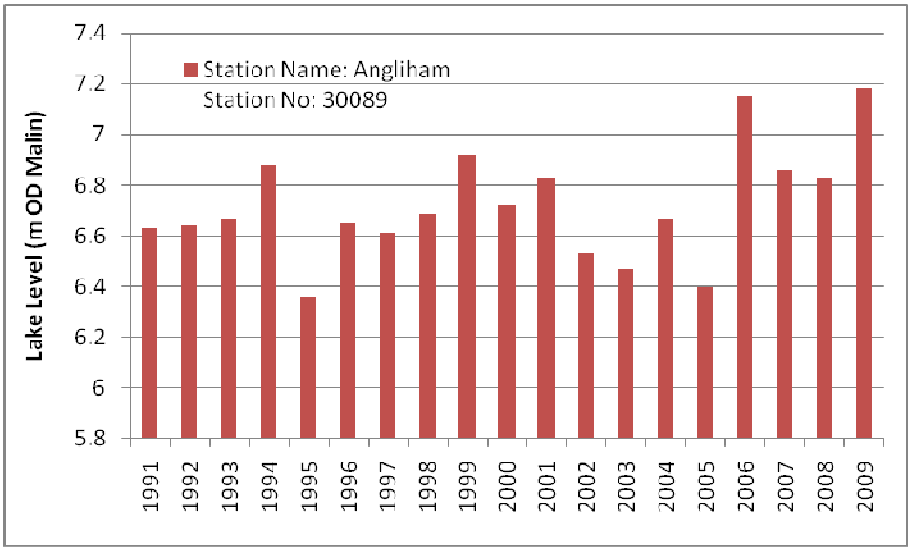


Figure 4.1 Annual Maxima Lake Level Series Lough Corrib at Angilham (30089)

Return Period Lake Level Predictions - Angliham (30089)

Return Period	YT	HT	s.e.	HT + S.E.
5	1.50	6.888	0.016	6.904
10	2.25	7.021	0.021	7.042
25	3.20	7.190	0.027	7.217
50	3.90	7.315	0.032	7.347
100	4.60	7.439	0.037	7.475
200	5.30	7.562	0.041	7.604

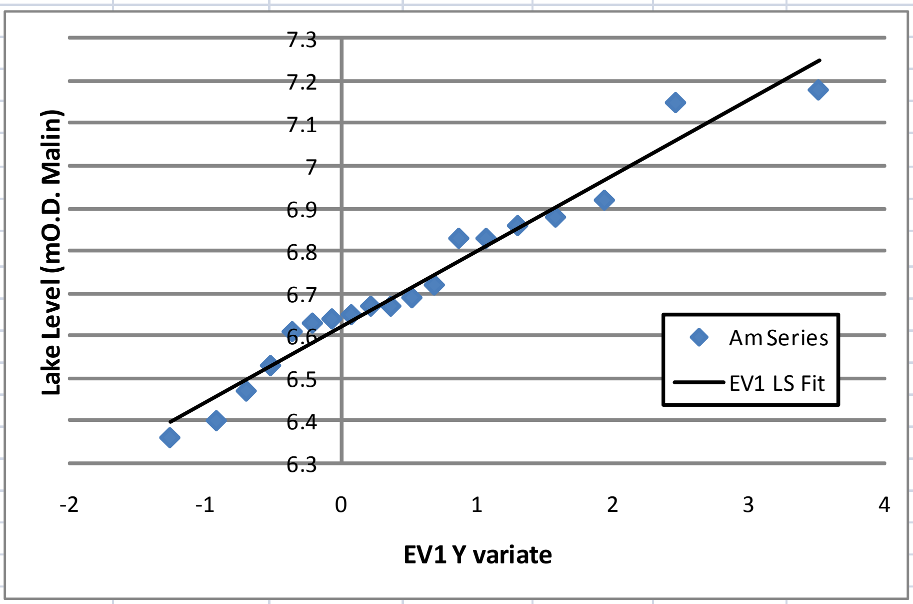


Figure 4.2 EV1 Analysis - Anglinham

An EV1 analysis of the lake level nineteen year Annual Maxima series for the Anglinham gauge on Lower Lough Corrib, downstream of the Clare River outfall, gave a mean annual maximum flood level of 6.72m and a 100year flood level estimate of 7.44mOD Malin. The flooding in Lower Lough Corrib which peaked on 25 November during the November 2009 flood event on the Clare River, was recorded at 7.18m OD Malin making it the highest recorded event over the nineteen year series and possibly extending back at least 50 years.

4.4 River Corrib Flood Flow Magnitude (Wolfe Tone Bridge Gauge (30061)

The predicted return period flood flow for Wolfe Tone Bridge gauge representing the entire Corrib outflow is presented in Table 4.2 below;

Return Period Flow Estimates - Wolfe Tone Bridge				
T	**F(T)**	**EV1 variate**	**QT (cumec)**	**St. Error**
2	0.5	0.37	**249**	8.5
5	0.8	1.50	**295**	14.4
10	0.9	2.25	**326**	19.4
25	0.96	3.20	**364**	26.1
50	0.98	3.90	**393**	31.3
100	0.99	4.60	**421**	36.4
200	0.995	5.30	**450**	41.6
100+20%CC			**505.5**	

Table 4.2 Predicted Return Period Flow for Wolfe Tone Bridge Gauge

A relationship between the return period estimated flows at Wolfe Tone Bridge and the return period lake levels at Anglinham gauge is presented below. A 20% Climate Change (CC) increase in flood flow from Lough Corrib representing 505.5 cumec, equates to a lake level of 7.82m OD Malin.

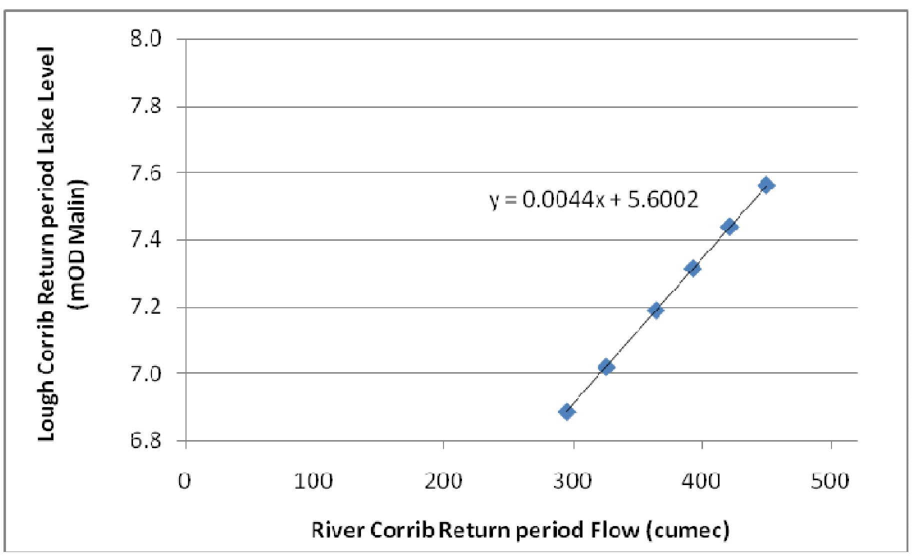


Figure 4.3 Return Period Lake level Estimate V's River Corrib Outflow

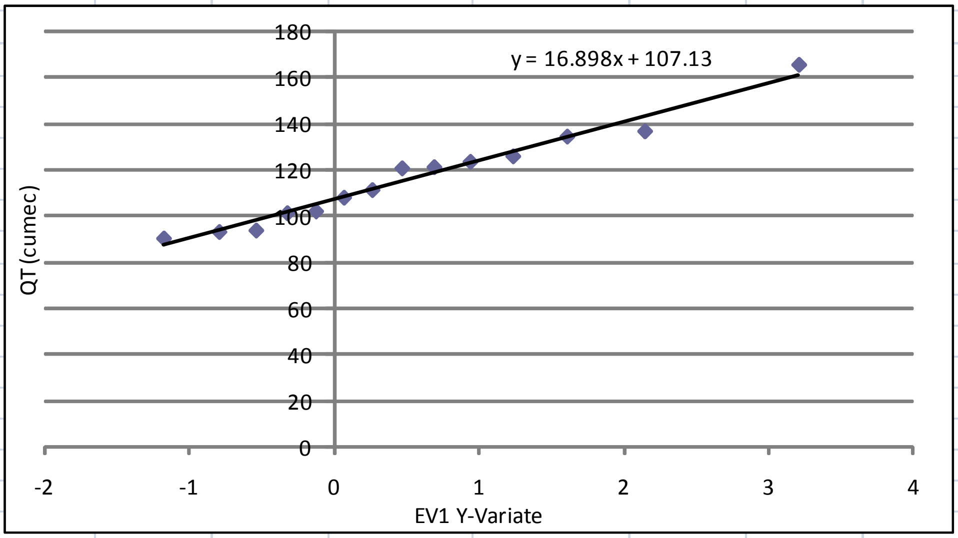
4.5 Flood Peak Estimation of River Clare at Claregalway (30012)

Statistical Analysis of Claregalway Gauge (30012)

1996 - 2010

T	Yvariate	QT	XT	S.E.
5	1.50	132.5	1.142	7.737
10	2.25	145.2	1.251	9.924
25	3.20	161.2	1.389	12.859
50	3.90	173.1	1.492	15.099
100	4.60	184.9	1.594	17.352
200	5.30	196.6	1.695	19.617

QBAR	116.4		
Qmax	165.3		
Q100	185	Q100 +s.e.	202.2
Q100+CC	222	Q100 +s.e. + 20%C.C.	242.7



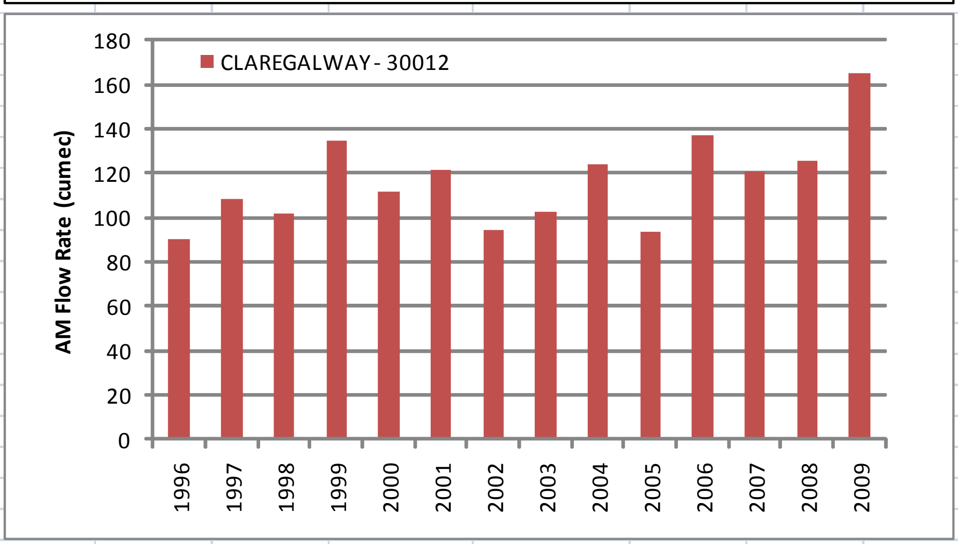


Figure 4.4 Annual Maxima Flow Series for Clare River at Claregalway (30012)

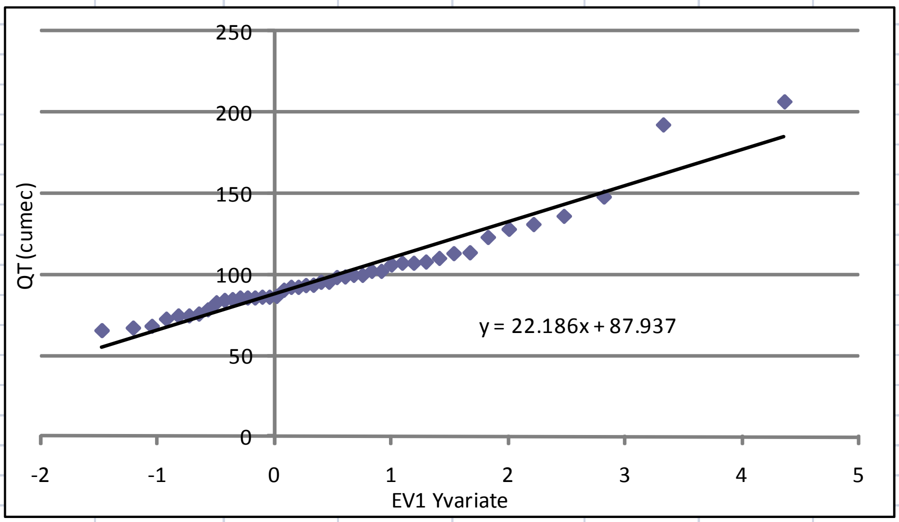
4.6 Flood Peak Estimation of River Clare at Corofin (30004)

Statistical Analysis of Corofin Gauge (30004)

1964 to 2010

T Return perio	QT (cumec)	XT Growth Factor	s.e.
5	121.2	1.42	6.077
10	137.9	1.61	7.796
25	158.9	1.86	10.101
50	174.5	2.04	11.860
83	185.8	2.17	13.153
100	190.0	2.22	13.630
200	205.4	2.40	15.409

QBAR	100.5		
Qmax	207.0		
Q100	190.0	Q100 +s.e.	203.6
Q100+CC	228.0	Q100 +s.e. + 20%C.C.	244.4



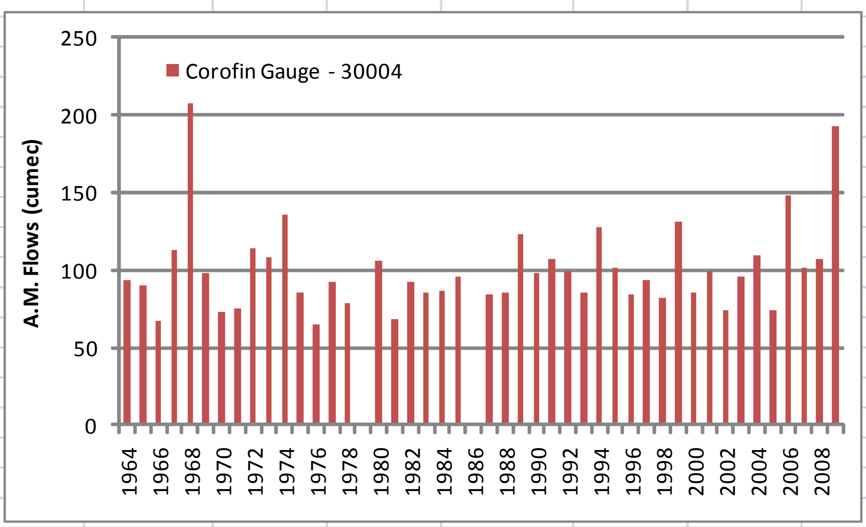


Figure 4.5 Annual Maxima Flow Series Clare River at Corofin (30004)

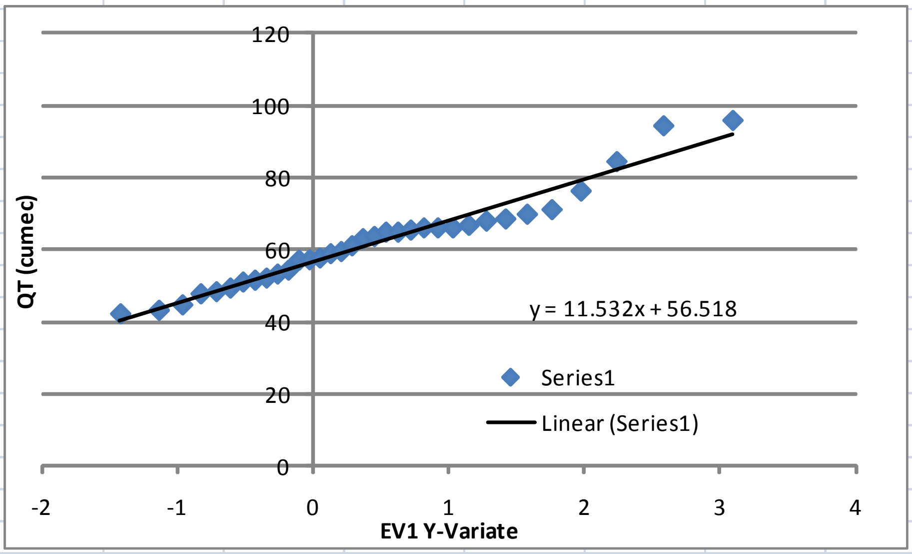
4.7 Flood Peak Estimation of River Clare at Ballygaddy Tuam (30007)

Statistical Analysis of Ballygaddy Gauge (30007)

1974 to 2010

T	QT	XT	S.E.
5	71.4	1.15	3.548
10	79.0	1.28	4.551
25	88.7	1.43	5.897
50	95.8	1.55	6.924
100	103.0	1.67	7.957
200	110.0	1.78	8.996

QBAR	61.8		
Qmax	108.9		
Q100	103.0	Q100 +s.e.	110.9
Q100+CC	123.5	Q100 +s.e. + 20%C.C	133.1



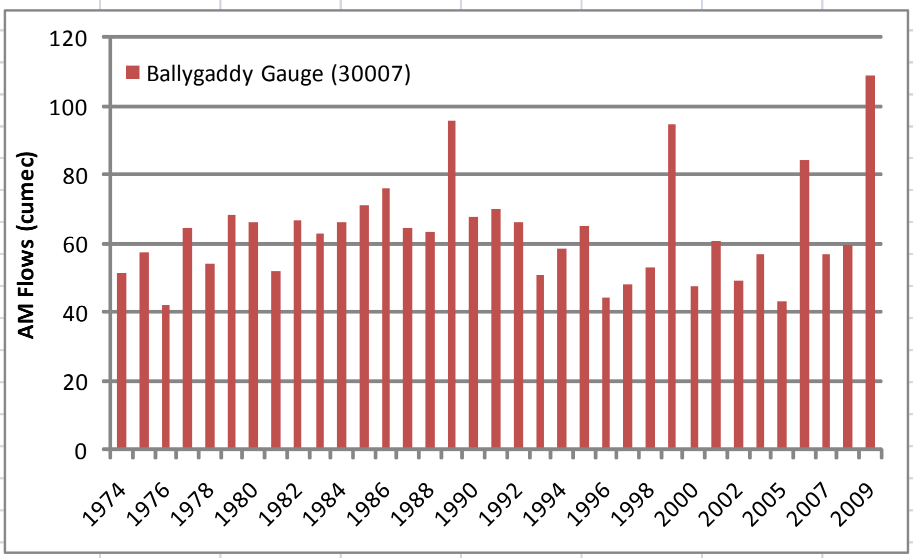


Figure 4.6 Annual Maxima Flow Series River Clare at Ballygaddy (30007)

4.8 Discussion of Flood Frequency Results

The statistical analysis of the Corofin and Ballygaddy gauges which have forty four and thirty five years of Annual Maxima flow series respectively and are rated in the recent Flood Studies Update as having reliable rating classes of A1 and A2, both indicate that the November 2009 flood peak at these stations was in excess of 100 years return period. There is further evidence from the rainfall data for Galway that extreme long duration rainfall occurred with rainfall durations of three days up to twelve days exceeding the Met Eireann 200 year rainfall amounts.

A statistical analysis of the Claregalway gauge was carried out using the available 14 years of Annual Maxima flow data. This series is of short duration and thus limited for extrapolating out to the larger return period flood. Generally an Annual Maxima series is only considered reliable out to twice its series length i.e. the 28 year return period in this case. Taking into account the upstream gauges at Corofin and Ballygaddy and the rainfall statistics it can be concluded that the recorded flood flow at Claregalway of 165 cumec is likely to have exceeded the 100 year return period flood event. Therefore the estimate using the limited Annual Maxima series for Claregalway of Q_{100} = 185 cumec is likely to err on the conservative side and thus is proposed to be used as the Design Flow magnitude to provide a degree of safety for the design.

To summarise, the Design Flood referred to throughout the remainder of this report is a flood of 185 cumec magnitude at Claregalway.

4.9 Flood Growth Curve

The Flood Growth Curve for the Clare River at Claregalway and the Corrib River measured at Wolfe Tone Bridge are very flat when compared to national and regional average growth curves. It is possible that this is an indication of the impact of flood storage in the catchment on the development of the flood peak, which may dampen out the degree of growth requiring extended periods of rainfall.

The gauge at Claregalway has a relatively short record and possibly over-predicts the Mean Annual Flood, thus producing a lower growth curve. The Corofin gauge Growth Curve is very steep relative to west of Ireland norms from other similar catchments. The Growth Curve for Ballygaddy upstream and for Claregalway downstream are also considerably flatter than the Corofin Growth Curve, thus raising questions as to the accuracy of the gauged flows and the rating relationship used at this gauge. These growth curves are illustrated in Figure 4.7 overleaf.

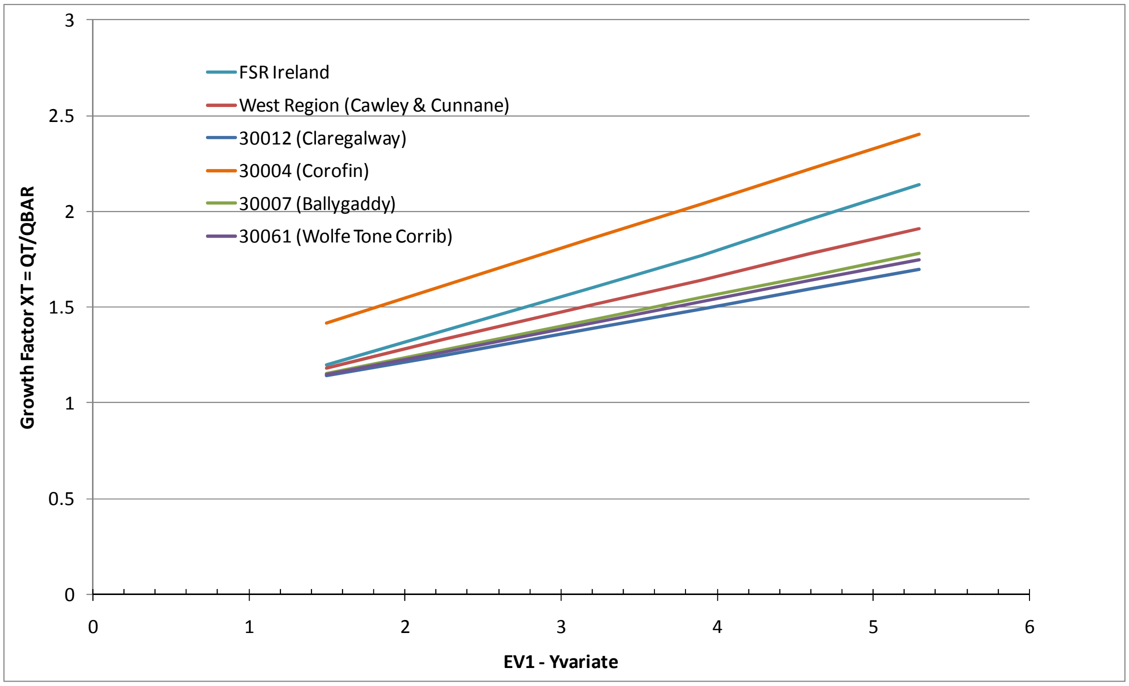


Figure 4.7 Comparison of computed Flood Growth Curves for the Clare River to Irish norms

4.10 FSR Catchment Characteristics Index Flood method for ungauged catchments

The ungauged FSR method used to estimate return period flood flows is based on the Original 1975 Flood Study Report 6-variable catchment characteristics flood estimation equation. The original 1975 FSR investigation involved flood frequency analysis of some 5,500 record years from 430 British gauging Stations and 1,700 record years from 112 Irish sites. The catchment areas varied from 0.05 to 9,868km^2 and annual maximum flows from 0.06 to 997cumec. The FSR six-variable catchment characteristic regression equation for Ireland to estimate the mean annual maximum flood is as follows:

$$Q_{BAR} = C\ AREA^{0.95} F_S^{0.22} SOIL^{1.18} SAAR^{1.05} S_{1085}^{0.16} (1+LAKE)^{-0.93}$$

where the multiplier C = 0.00042 for Ireland.

- AREA is the catchment area (km^2).
- STMFRQ (stream frequency) is the number of stream junctions per km^2 on a 1:25,000 scale map. For Ireland this can be determined from a 1inch map and converted (using a formula given in the FSR) to an equivalent 1:25,000 (2.5 inch) number.
- S1085 is the slope of the main channel between 10% and 85% of it's length measured from the catchment outlet (m/km)
- SAAR is longterm mean annual rainfall amount in mm and 1:625,000 mapping of this parameter is available for Ireland based on meteorological records from 1941 to 1970.
- SOIL is an index of how the soil may accept infiltration and is a measure of the Winter Rainfall Acceptance Potential (WRAP). It can be determined from FSR mappings at 1 : 625,000 scale for Ireland. The SOIL index is based on only five classifications (very high, high, moderate, low and very low WRAP) and the mapping scale and number of categories are regarded as providing a very coarse measure of catchment runoff potential. The Flood Estimation Handbook in the UK have replaced the SOIL index by a more extensively classified and calibrated variable called HOST (Hydrology Of Soil Types) provided at a grid resolution of 0.5km^2.

- LAKE is an index defined as the fraction of catchment draining through lakes or reservoirs and the areas contributing to lakes whose surface area exceeds 1% of the contributing area is recorded.

The FSR equation has a standard factorial error of 1.47. The factorial error applies to the middle of the data set and consequently will be significantly higher at both ends of the data set.

The Q_{BAR} estimate is multiplied by a growth factor derived either from the national, regional or pooled growth curve to arrive at the T – year return period flood estimate. This method is now applied to the Clare River catchment at Claregalway, Corofin and Ballygaddy and the Abbert River at it's confluence with the River Clare as set out in the tables below;

- **Claregalway Gauge (30012) Clare River**

MSL (km)	84.54
AREA (km^2)	1073
St freq (jns per km^2)	0.509843
S1085 (m per km)	0.769
SAAR (mm)	1099
SOIL	0.252141
RSMD (mm)	42.2149
Lake (fraction)	0
QBAR (cumec)	**84.2**
Gauged QBAR =	116.4cumec

Table 4.4 FSR Catchment Characteristics –Clare River (30012)

- **Corofin Gauge (30004) Clare River**

MSL	65.66
AREA	699
St freq	0.601
S1085	0.985
SAAR	1104
SOIL	0.284
RSMD	42.40
Lake	0
QBAR (cumec)	**71.1**
Gauged QBAR =	100.5cumec

Table 4.5 FSR Catchment Characteristics – Clare River (30004)

- **Ballygaddy Gauge (30007) Clare River**

MSL	50.334
AREA	470
St freq	0.642553
S1085	1.127
SAAR	1115
SOIL	0.30355
RSMD	42.81121
Lake	0
QBAR (cumec)	**55.9**
Gauged QBAR =	61.8cumec

Table 4.6 FSR Catchment Characteristics – River Clare (30007)

- **Abbert River (ungauged)**

MSL	38.52
AREA	240
St freq	0.65
S1085	1.903773
SAAR	1115
SOIL	0.21892
RSMD	42.81121
Lake	0
QBAR (cumec)	**21.7**

Table 4.7 FSR Catchment Characteristics – River Abbert at Anbally

Using the FSR ungauged method with the National Growth curve of 1.96 the Q_{100} estimate for the Abbert River is Q_{100} = 21.7* 1.96 = 42.5cumec. When the standard factorial error of 1.47 is included, Q_{100} is estimated at 62.5cumec.

4.11 Donor Station Analysis for Abbert River

The FEH recommends that use is made of donor and/or analogue catchments to improve estimates of the index flood at un-gauged sites. This approach is used to determine the flood flow for the ungauged Abbert River using the ungauged and gauged information from the Clare River gauging stations.

Using neighbouring gauged stations on the Clare River as donor stations which have reasonably similar characteristics, a more reliable QBAR rate for the Abbert River can be determined as set out in Table 3.8 overleaf;

Gauging Station	Area (km²)	Gauged QBAR (cumec)	FSR QBAR (cumec)	Difference (%)
30012	1,073	116.4	84.2	38.2
30004	699	100.5	71.1	41.3
30007	470	61.8	55.9	10.8
Abbert	232		21.7	

Table 4.8 Donor Catchment gauged and ungauged QBAR estimates

Using the average difference between the gauged and FSR estimates, the QBAR flow for the Abbert River is adjusted up from its ungauged estimate of 21.7cumec to 25.8cumec (i.e. 27.8% higher than the FSR ungauged estimate).

The growth curves for the gauged stations on the Clare River are considerably lower than the FSR Regional Growth curve, most likely due to the damped karstic nature of the catchments. Cawley and Cunnane (2003) demonstrated for the western catchments of Ireland that the flood growth curve was generally lower than the FSR National Growth Curve. Therefore, the use of the national growth curve for estimating the 100 year design flow in the Abbert River should ensure a degree of conservatism in the flow estimate i.e. over-predict the flow.

Based on the above analysis and using the national growth factor of 1.96, the estimated Q_{100} flow peak magnitude for the Abbert River is 50.6cumec and the Q_{100} + 20% CC is 60.7cumec.

4.12 Climate Change Allowance

Climate change scenarios produced by the UK Hadley centre suggest fluvial floods in the 2080's increasing by up to 10% for low and medium low scenarios or by up to 20% for medium high and high scenarios. Present recommendations are to include in the design flow a 20% increase in flood peaks over 50 years return period to take account of potential climate change. This scenario based on the Irish growth curve will result in a present day 100 year flood becoming a 25 year flood in approximately 50 years time.

Other predicted climate change effects for the UK are:

- A 4 to 5mm per annum rise in mean sea level
- Additional intensity of rainfall of 20%
- An additional 30%winter rainfall by the 2080's
- A reduction of 35/45% Rainfall in summer
- The 1 in 100year rainfall storm to increase by 25%

Kiely (1999) published results which indicate significant changes in rainfall totals at several Irish locations since the mid 1970's. He attributes this to changes in the North Atlantic Oscillation (NAO), a quantity based on seasonal pressure difference between Iceland and the Azores. Kiely (1999) also found differences in rainfall frequencies at a number of the synoptic weather stations; for Valentia he found that, for several durations, 10 and 30 year return period rainfall depths are increased by approximately 20% when calculated from the most recent data (1976 – 1996) as compared to values calculated from the entire period of record (1940 –1996). While such changes in rainfall regime provide a warning, it is strange that changes in flood behaviour and in particular increase in flood magnitudes were not noticed in many rivers until the 1990's.

Changes in circulation patterns across Europe have been linked to changes in flood frequency and hence increased risk of flooding in parts of southwest Germany. The circulation pattern known in Germany as "West Cyclonic" during the winter months has increased over the last century giving rise to increased risk of flooding. Caspary (2003) has shown flood magnitudes that were once deemed to be 100 year return period floods, would be deemed to have much smaller return periods (5 to 30years), if judged on data of the past 25 years.

The changes observed in southwest Germany may not be replicated in Ireland but it is clear that account must be made for climate change impact in view of the above findings.

4.12.1 DEFRA Guidance

In the UK research is ongoing to assess regional variations in flood allowances and the rate of future change. Current research thus far does not provide any evidence for the rate of future change let alone consider regional variations in such a rate. The UK Flood and Coastal Defence Appraisal Guidance (DEFRA, 2006) gives sensitivity climate change ranges as set out in Table 4.9 below. As a pragmatic approach, it is suggested that 10% should be applied up to 2025, rising to 20% beyond 2025.

Parameter	1990-2025	2025- 2055	2055-2085	2085-2115
Peak rainfall intensity (preferably for small catchments)	+5%	+10%	+20%	+30%
Peak river flow (preferably for larger catchments)	+10%	+20%		

Table 4.9 UK Flood and Coastal Defence Appraisal Guidance (DEFRA, 2006)

The proposed climate change allowance considered appropriate for this study is a 20% increase in peak flow rates.

4.13 Summary of Flood Estimation Results

The recommended peak flood flow rates which will be used in this study are presented below in Table 4.10.

River/Station	QBAR cumec	QNOV '09 cumec	Q_{100} cumec	Q_{100}+CC cumec
Claregalway	116.4	165.0	185	222
Corofin	100.5	192.5	190	228
Abbert	28.0	56.0	55	66
River Corrib at Galway	257.0	-	421	506
Lake	**HBAR m OD**	**HNOV '09 m OD**	**H_{100} m OD**	**H_{100}+CC m OD**
Lough Corrib	6.72	7.18	7.44	7.82

Table 4.10 Summary of Recommended Flow Rates and Lake Level for the Clare & Abbert Rivers

The estimated peak flood flow at Corofin of 192.5 cumec for the November 2009 and 190 cumec for the 100 year return period is significantly higher than the estimated flow at Claregalway, even though the catchment area to Claregalway is approximately 50% larger. This suggests that significant attenuation occurs between Corofin and Claregalway and that possibly a large portion of the downstream catchment

area which is karstic and devoid of a surface drainage network does not contribute very effectively to flood flows in the Clare River. There is also some doubt over the upper flood rating at Corofin as suggested by its Flood Growth Curve presented earlier in Figure 3.6 and the inconsistency with the flood flow characteristics at the upstream Ballygaddy and downstream Claregalway gauges. It is also important to note that the EPA carried out an actual flow measurement on the Clare River at Claregalway very close to the peak of the flood on the 21 November 2009 and therefore the flow estimate of 165cumec at this time is very reliable.

The statistical analysis of flow and flood levels for Corofin and Ballygaddy gauges having 44 and 34 years Annual Maxima Series respectively, indicate that the flood event at Claregalway measured at a peak flow of 165 cumec is in excess of 100years. The recorded rainfall amounts for durations of 3 days to 12 days, which would be the more critical storm duration for flooding in the Clare River at Claregalway due to the large attenuating and slow groundwater contribution, indicated rain depths in excess of 200 year return period.

To allow for a degree of conservatism (i.e. factor of safety), it is recommended that the higher estimate of 185 cumec based on the frequency analysis of the gauged flows at Claregalway is used to represent the 100 year design flow as opposed to the recorded November 2009 peak flow of 165cumec. The 100 year at Corofin and the 100 year for the Abbert river are slightly less than the November 2009 Flood Flows (0.5% less).

5. Hydraulic Analysis

RYAN HANLEY

5.1. Introduction

A hydraulic model of the Clare River and its tributary the Abbert River, from Lough Corrib upstream to Corofin on the Clare River and from Anabally to Ballyglunin on the Abbert River was developed to predict the peak flood level profile within the modelled reach under existing conditions and under various proposed flood risk management measures for a range of return period flood events.

The selected software used for this hydraulic assessment is the latest HEC-RAS 4.1 version. This software is considered the industry standard for simulation of one-dimensional river flows and is generally the model of choice when carrying out preliminary Flood Risk Assessment and flood relief design. HEC-RAS implements a 1-dimensional model of river flow (depth and width averaged) and can solve for water elevation under steady conditions and gradually varying unsteady flows solving the full Saint Venant equations of open channel flow. HEC-RAS takes account of the conveyance and storage effects of floodplains in a one-dimensional manner only (i.e. in the longitudinal direction of flow). It does not resolve the possibly complex 2-dimensional aspects of floodplain flow or secondary flow caused by a structure.

The model requires the following information:

- topographic survey data of river channel and flood plain (cross-section station, bed elevation and channel and overbank reach lengths);
- dimensions and elevation of relevant structures;
- upstream and internal flow boundary conditions;
- downstream water elevation boundary condition, and in the case of supercritical flow regime (Froude No. > 1), the upstream water elevation boundary condition;
- channel and flood plain roughness coefficients and;
- local expansion and contraction shock loss coefficients.

5.2 Model Development

The hydraulic model was developed for a total reach length of 27.5km for the Clare River from Lough Corrib to Corofin and 7.5km on the Abbert from its outfall with the Clare River at Anabally upstream to Ballyglunin shown on Figure 5.1 overleaf. A total of 170 river channel sections and 11 bridge sections were specified on the Clare River and 50 river sections and 10 bridge structures were specified on the Abbert River. This represents an overall average channel cross section spacing of 160m. The river sections were extended out across the overbank floodplain, where the OPW land benefitting and aerial photography indicated floodplain areas.

In the HEC-RAS modelling, the model was run as one river system with both the Abbert and Clare reaches connected by a river junction to represent the confluence at Anabally such that the simulation could include the combined effects of both rivers.

In constructing the hydraulic model additional cross-sections at 25m spacing were included, derived by interpolation from adjoining measured cross-sections. This refined spacing reduces numerical error and stability problems associated with the larger spacing but does not include for natural variability from river section to river section.

The majority of bridges on both river reaches were specified using the culvert module as opposed to the bridge module as the culvert module allows for direct specification of the entrance and exit losses which during model calibration was found necessary to reproduce the substantial afflux observed at a number of

the bridge sites, particularly at Claregalway and Crusheen Bridges. The entrance and exit losses specified are typical of culverts with an entrance loss coefficient of 0.7 and exit loss coefficient of 1.0. The Bridge Routine modelling the energy equation in HEC-RAS was unable to reproduce the observed bridge afflux at Claregalway and Crusheen bridges substantially, under estimating the headloss by over 50%.

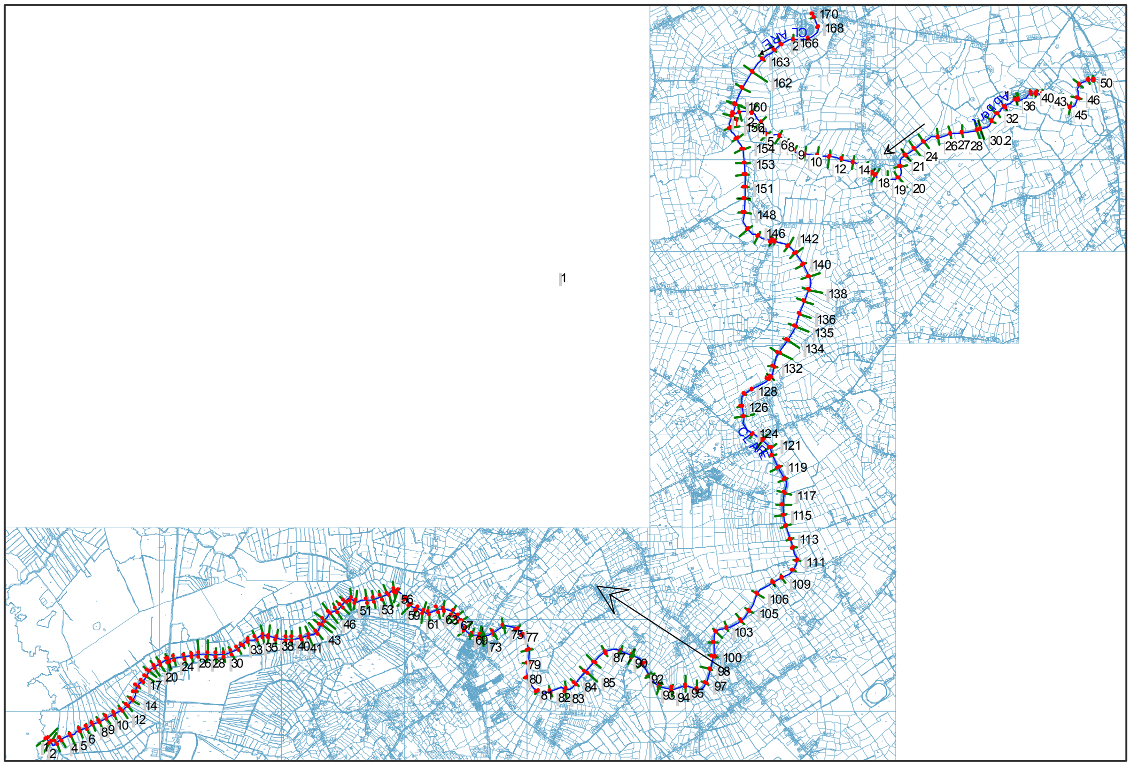


Figure 5.1 HEC-RAS Model Domain of Clare River and Abbert River

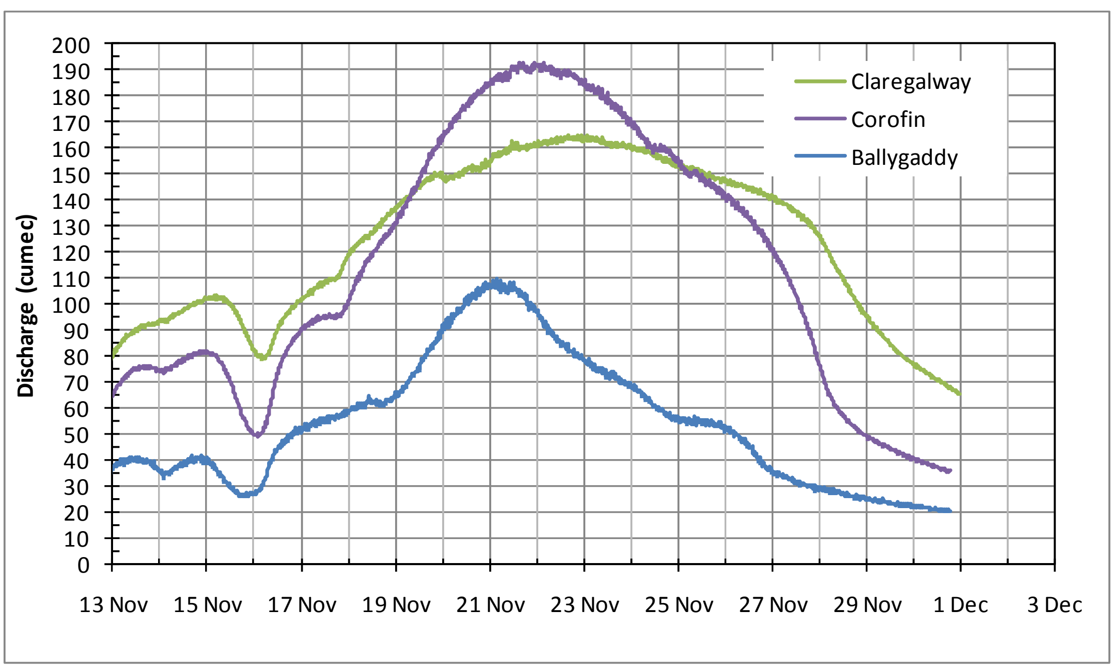


Figure 5.2 Recorded Flood Hydrographs for November 2009 event on the Clare River

5.3 Model Calibration

The HEC-RAS model was developed to predict the peak flood profile in the river for inputted peak flood flows in the Abbert and Clare Rivers and downstream lake level in Lough Corrib as set out in Chapter 4. The model was run for steady state condition. This was considered appropriate as the flood peak remained virtually constant for well over 24 hours and longer, as illustrated by the recorded flood hydrographs presented in Figure 5.2.

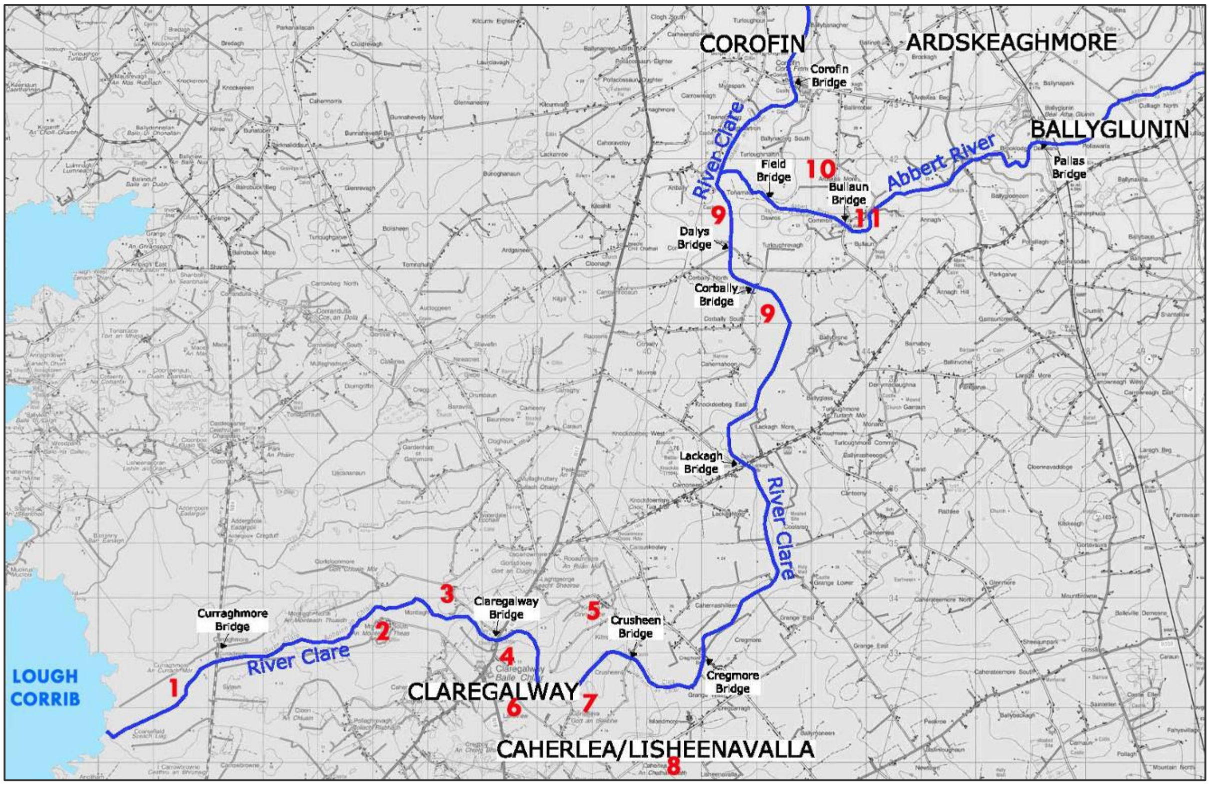
The model was not run in unsteady flow mode to investigate the flood hydrograph as it propagated through the study reaches. This would have required the use of a full digital terrain model (DTM) of the full flood plain area to accurately include the storage attenuation effects of the floodplain on the flood peak and flood hydrograph. Therefore the potential impact of lowering the flood levels as a result of flood risk management measures was not modelled and thus the impact or changes to the downstream flood peak and hydrograph could not be evaluated within the scope of this study.

Calibration of the steady state model involved tuning the roughness coefficients specified for the channel and left and right overbanks and the bridge shock loss coefficients until reasonable agreement was achieved between computed and observed flood level over the study reach. The calibration run was the recent November 2009 flood event which is presented below in Figures 5.3 and 5.4 and Tables 5.1 and 5.2 for the Clare and Abbert rivers respectively. The calibration exercise showed that overbank conveyance was very limited with the majority of the flood conveyance taking place in the main channel. To achieve this calibration, the Manning's roughness coefficient n varied from 0.04 to 0.06 along the main channel and was artificially roughened for the very wide overbanks using roughness values of 0.1 to 0.5 to reduce their contribution. The other significant tuning coefficient in the model were the entrance and exist losses to bridges/culverts with coefficients of 0.7 and 1.0 respectively achieving best results in respect to the observed bridge afflux.

The calibrated model achieves reasonably good agreement with observed flood levels at the key flood locations as shown in the table of calibration results (Tables 5.1 and 5.2). The final roughness and shock loss coefficients used in the model are not inconsistent with other studies and guidance from hydraulic literature (HEC-RAS reference manual). The modelling of the floodplain as functioning primarily as a storage reservoir as opposed to providing conveyance is consistent with observations and particularly given the number of field boundaries, roads and other obstructions present on the overbanks, including dredge material heaps.

The map overleaf identifies the key locations mentioned throughout the sections that follow. The areas are identified on the map as follows;

- Area 1 Lough Corrib to Curraghmore Bridge
- Area 2 Miontach South
- Area 3 Miontach North
- Area 4 Claregalway
- Area 5 Kinishka
- Area 6 Lakeview
- Area 7 Gortatleva
- Area 8 Caherlea/Lisheenavalla
- Area 9 Lackagh Bridge to Corofin Bridge
- Area 10 Ardskeaghmore
- Area 11 Bullaun



Map of Key Locations

5.3.1 Calibration results for the River Clare at Claregalway and Crusheen Bridge

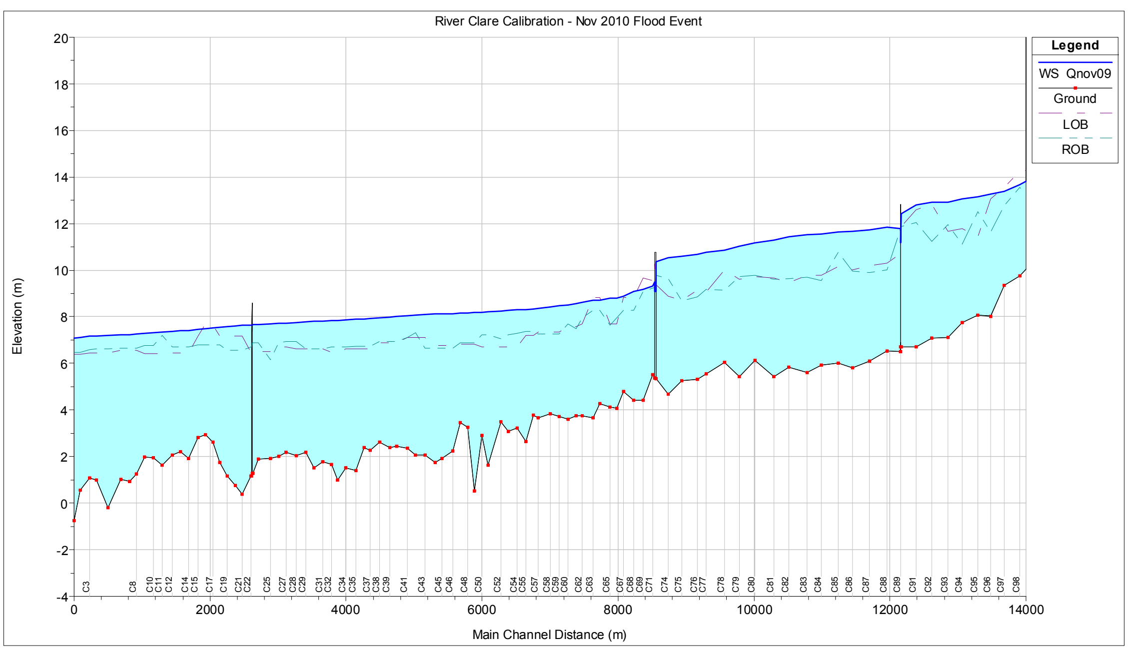


Figure 5.3 Plot of flood peak profile in the Lower Clare River for November 2009 flood event

Description	Cross Section Reference	Chainage m	Observed Peak Level m OD	Computed Flood level m OD
Curraghmore Bridge	C23	2628		7.64
Miontach South	C52	6276	8.27	8.25
Miontach North	C63	7628	8.7	8.70
Claregalway Gauge (d/s bridge)	C72	8506	9.49	9.49
u/s Claregalway Bridge	C73	8557	10.336	10.37
Kinishka	C75	8936		10.58
Lakeview, Cuirt na hAbhainn	C78 - C80	9565	10.8	10.87
Gortatleva	C83	10785	11.3	11.53
d/s face Crusheen Br	C89	12153		11.79
u/s face Crusheen Br	C90	12163		12.41
Caherlea / Lisheenavalla	C91 - C93	12856	13	12.92

Table 5.1 Calibration results in flood affected areas for Nov 2009 flood event – Clare River reach

5.3.2 Calibration results for the River Clare at Claregalway and Crusheen Bridge

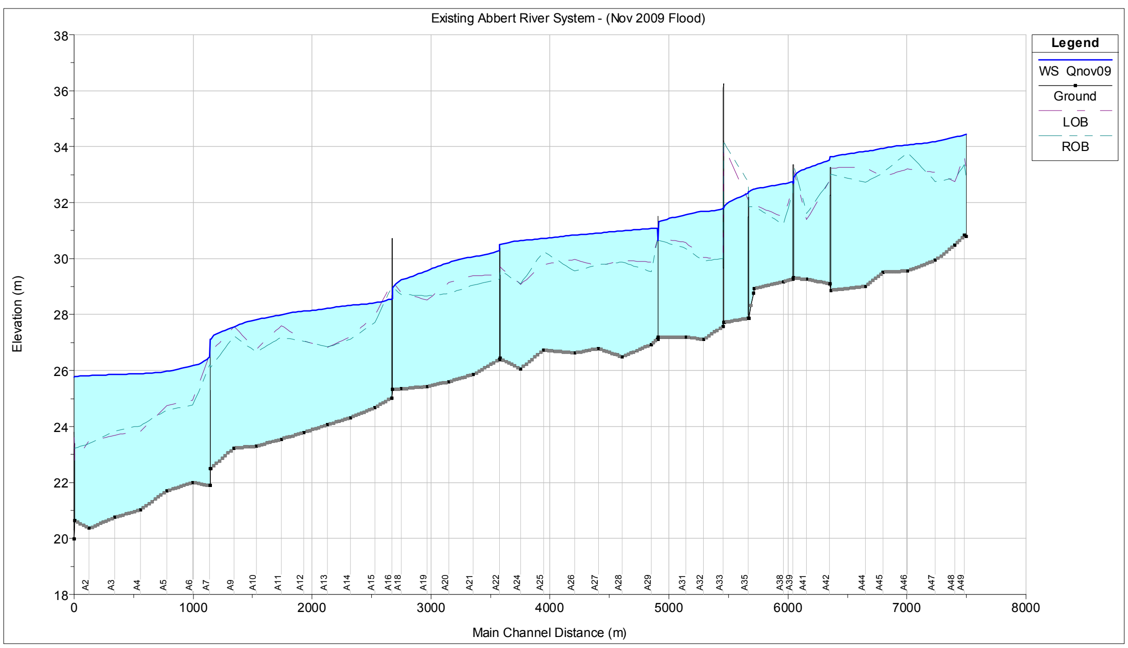


Figure 5.4 Plot of flood peak profile for November 2009 flood event – Calibration Run Abbert River

Description	Cross Section Reference	Chainage m	Observed Peak Level m OD	Computed Flood level m OD
Ardskeaghmore	A11	1743	27.88	27.98
Bullaun Bridge	A17	2678		28.95
u/s of Bullaun Br.	A21	3356	30.30	30.10

Table 5.2 Calibration Results For November 2009 Flood – Abbert River

5.4 Sensitivity of Flooding at Claregalway to Lough Corrib Lake Levels

This simulation run was carried out to examine the effect of Lough Corrib lake level on flooding in the Clare River upstream in the vicinity of Claregalway. The November 2009 flood event was re-run with the lake level boundary condition reduced from 7.10 mOD to 6.00m OD Malin. A comparison between the two models is presented in Table 5.3 below. The results clearly show that a reduction in Lough Corrib lake level has a very limited influence on the flood levels at Claregalway and thus it can be concluded that the management of flood levels in Lough Corrib does not constitute a flood alleviation option for Claregalway, particularly in the vicinity of the N17 Claregalway Bridge.

The raised bed section downstream of the Headford Road (C3 to C17) was also lowered to examine if it had any impact on flood levels. The model demonstrated that the lowering of bed levels in this area has no perceptible impact on flood levels in the flood affected areas upstream at Claregalway.

Location	Cross Section Reference	Chainage m	Nov 2009 Flood Event mOD	Nov 2009 Flood with Lough Corrib level reduced to 6 mOD
Curraghmore Bridge	C0	0	7.10	6.00
Miontach South	C23	2628	7.64	7.18
Miontach North	C52	6276	8.27	8.06
Claregalway Gauge (d/s bridge)	C63	7628	8.70	8.60
u/s Claregalway Bridge	C72	8506	9.49	9.46
Kinishka	C73	8557	10.37	10.34
Lakeview, Cuirt na hAbhainn	C75	8936	10.58	10.56
Gortatleva	C79	9785	11.02	11.01
d/s face Crusheen Br	C83	10785	11.53	11.52
u/s face Crusheen Br	C89	12153	11.79	11.79
Caherlea / Lisheenavalla	C90	12163	12.41	12.41
Curraghmore Bridge	C93	12856	12.92	12.92

Table 5.3 Model Results under different Lake level conditions in Lough Corrib for the Nov 09 Flood

5.5 Modelling of Flood Alleviation Measures

5.5.1 Flood Alleviation at Claregalway, Crusheen Bridge and Caherlea/Lisheenavalla

The technical viability of the following flood relief measures were investigated using the calibrated HEC-RAS hydraulic model of the Clare River. It is noted that these measures are assessed for viability with respect to other criteria in Chapter 7.

- Do Nothing Measure (Existing Case)
- Provide Flood Culverts at Claregalway and Crusheen Bridge with Local Widening and Re-grading works
- Provide Flood Culverts at Claregalway and Crusheen Bridge with Channel Widening from Curraghmore (C22) to upstream of Crusheen Br (C94)
- Provide Flood Culverts at Claregalway and Crusheen Bridge with Channel Widening from Claregalway (C71) to upstream of Crusheen Br (C94).

The benefit of the various measures at key flood risk locations (identification of these locations and discussion of flood risk provided in Chapter 6) was assessed by modelling the mean annual flood, the November 2009 flood, the 100 year Design Flood and the 100 year Design Flood with Climate Change events.

- **Do Nothing Measure (i.e. Existing River)**

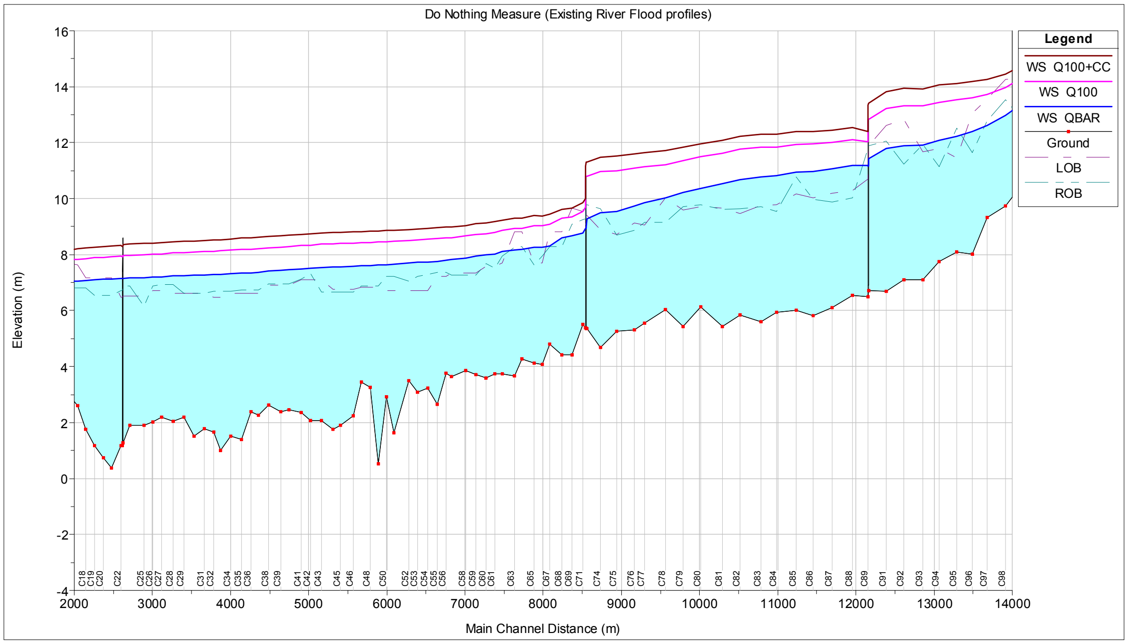


Figure 5.5 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	Nov 2009 Flood m OD	100 year Flood m OD	100 year Flood with CC m OD
Curraghmore Bridge	C23	2628	7.15	7.64	7.96	8.36
Miontach South	C52	6276	7.70	8.27	8.51	8.90
Miontach North	C63	7628	8.17	8.70	8.93	9.30
Claregalway Gauge (d/s bridge)	C72	8506	8.93	9.49	9.68	9.99
u/s Claregalway Bridge	C73	8557	9.28	10.37	10.79	11.31
Kinishka	C75	8936	9.55	10.58	10.99	11.52
Lakeview, Cuirt na hAbhainn	C79	9785	10.22	11.02	11.36	11.85
Gortatleva	C83	10785	10.78	11.53	11.83	12.30
d/s face Crusheen Br	C89	12153	11.19	11.79	12.03	12.41
u/s face Crusheen Br	C90	12163	11.44	12.41	12.82	13.41
Caherlea / Lisheenavalla	C93	12856	11.92	12.92	13.31	13.93

Table 5.4 Simulation Results for the Do Nothing Measure – Clare River at key flood reference Points

This option indicates serious flooding at Claregalway and the Crusheen Bridge area with potential flood levels of 11.31m OD upstream of Claregalway Bridge and 13.93m OD at Caherlea / Lisheenavalla under potential future climate change conditions.

- **Provide Additional Flood Culverts at Claregalway and Crusheen Bridges**

This option investigated the provision of an additional flood culvert measuring 12m by 3m at Claregalway and included local re-grading of the river in the vicinity of the bridge and some channel widening to facilitate the culvert. The option also included twin 6m by 3m culverts on either bank at Crusheen Bridge with some channel widening to facilitate these culverts.

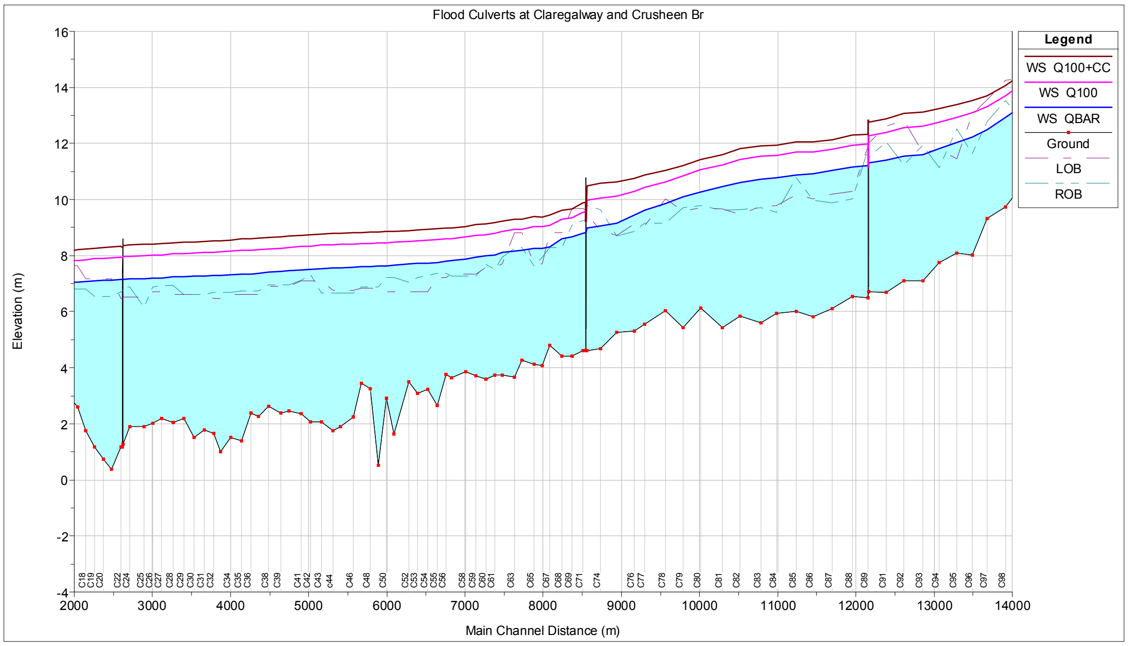


Figure 5.6 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	Nov 2009 Flood m OD	100 year Flood m OD	100 year Flood with CC m OD
Curraghmore Bridge	C23	2628	7.15	7.64	7.96	8.36
Miontach South	C52	6276	7.70	8.27	8.51	8.90
Miontach North	C63	7628	8.17	8.70	8.93	9.30
Claregalway Gauge (d/s bridge)	C72	8506	8.82	9.38	9.58	9.90
u/s Claregalway Bridge	C73	8557	8.98	9.68	9.97	10.49
Kinishka	C75	8936	9.15	9.83	10.11	10.63
Lakeview, Cuirt na hAbhainn	C79	9785	10.09	10.64	10.84	11.21
Gortatleva	C83	10785	10.72	11.32	11.54	11.91
d/s face Crusheen Br	C89	12153	11.21	11.79	12.12	12.33
u/s face Crusheen Br	C90	12163	11.30	12.00	12.33	12.76
Caherlea / Lisheenavalla	C93	12856	11.6	12.33	12.60	13.11

Table 5.5 Simulation Results at key flood reference points for provision of Flood culverts at Claregalway and Crusheen Bridges – Clare River

- **Full Channel Widening (15 to 20m wide flood berm) from Headford Road to upstream of Crusheen Bridge (c22 to C94)**

This option is in addition to providing the flood culverts at Claregalway and Crusheen Bridge and includes for channel widening in the form of a 15m base width flood berm and 20m top width from the Curraghmore Bridge to 900m upstream of Crusheen Bridge.

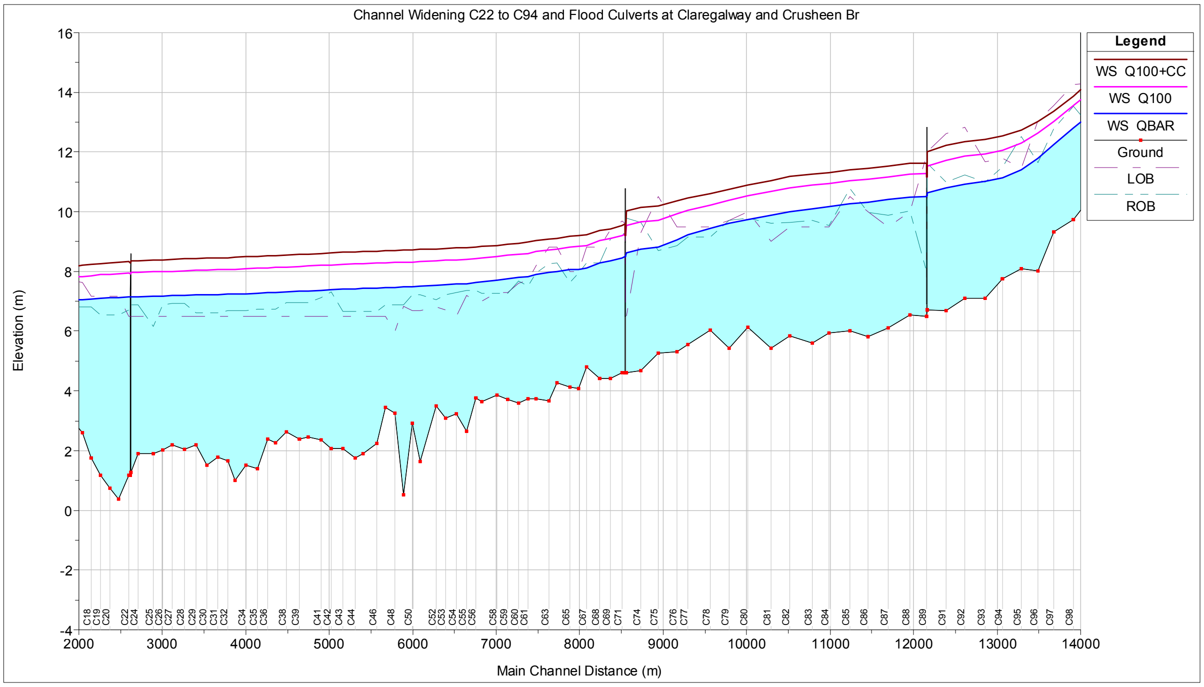


Figure 5.7 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	Nov 2009 Flood m OD	100 year Flood m OD	100 year Flood with CC m OD
Curraghmore Bridge	C23	2628	7.14	7.65	7.93	8.36
Miontach South	C52	6276	7.54	8.11	8.36	8.76
Miontach North	C63	7628	7.96	8.49	8.73	9.09
Claregalway Gauge (d/s bridge)	C72	8506	8.50	9.05	9.26	9.54
u/s Claregalway Bridge	C73	8557	8.63	9.26	9.54	10.02
Kinishka	C75	8936	8.82	9.45	9.72	10.19
Lakeview, Cuirt na hAbhainn	C79	9785	9.61	10.17	10.38	10.76
Gortatleva	C83	10785	10.11	10.68	10.90	11.27
d/s face Crusheen Br	C89	12153	10.52	11.09	11.28	11.62
u/s face Crusheen Br	C90	12163	10.63	11.27	11.53	12.01
Caherlea / Lisheenavalla	C93	12856	11.01	11.68	11.94	12.41

Table 5.6 Computed flood levels at key flood reference points for the full widening option on the Clare River from C22 to C94.

- **Channel Widening from Claregalway to upstream of Crusheen Bridge (C71 to C94)**

This option is in addition to providing the flood culverts at Claregalway and Crusheen Bridge and includes for channel widening in the form of a 15m base width flood berm from 150m downstream of Claregalway Bridge to 900m upstream of Crusheen Bridge.

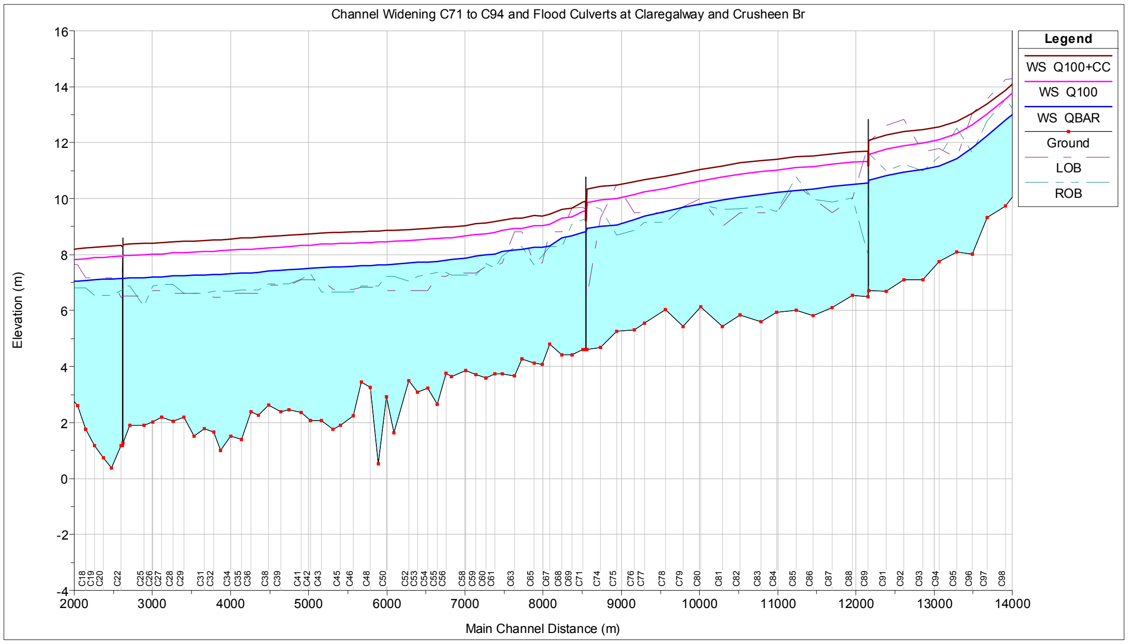


Figure 5.8 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	Nov 2009 Flood m OD	100 year Flood m OD	100 year Flood with CC m OD
Curraghmore Bridge	C23	2628	7.15	7.64	7.96	8.36
Miontach South	C52	6276	7.70	8.27	8.51	8.90
Miontach North	C63	7628	8.17	8.7	8.93	9.30
Claregalway Gauge (d/s bridge)	C72	8506	8.82	9.38	9.58	9.91
u/s Claregalway Bridge	C73	8557	8.93	9.6	9.87	10.35
Kinishka	C75	8936	9.07	9.74	10.00	10.48
Lakeview, Cuirt na hAbhainn	C79	9785	9.70	10.29	10.51	10.91
Gortatleva	C83	10785	10.15	10.75	10.97	11.37
d/s face Crusheen Br	C89	12153	10.55	11.13	11.33	11.68
u/s face Crusheen Br	C90	12163	10.67	11.31	11.58	12.08
Caherlea / Lisheenavalla	C93	12856	11.03	11.67	11.98	12.46

Table 5.7 Simulation results at key flood reference points for provision of Flood culverts at Claregalway and Crusheen Bridges and widening from C71 to C94 – Clare River

5.5.2 River Abbert Flood Alleviation at Ardskeaghmore and upstream of Bullaun Bridge

The following flood risk management measures were investigated using the calibrated HEC-RAS hydraulic model of the Abbert River;

- Do Nothing Measure (Existing Case)
- Provide Flood Culverts at A7 and A17 (Bullaun Bridge) with local widening and re-grading works
- Provide Flood Culverts at A7 and A17 (Bullaun Bridge) with channel re-grading and widening from A7 to A15 and widening from A16 to A22
- Provide Flood Culverts at A7 and A17 (Bullaun Bridge) and widening from A16 to A22.

- **Do Nothing Measure (existing River)**

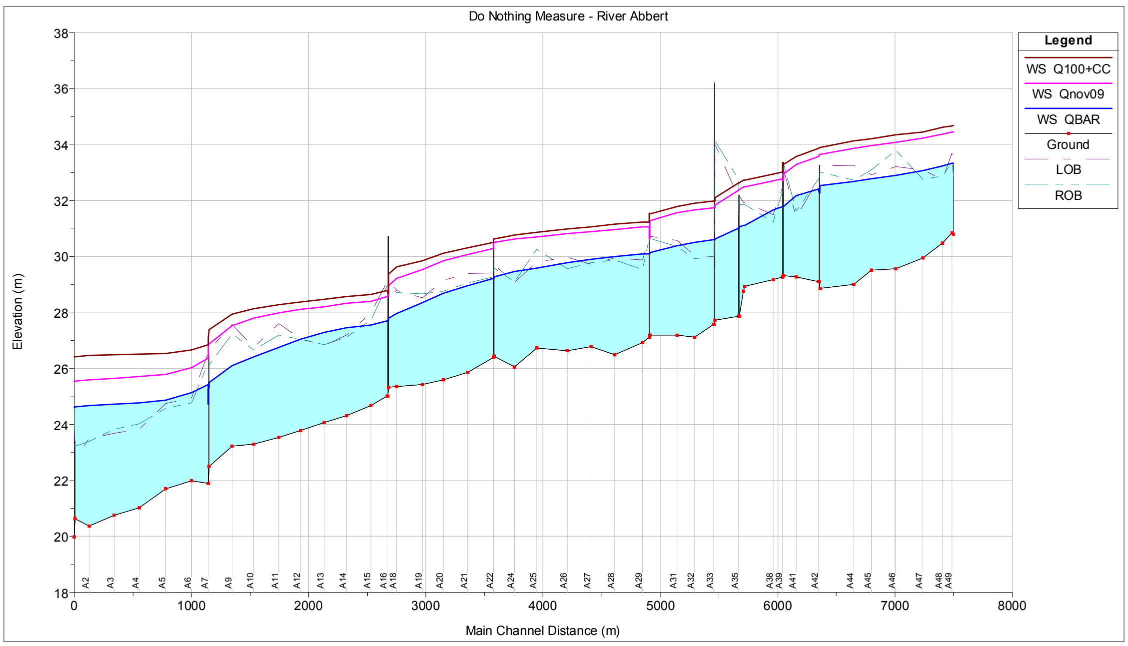


Figure 5.9 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	100 year Flood m OD	100 year Flood with CC m OD
River Clare Confluence	A1	0	24.61	25.52	26.41
Ardskeaghmore	A11	1743	26.74	27.98	28.27
Bullaun Bridge	A17	2678	27.8	28.95	29.38
u/s of Bullaun Bridge	A21	3356	28.95	30.10	30.32

Table 5.8 Simulation Results For the Do Nothing Measure – Abbert River at key flood reference points

- **Provide Flood Culverts and local widening at A7 and A17 (Bullaun) Bridges**

This option investigated the provision of an additional Flood Culvert measuring 6m by 3m or alternatively replacement of the existing bridge at bridges A7 and A17 (Bullaun Bridge) and included local channel widening to facilitate these culverts.

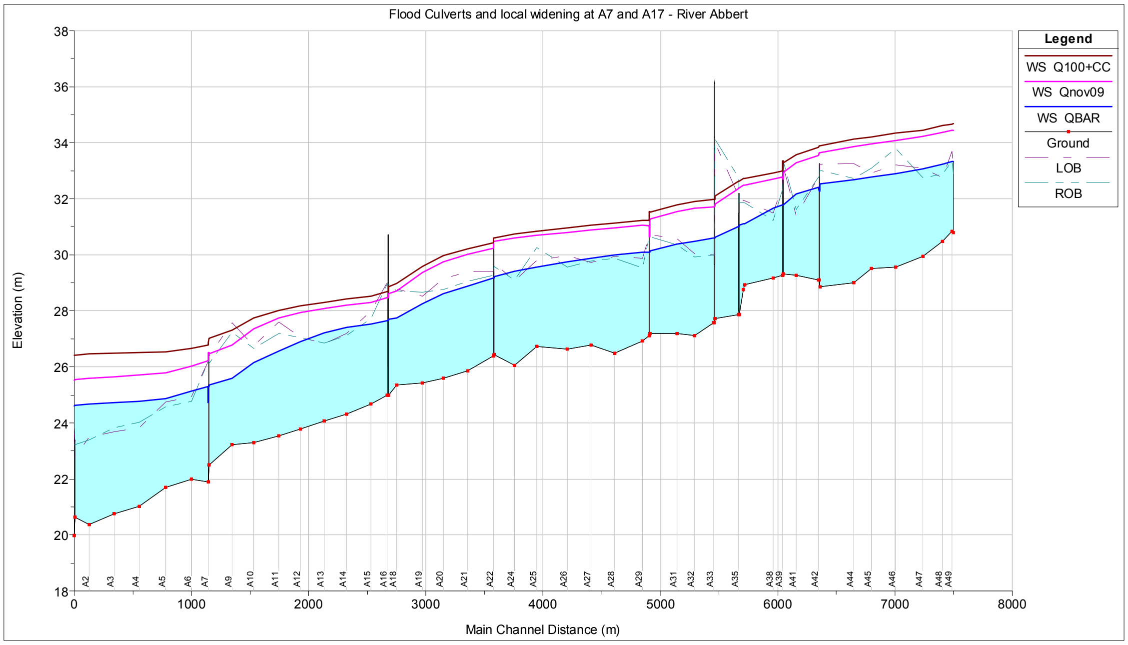


Figure 5.10 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	100 year Flood m OD	100 year Flood with CC m OD
River Clare Confluence	A1	0	24.61	25.52	26.41
Ardskeaghmore	A11	1743	26.56	27.75	28.02
Bullaun Bridge	A17	2678	27.68	28.59	28.84
u/s of Bullaun Br.	A21	3356	28.89	30.01	30.21

Table 4.9 Simulation results at key flood reference points for provision of Flood culverts at A7 and A17 Bullaun Bridge – Abbert River

- **Channel widening and re-grading from A7 to A15, widening from A16 to A22 and Flood Culverts at A7 and A17**

This option is in addition to providing the flood culverts at A7 and A17 and includes for channel re-grading from A7 to A17 and channel widening in the form of an 8 to 10m base width flood berm from A7 to A22 to reduce flooding at Ardskeaghmore, Bullaun and Ardskea.

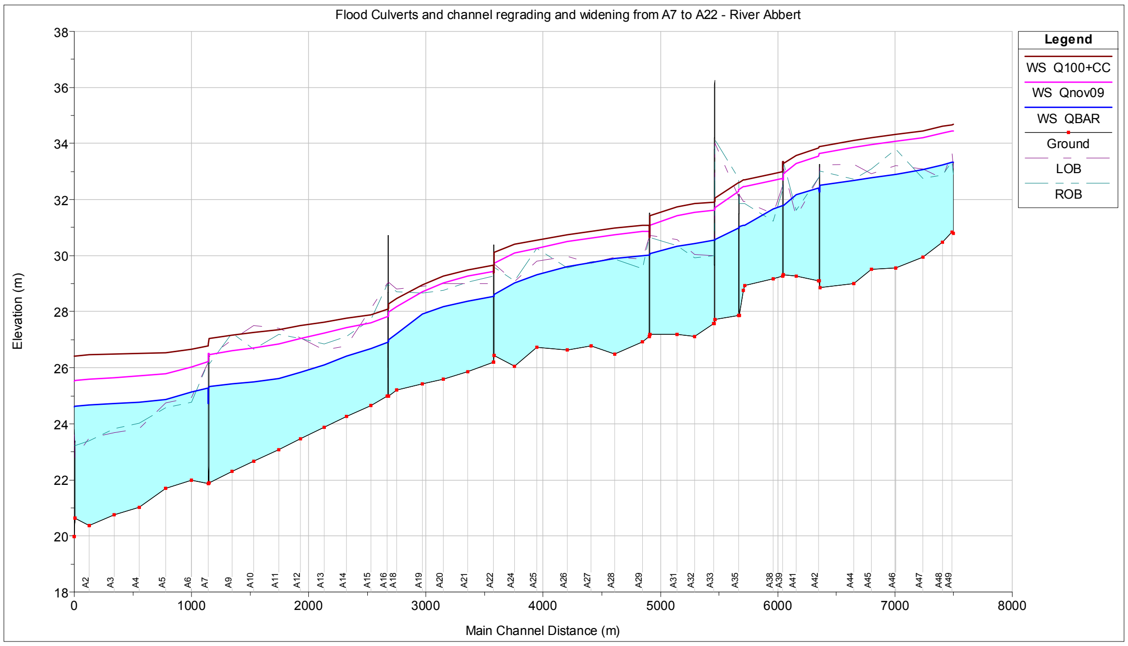


Figure 5.11 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	100 year Flood m OD	100 year Flood with CC m OD
River Clare Confluence	A1	0	24.61	25.52	26.41
Ardskeaghmore	A11	1743	25.62	26.85	27.36
Bullaun Bridge	A17	2678	26.99	27.98	28.28
u/s of Bullaun Br.	A21	3356	28.38	29.26	29.48

Table 5.10 Computed flood levels at key flood reference points for flood culverts, re-grading and widening option on the Abbert River from A7 to A22.

- **Channel widening from A16 to A22 and Flood Culverts at A7 and A17**

This option is in addition to providing the flood culverts at A7 and A17 and includes for channel widening in the form of an 8 to 10m base width flood berm A16 to A22 to reduce flooding at Bullaun and Ardskea.

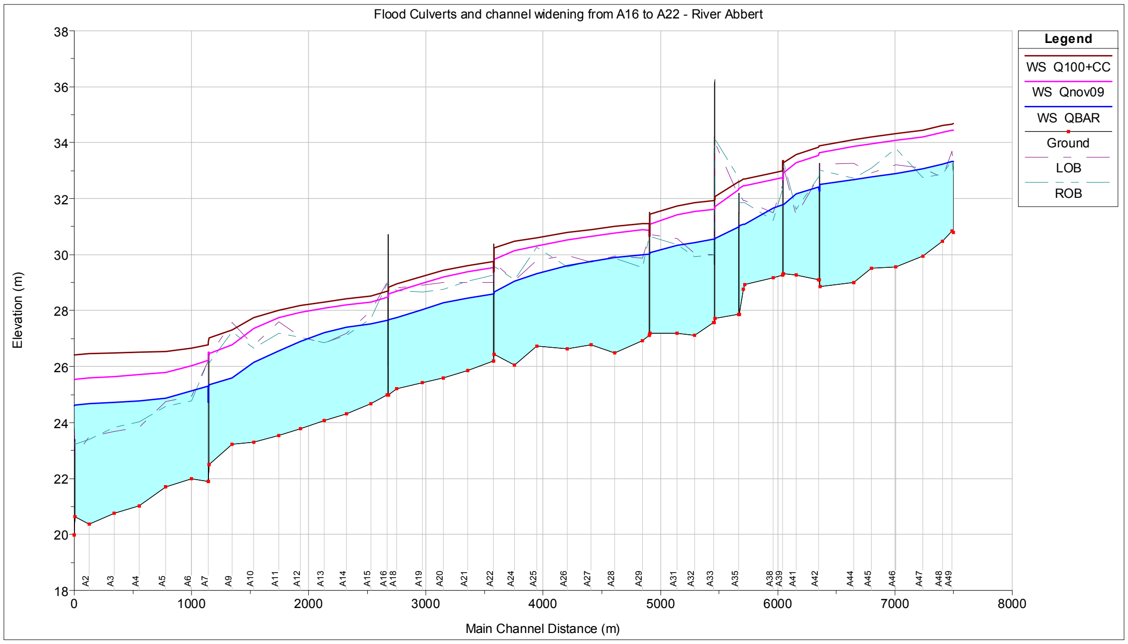


Figure 5.12 Computed longitudinal profile of flood peak for Design Flood events

Location	Cross Section Reference	Chainage m	Mean Annual flood m OD	100 year Flood m OD	100 year Flood with CC m OD
River Clare Confluence	A1	0	24.61	25.52	26.41
Ardskeaghmore	A11	1743	26.56	27.75	28.02
Bullaun Bridge	A17	2678	27.68	28.57	28.84
u/s of Bullaun Br.	A21	3356	28.44	29.38	29.61

Table 5.11 Computed flood levels at key flood reference points for flood culverts, re-grading and widening option on the Abbert River from A16 to A22.

5.6 Model Results

The results of the modelling detailed in this section are analysed and discussed in further detail in Chapter 7 in relation to each flood risk management measure's viability.

6. Flood Damage Analysis

6.1. General

A Flood Damage Analysis is described below for the November 2009 flood event based on the anecdotal evidence collected and the calibrated hydraulic model. This damage analysis is then extrapolated to the Design Flood event (185 cumec) and the Design Flood plus Climate Change event (220 cumec).

6.2. Flood Mapping

The extent of the inundation resulting from the flood of November 2009 is shown on the flood mapping contained in Appendix B. The flood extents shown on the drawing are based on aerial video footage taken on the 23 November 2009 for the more southerly parts of the catchment and aerial photography taken on the 21 November 2009 for the more northerly parts of the catchment where the peak of the flood occurred earlier than in the Claregalway region. These drawings also denote flooded properties, properties at risk of flooding, properties cut off by flooding and roads flooded in the November 2009 event.

6.3. Assessment of Impact of Flooding

6.3.1 Summary of Impacts consequent to November 2009 flooding

The flood mapping included in Appendix B gives an overview of the impact of the November 2009 floods. As well as showing the extent of the flood, these drawings show houses which were flooded, houses which were at risk of flooding and roads that were flooded and impassable as a result. These impacts will be the input to the Flood Risk Assessment and the Outline Flood Damage Analysis described below in Section 6.5. For ease of analysis, the main flood impacts from the November 2009 flood have been divided into ten areas working from the lake upstream as set out in Table 6.1 and also shown on Figure 6.1 below.

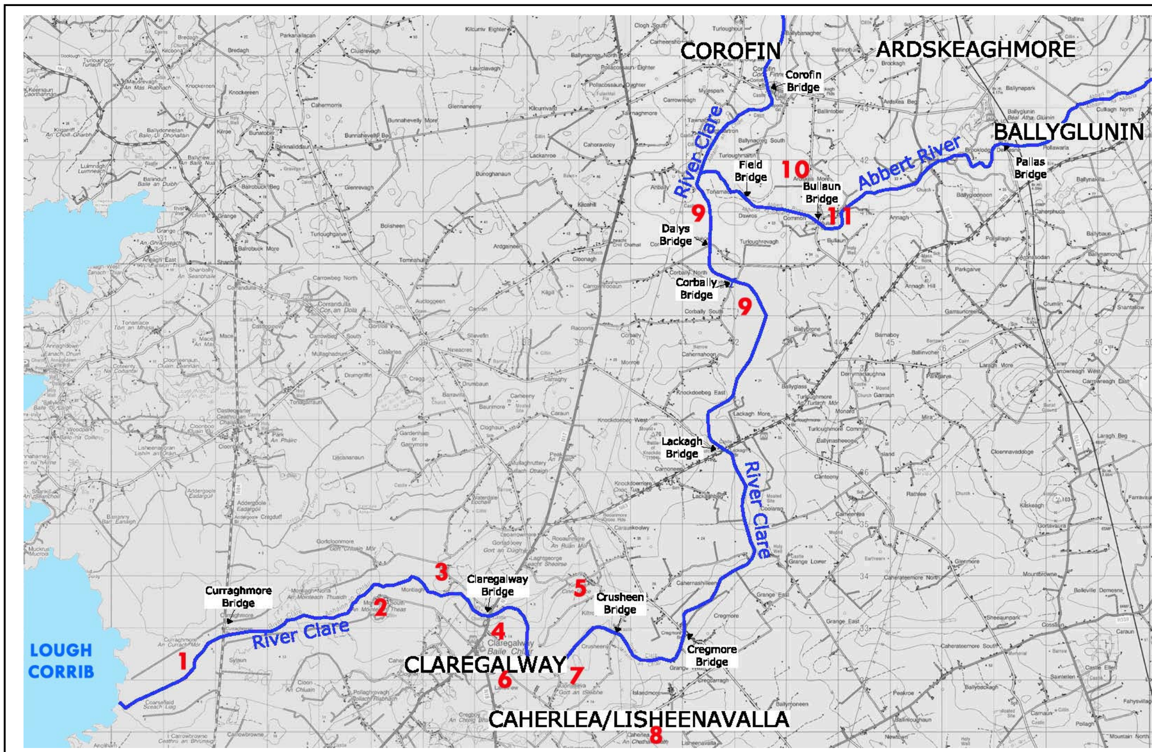


Figure 6.1 Map showing location of main flood impacts within the Study Area

Area	Cross Section Reference	Location	Peak Flood Level	Impact of Flood
CLARE RIVER				
1	C1 - C61	L Corrib to Curraghmore Bridge	7.64mOD at Curraghmore	Extensive land flooding. No property or property access affected. N84 (Galway-Headford Road) is raised above flood level
2	C52 - C61	Miontach South (downstream Claregalway Br - south of river)	8.27mOD	1km of access road to residential area flooded. Affected section of road varies from 7.6m to 8.25mOD.
3	C53 - C63	Miontach North (downstream Claregalway Br - north of river)	8.70mOD	2 separate sections of access road affected both sections approx 470m and 750m long. First section of flooded road – levels range from 8.35mOD to 8.75mOD. 1 No. house at FFL 8.44m flooded to a level of 8.70mOD. Neighbouring house at 8.73mOD came close to flooding. Second section of flooded road – levels range from 7.7mOD to 8.3mOD.
4	C73	Claregalway Village	10.34mOD	Roads in "An Mhainister" housing estate adjacent to river on southern side flooded. Access to Arches hotel and housing behind flooded. Castle and other buildings on site of castle and sheds upstream of castle FFL 9.84mOD flooded. N17 road closed. Road level 10.15m to 10.40mOD.
5	C75	Kinishka Townland (north of river)	10.58mOD	Access road flooded to village but remained passable.
6	C78 - C80	Lakeview (south of river). Cuirt na hAbhainn housing estate to Corporate Park.	10.80m OD (in river) 11.30mOD in vicinity of Corporate Park	Flooding appears to be related to turlough and not from river channel. Cuirt na hAbhainn housing estate road flooded and houses almost flooded. Estate road varies from 10.55mOD to 10.80mOD Minor flooding in low area at front of park. Peak flood level at corp park 11.30mOD. Lakeview housing estate roads at risk (within 200mm).
7	C83	Gortatleva	11.30mOD	Land flooding & 1 No. home flooded. FFL 10.9mOD.
8	C91 - C94	Caherlea/Lisheenavalla	13.00mOD	16 No. houses completely flooded or at risk of flooding. FFL's of houses range from 12.3mOD to 12.5mOD. Road flooded by up to 1m. Road level ranges from 11.9mOD to 13mOD.
9	C123 – C164	Lackagh Br to upstream of Corofin Br	Varies	Land flooding

ABBERT RIVER				
10	A7 - A12	Ardskeaghmore	27.88mOD	4 No. houses flooded to level of 27.88mOD. FFLs 26.6 & 26.97mOD. Road flooded in vicinity of houses.
11	A17 - A34	Upstream of Bullaun Br	30.30mOD	1 No. house flooded 28.49mOD FFL just upstream of Bullaun Br and 1 No. house flooded 29.69mOD at approx 400m upstream of bridge. Extensive land flooding in vicinity of Brooklodge & further upstream.

Table 6.1 Description of Flood Impact – November 2009 Flood

6.3.2 Estimation of flood damages and benefits accruing from flood alleviation options

An outline flood damage analysis has been conducted for the November 2009 flood, as well as the Design Flood and the Design Flood plus Climate Change event based on the approach detailed in the "Multi Coloured Manual" (MCM) produced by the Flood Hazard Research Centre (Middlesex University). The "Weighted Annual Average Damages" approach is adopted in the calculation of economic damages to property as a result of the various flood events.

The following categories of damages are assessed under the MCM methods;

- Residential property damages – both direct and intangible
- Non-residential property damages
- Emergency costs
- Costs due to roads being impassable

The MCM also sets out an approach to estimating damages relating to the flooding of agricultural land. However, this category of damages is not assessed here as the input data required is extensive (including individual farm surveys) and beyond the scope of an outline assessment. It is considered that using the MCM method, the estimate of economic damages caused by property flooding and road closures far outweighs the estimated damages caused by the flooding of agricultural land and therefore, omitting this category does not unduly influence the result of the exercise.

6.3.3 Basis for Outline Damage Analysis – November 2009 flood event

The outline damage analysis below for the November 2009 flood event is based on the following facts and assumptions;

- The N17 at Claregalway remained closed for 6 days.
- The number of diverted traffic journeys, resulting from the above closure is based on AADT (Annual Average Daily Traffic) figures obtained from the National Roads Authority (NRA) for the N17, 1km north of Claregalway. The average of the AADT's for the past three years (2007, 2008, 2009) of 22,452 is used in the analyses.
- AADT's for the N84 (the main diversion route) were obtained from analyses carried out for the proposed Galway City Outer Bypass design as actual AADT figures were not available.
- Diverted journeys on local roads are not included in the assessment.
- Flooded residential properties are assessed based on depth of flooding.
- An allowance of €241 (£200) per residential property flooded is included for intangible losses as recommended in the MCM.

- Non-residential property damages are based on the class of commercial activity involved. Weighted annual average damages are assigned on the basis of a damages cost per square metre.
- An allowance of 10.7% of total economic property damages is applied for the cost of emergency services and other services involved in the flood relief efforts as recommended in the MCM.

6.3.4 Basis for outline damage analysis – Design Flood

The outline damage analysis below resulting from the flood level caused by the Design Flood event is based on the same assumptions as for the November 2009 flood event with the following amendments;

- The N17 road would be closed for 7 days.
- Additional residential and non-residential properties would be flooded.
- Properties flooded in the November 2009 flood would now be flooded to a greater depth.

6.3.3 Basis for outline damage analysis – Design Flood plus Climate Change

Similarly, when a Climate Change allowance is applied to the Design Flood event the following assumptions apply;

- The N17 road would be closed for 8 days.
- Additional residential and non-residential properties would be flooded.
- Properties flooded in the November 2009 flood and the Design Flood would now be flooded to a greater depth.

The cost of damages for the “Do Nothing” scenario i.e. maintaining the channel in its existing condition and carrying out no works, will be used later in the study as input to the cost benefit analysis of each of the potentially viable flood risk management measures.

The following tables provide a summary of the estimated economic cost of damages or the benefit for each area in respect of the November 2009 flood event (Table 6.3), the Design Flood event (Table 6.4) and for the Design Flood plus Climate Change event (Table 6.5)

DO NOTHING SCENARIO OUTLINE DAMAGE ANALYSIS - NOVEMBER 2009 FLOOD EVENT							
		Economic Damage Category					Total Economic Damages - Nov 2009 Flood Event €
		Residential Property		Non-Residential Property €	Emergency Costs €	Roads €	
Area	Location	Direct €	Intangible €		10.7% of total property damages		
Clare River							
1	L Corrib to Curraghmore Br	-	-	-	-	-	-
2	Miontach South	-	-	-	-	-	-
3	Miontach North	39,514.24	241.28	-	4,253.84	-	44,009.36
4	Claregalway Village	65,239.41	723.84	-	7,058.07	11,054,607.41	11,127,628.73
5	Kinishka Townland (north of river)	-	-	-	-	-	-
6	Lakeview (south of river)	-	-	-	-	-	-
7	Gortatleva	40,362.31	241.28	-	4,344.58	-	44,948.17
8	Caherlea/Lisheenavalla	547,219.79	3,136.64	-	58,888.14	-	609,244.57
9	Lackagh Br to Corofin Br	-	-	-	-	-	-
CLARE RIVER TOTALS		**692,335.75**	**4,343.04**	**-**	**74,544.63**	**11,054,607.41**	**11,825,830.83**
Abbert River							
10	Ardskeaghmore	180,835.41	965.12	-	19,452.66	-	201,253.19
11	Upstream of Bullaun Br	84,257.51	482.56	-	9,067.19	-	93,807.26
ABBERT RIVER TOTALS		**265,092.92**	**1,447.68**	**-**	**28,519.84**	**-**	**295,060.44**
CLARE RIVER + ABBERT RIVER TOTAL		**957,428.67**	**5,790.72**	**-**	**103,064.47**	**11,054,607.41**	**€ 12,120,891.27**

Table 6.3 November 2009 Flood Event Outline Damage Analysis – Do Nothing Scenario

DO NOTHING SCENARIO OUTLINE DAMAGE ANALYSIS - DESIGN FLOOD EVENT							
		Economic Damage Category					Total Economic Damages - Design Flood Event €
		Residential Property		Non-Residential Property €	Emergency Costs €		
Area	Location	Direct €	Intangible €		10.7% of total property damages	Roads €	
Clare River							
1	L Corrib to Curraghmore Br	-	-	-	-	-	-
2	Miontach South	-	-	-	-	-	-
3	Miontach North	41,243.57	241.28	-	4,438.88	-	45,923.73
4	Claregalway Village	123,730.72	723.84	26,395.88	16,141.00	12,897,041.98	13,064,033.41
5	Kinishka Townland (north of river)	79,002.29	482.56	-	8,504.88	-	87,989.72
6	Lakeview (south of river)	1,817,052.58	11,098.88	34,145.25	199,265.75	-	2,061,562.46
7	Gortatleva	42,941.37	241.28	-	4,620.54	-	47,803.19
8	Caherlea/Lisheenavalla	891,890.31	4,825.60	-	95,948.60	-	992,664.51
9	Lackagh Br to Corofin Br	-	-	-	-	-	-
CLARE RIVER TOTALS		**2,995,860.83**	**17,613.44**	**60,541.13**	**328,919.65**	**12,897,041.98**	**16,299,977.02**
Abbert River							
10	Ardskeaghmore	180,835.41	965.12	-	19,452.66	-	201,253.19
11	Upstream of Bullaun Br	84,257.51	482.56	-	9,067.19	-	93,807.26
ABBERT RIVER TOTALS		**265,092.92**	**1,447.68**	**-**	**28,519.84**	**-**	**295,060.44**
CLARE RIVER + ABBERT RIVER TOTAL		**3,260,953.75**	**19,061.12**	**60,541.13**	**357,439.49**	**12,897,041.98**	**€16,595,037.47**

Table 6.4 Design Flood Event Outline Damage Analysis – Do Nothing Scenario

DO NOTHING SCENARIO OUTLINE DAMAGE ANALYSIS - DESIGN FLOOD PLUS CLIMATE CHANGE EVENT							
		Economic Damage Category					Total Economic Damages - Design Flood + Climate Change Event €
		Residential Property		Non-Residential Property €	Emergency Costs €		
Area	Location	Direct €	Intangible €		10.7% of total property damages	Roads €	
Clare River							
1	L Corrib to Curraghmore Br	-	-	-	-	-	-
2	Miontach South	-	-	-	-	-	-
3	Miontach North	68,470.71	723.84	-	7,403.82	-	76,598.37
4	Claregalway Village	135,377.85	723.84	354,094.04	52,450.94	14,739,476.55	15,282,123.22
5	Kinishka Townland (north of river)	87,535.87	482.56	-	9,417.97	-	97,436.40
6	Lakeview (south of river)	2,013,325.01	11,098.88	34,145.25	220,266.90	-	2,278,836.03
7	Gortatleva	45,657.39	241.28	-	4,911.16	-	50,809.82
8	Caherlea/Lisheenavalla	1,713,118.18	8,444.80	-	184,207.24	-	1,905,770.21
9	Lackagh Br to Corofin Br	-	-	-	-	-	-
CLARE RIVER TOTALS		**4,063,485.01**	**21,715.20**	**388,239.29**	**478,658.03**	**14,739,476.55**	**19,691,574.07**
Abbert River							
10	Ardskeaghmore	188,277.59	965.12	-	20,248.97	-	209,491.68
11	Upstream of Bullaun Br	87,535.87	482.56	-	9,417.97	-	97,436.40
ABBERT RIVER TOTALS		**275,813.46**	**1,447.68**	**-**	**29,666.94**	**-**	**306,928.09**
CLARE RIVER + ABBERT RIVER TOTAL		**4,339,298.47**	**23,162.88**	**388,239.29**	**508,324.97**	**14,739,476.55**	**€ 19,998,502.15**

Table 6.5 Design Flood Plus Climate Change Flood Event Outline Damage Analysis – Do Nothing Scenario

The tables above detail the economic cost of the damages resulting from the November 2009 flood event, the Design Flood event and the Design Flood plus Climate Change event. The assessment of the impact in terms of the cost of damages is summarised in Table 6.6 below;

Flood Event	Assessment of Damages Clare River	Assessment of Damages Abbert River	Assessment of Damages Clare & Abbert Rivers
November 2009 Flood	**€11,825,830.83**	**€295,060.44**	**€12,120,891.27**
Design Flood	**€16,299,977.02**	**€295,060.44**	**€16,595,037.47**
Design Flood plus Climate Change	**€19,691,574.07**	**€306,928.09**	**€19,998,502.15**

Table 6.6 Summary of Damage Analysis for Various Flood Scenarios– Do Nothing Scenario

6.4. Outline Flood Risk Assessment

The flood mapping included in Appendix B shows the areas of the catchment at risk of flooding. The outline risk assessment presented below further describes the impact of the flooding. The impact is considered in relation to five categories below namely; human health risk, critical infrastructure risk, economic risk, environmental risk and cultural heritage risk.

6.4.1. Human Health Risk

The location of properties subject to flooding and flood risk are shown on the flood maps. It is noted that there are no hospitals, nursing homes etc at risk of flooding in the study area.

There is an obvious danger to human health in all of these areas as a result of drowning.

However, there is also a significant human health risk in these areas relating to contamination of the flood waters with foul sewage from septic tanks and other foul water disposal systems in areas subject to flooding. This is particularly relevant in the Claregalway Town area where numerous housing and commercial developments are served by package wastewater treatment plants. A number of these were flooded during the flood events of December 2006 and November 2009 flood events resulting in untreated foul water mixing with flood waters discharged to Lower Lough Corrib. The wastewater treatment plant for the housing estates in the Lakeview area is located in the field adjacent to the river bank on the upstream side of the Bridge. This plant was completely inundated during the November 2009 event and also during flood events of smaller magnitude such as the December 2006 flood.

A major drinking water abstraction (55,000m^3/day) is located off the River Corrib in Galway City downstream of Lower Lough Corrib into which the River Clare flows. Because of the proximity of the inflowing Clare River and the outflowing Corrib River channels at the southerly end of the lower Lake, the risk of short-circuiting of flood flows from the Clare to the Corrib channels is heightened. Subsequent to the increased incidence of cryptosporidiosis in the Galway City drinking water supply in 2007, epidemiological investigations and the genotyping of *Cryptosporidium* revealed that the majority of recorded cases were caused consequent to contamination by faecal material of human origin. The risk of faecal contamination of drinking water supplies is exacerbated by the continued inundation of foul sewage treatment systems associated with development within the Study Area.

The particular treatment risk at Galway City's Terryland Water Treatment plant associated with the 2007 incidence of cryptosporidiosis has been reduced by major infrastructural investment in both the treatment capacity and disinfection process at the Plant.

There is also human health risk associated with the fact that the flooding forced people to travel through such contaminated waters, often by foot.

The psychological impact to human health of persons affected by flood inundation in or close to their homes is difficult to quantify but is significant. Anecdotally, many of the occupants of houses that have been flooded live in constant fear of a similar flood event in the future.

6.4.2. Critical Infrastructure Risk

Critical infrastructure assets include all transport routes (e.g road and rail) and utility assets (e.g water/wastewater supply/treatment, Garda/fire stations).

Table 6.7 below details the length of transport routes and the number of utility assets in the catchment at risk during the November 2009 flood event, the Design Flood event and the Design Flood plus Climate Change event. In this case, the utility assets refer to wastewater treatment plants located within the flood boundary in Claregalway. It is assumed for the Design Flood event and the Design Flood plus climate change event that the length of transport routes at risk increases by 10% and 20% respectively on the November 2009 flood event.

Flood Event	Length of Transport Routes at Risk (km)	Number of Utility Assets at risk
November 2009 Flood Event	20.22	3
Design Flood Event	22.24	5
Design Flood Event plus Climate Change	24.26	6

Table 6.7: Level of Flood Risk to Critical Infrastructure Assets

6.4.3. Economic Risk

The economic risk associated with flooding from the November 2009 flood event, the Design Flood event and the Design Flood plus Climate Change event has been evaluated above in Section 6.3. The economic risk for the study area is summarised in Table 6.8 below.

Flood Event	Economic Risk
November 2009 Flood	**€12,120,891.27**
Design Flood Event	**€16,595,037.47**
Design Flood Event plus Climate Change	**€19,998,502.15**

Table 6.8: Summary of Economic Flood Risk

6.4.4. Environmental Risk

The risk assessment in this case relates to the impact of flooding on Integrated Pollution, Prevention and Control (IPPC) licensed installations, other sites capable of causing pollution if inundated and conservation sites such as Special Area's of Conservation (SAC), Special Protection Area's (SPA) and National Heritage Area's (NHA).

There are no IPPC licensed installations at risk of flooding, however, there are numerous farmyards from which there is a risk of contamination from farmyard runoff or slurry pit overflow. There is also a risk from wastewater treatment plants discussed under critical infrastructure and human health above.

The River Clare catchment forms a key component of the Lough Corrib cSAC which is selected for the numerous aquatic habitats and water-dependent species occurring there that are listed in Annex I and II of the EU Habitats Directive, including; hard water lakes, lowland oligotrophic lakes, Atlantic salmon, White-clawed crayfish, Otter, Pearl mussel, Sea lamprey, Brook lamprey and Slender naiad. The River Clare catchment is considered to be one of the most important salmon spawning tributaries of the Corrib system.

Seasonal flooding is a natural feature of many Irish rivers, particularly those in flat lowland regions. However, major flood events which are exacerbated by artificial features such as bridges and historical channel realignment may have a wide range of impacts on the habitats and species within a river catchment including;

- Inundation of river bank wildlife resting or breeding areas, such as otter holts and badger setts. Spring floods may disrupt ground-breeding species such as Irish hare and numerous bird species.
- Flood events which rise above the level of existing bridge arches may drive species such as otters up on to roads thereby increasing the risk of roadkills.
- Significant erosion of surrounding agricultural lands leading to sediment and/or fertiliser laden run-off entering the river. This may have significant consequences for silt-sensitive species such as Pearl mussel, Salmon and White-clawed crayfish.
- Material stripped from surrounding landscape may cause increased levels of scouring within the river channel. This may damage salmonid spawning habitat.
- Floods may also release materials from septic tanks and wastewater treatment plants which may have a toxic or eutrophication affect on the receiving waters.

6.4.5. Cultural Heritage Risk

The National Monuments Service was consulted in order to determine the flood risk to any recorded monuments. The entire catchment and particularly the study area are rich in cultural heritage with numerous monuments identified including Claregalway Abbey which is a friary in state ownership and located in Claregalway. Its identifier on the Record of Monuments and Places is GA070-035001 and it is registered as National Monument No. 165.

There are numerous other recorded monuments and sites at risk of flooding including twenty six alone to the north of the bridge in Claregalway including a graveyard, several 17th century grave slabs, a tomb alter, plaques and memorial stones. These are all located within the site denoted “Abbey in ruins” on the vector mapping. On the south bank of the river there is a graveyard and church. These were flooded during the November 2009 flood event. Immediately upstream of the bridge on the southern bank there is an enclosure, possible earthworks and a moated site. A castle and tower house in private ownership is in the process of being restored on the opposite bank. These were all inundated during the November 2009 flood event.

In Kiltrogue townland, an enclosure and possible burial site have been recorded which are at risk of flooding. In the same townland, the ruins of Kiltrogue castle are located immediately downstream of Crusheen bridge on the river bank. There were all either inundated during the November 2009 flood event or at risk of flooding.

A ringfort has been recorded upstream of Cregmore and a designed landscape feature at Coolaran between Cregmore and Lackagh. A church, graveyard and towerhouse are located just upstream of Lackagh Bridge. These are at risk of flooding.

In the Corbally area , there is an enclosure in Ballybrone downstream of Corbally Bridge as well as Corbally House, a country house just upstream of Corbally Bridge.

There is a castle, bawn, souterrain and ringfort in Anbally just downstream of Abbert outfall and a childrens burial ground and castle ruins in Tawnaghmore upstream of Abbert outfall. Again all of the above monuments were either flooded or at risk of flooding during the November 2009 flood event.

In relation to the Abbert River, ringforts and an enclosure are located between the outfall and Bullaun Bridge. There is evidence of a children's burial ground on the southern bank just downstream of Bullaun bridge and an enclosure on southern bank upstream of Bullaun Bridge.

There is also a country house recorded at Annagh as well as a Ringfort at Ballyglooneen on the northern bank and another country house on the southern bank. A country house, ice house, tower house and chapel are located in Brooklodge Demesne. All of the monuments noted are subject to flood risk or inundation.

It is difficult to evaluate the impact of flooding on the integrity of these historical sites. In some cases, the monuments are regularly inundated as they are located within the flood plains. However, it is likely that persistent and regular flooding impacts negatively on the structure and integrity of some of these monuments.

7. Alleviation Options

7.1. General

The impacts of the November 2009 flood event, the Design Flood event and the Design Flood event plus Climate Change are analysed and evaluated where possible in Chapter 6. In this chapter, potential flood risk management measures to mitigate the impacts of floods of these magnitudes are investigated.

A range of potential flood risk management measures have been identified to mitigate the risks. The brief for this study calls for practical measures to eliminate or reduce flooding from an event similar in magnitude to the November 2009 event. In assessing the measures presented below, the efficacy of a particular measure will be evaluated in relation to both the November 2009 event, the Design Flood event and the Design Flood plus Climate Change event.

7.2. Potential Alleviation Options

There are numerous potential alleviation options which may be appropriate. The majority of the flood risk management options evaluated fall into the general categories listed below:

- Do Nothing
- Do Minimum (local site specific improvements)
- Non-structural Measures (Flood Warning System, provide individual protection of properties)
- Flow Reduction (catchment management (reduce runoff), upstream flood storage (provide attenuation), etc.)
- Flow Diversion (diversion of entire stream / river, flood bypass channel, etc.)
- Increase Channel/Floodplain Conveyance (channel widening, channel re-grading, decrease channel roughness, remove / reduce channel constrictions)
- Increase Floodplain Storage (impoundment, online/offline storage)
- Construct Flood Defences(embankments, walls , flap valves on storm pipes, demountable defences)
- Local Runoff Measures (stormwater management).

It is important to emphasise at this point the fact that the catchment is underlain by karst limestone. This will be a key consideration particularly if the construction of flood defence measures such as embankments and walls are being assessed. In general, flood defence measures such as these are not considered appropriate for the catchment, particularly in the absence of detailed hydrogeological data.

In the following sections, flood risk management measures are considered in relation to each of the catchment areas, 1 to 11 as defined in the outline flood damage analysis in Chapter 6. See Figure 6.1 for location plan of areas discussed overleaf.

The potential viability of the flood risk management measures considered will be assessed through a preliminary viability screening process whereby each measure will be examined in relation to the following criteria;

- Technical viability
- Economic viability
- Environmental viability
- Social acceptability

7.2.1. Area 1 Lough Corrib to Curraghmore Bridge

This area of the catchment suffers from flooding relating to lake levels in Lough Corrib. The main impact of this flooding is on agricultural land and bog. The level of the N84 road was raised so that it remains passable during a flood event of at least the magnitude of that of November 2009. The proposed measure for this area is “Do Nothing”.

7.2.2. Area 2 Miontach South

The townland of Miontach South was cut off by the November 2009 flood due to inundation of the access road from Claregalway. The road was impassable to cars and people and essential supplies had to be transported by tractor and trailer or other similarly high vehicles. At the peak of the flood the lowest point of the road was inundated to 700mm above road level.

Potential measures warranting consideration to reduce the impact of a flood of similar magnitude to the November 2009 event come under the “Do Minimum” category as the measures required are local site specific improvements. Local site specific measures considered include;

- Raising the level of the access road
- Providing flood wall or embankment to both sides of the road

The above measures are screened for viability in Table 7.1 below;

AREA 2 MEASURES – VIABILITY SCREENING			
Potential Measure		**Raise Level of Road**	**Provide Flood Wall or Embankment to both sides of road**
Viability Screening	**Technical Viability**	Technically possible but road will be substantially higher than surrounding land. Road will have to be battered at either side down to field level which will increase road corridor or some form of retaining structure will be required to retain road sub-base. Safety measures will be required to either side in the form of crash barriers or railings. Existing drains may need to be piped.	Technically possible but measure may prove to be ineffective due to the karst nature of the substrate, in which case water may flow under a flood barrier. Also access to fields may be difficult to accommodate. Removable barriers would have to be provided at access points. Existing drains would have to be piped.
	Economic Viability	Should be viable subject to cost benefit analysis.	More expensive than alternative of raising the road when all aspects are considered.
	Environmental Viability	Negligible environmental impact.	May act as barrier to passage of fauna across road from field to field.
	Social Acceptability	Acceptable.	Probably acceptable but more visually obtrusive than alternative.

Table 7.1 Viability Screening – Area 2 Measures

Based on the preliminary screening process above, raising the level of the existing road is the preferred option. It is also recommended that if the road is being raised, an existing undersized culvert should be replaced in conjunction with the works. The existing culvert is 1.2 x 0.8m and while it is not considered that the upsizing of the culvert would mitigate the impacts of flooding from an event of the magnitude of November 2009, it is likely that increasing the capacity would assist in conveying flow from the land more efficiently during moderate events.

It is recommended that the road be raised to a level of 8.60mOD minimum which is 130mm higher than the November 2009 flood level and 100mm higher than the predicted water level resulting from the Design Flood.

If a 20% increase in flow is to be provided for to take account of climate change, the road would need to be raised to a level of at least 8.90mOD.

It is recommended that the raising of the road to 8.90mOD to take account of climate change be considered as a future potential phase of works if required.

Drains in the vicinity of the access road should also be the subject of a regular cleaning regime. The drain downstream of the road is in the ownership of the OPW; however, the drains upstream of the road are generally in private ownership. Landowners should be encouraged to carry out regular maintenance.

To summarise, the following measures are recommended to proceed to more detailed viability assessment in Area 2;

- **Measure 2a – raise access road**
- **Measure 2b – increase size of culvert in conjunction with road works**
- **Measure 2c – clean out drains in vicinity**

A sketch of the proposed outline design relating to the proposed measures is provided in Sketch 2.1 in Appendix C.

7.2.3. Area 3 Miontach North

The townland of Miontach North on the opposite bank of the river to Miontach South was cut off by the November 2009 flood due to inundation of the two sections of access road from Claregalway. The road was impassable to cars and people and essential supplies had to be transported by tractor and trailer or other similarly high vehicles. At the peak of the flood the lowest point of the road was inundated to a depth of 350mm along the section nearest Claregalway and by up to 1m along the second section of road.

One house in the townland was also flooded. The occupants of the house report that the flood waters rose up through the floor of the house.

Potential measures warranting consideration to reduce the impact of a flood of similar magnitude to the November 2009 event come under the "Do Minimum" category for the road flooding as the measure required is a local site specific improvement.

Local site specific measures considered to mitigate road flooding include;

- Raising the level of the access road
- Providing flood wall or embankment to both side of the road

The above measures are screened for viability in Table 7.2 below;

AREA 3 MEASURES – VIABILITY SCREENING ROAD FLOODING MEASURES			
Potential Measure		Raise Level of Road	Provide Flood Wall or Embankment to both sides of road
Viability Screening	Technical Viability	Technically possible but road is somewhat higher than surrounding land. Road may need to be battered at either side down to field level which will increase road corridor or some form of retaining structure will be required to retain road sub-base. Safety measures may be required to either side in the form of crash barriers or railings. Careful design of driveway levels required to ensure that any surface water does not drain towards houses.	Technically possible but measure may prove to be ineffective due to the karst nature of the substrata, in which case water may flow under a flood barrier. Also access to fields may be difficult to accommodate. Removable barriers would have to be provided at access points. Any permanent barrier would have to run behind housing to allow access.
	Economic Viability	Should be viable subject to cost benefit analysis	More expensive than alternative of raising the road when all aspects are considered.
	Environmental Viability	Negligible environmental impact	May act as barrier to passage of fauna across road from field to field.
	Social Acceptability	Acceptable	Probably acceptable but more visually obtrusive than alternative

Table 7.2 Viability Screening – Area 3 Measures (Roads)

Based on the preliminary screening process above, raising the level of the existing road is the preferred option, particularly in consideration of the fact that a flood barrier such as a wall or embankment may not be technically effective in providing a barrier to water movement.

It is recommended that the road be raised to a level of 9.00mOD minimum which is 300mm higher than the November 2009 flood level and 70mm higher than the Design Flood.

If a 20% increase in flow is to be provided for to take account of climate change, the road would need to be raised to a level of at least 9.30mOD at a minimum. It is recommended that the raising of the road to 9.30mOD to take account of climate change be considered as a future potential phase of works if required.

Potential local protection measures and channel conveyance measures were examined to reduce the impact of the flooding of the house along the first section of the road discussed above. This house flooded

to a depth of approximately 250mm above finished floor level. The mitigation measures assessed include the construction of flood defence works and non-structural measures as set out below;

- Provision of flood wall or embankment around the house
- Installation of pump stand at the lowest point of the site
- Channel widening to Curraghmore Bridge

The above measures are screened for viability in Table 7.3 below;

AREA 3 MEASURES – VIABILITY SCREENING PROPERTY FLOODING MEASURES				
Potential Measure		Provision of flood barrier eg flood wall or embankment	Installation of pump stand within house site	Channel Widening
Viability Screening	Technical Viability	Considering the fact that the flood waters rose up through the floor of the house in November 2009, it is likely that a similar situation would occur with a flood barrier ie water would travel underneath and rise up inside the wall to the same level as outside of the wall. Also the entire perimeter of the site would need to be surrounded while still providing some means of access at driveway.	A pump stand could be installed which would facilitate the speedy installation of a storm pump in the event of rising flood waters. However, in November 2009, all the surrounding land was flooded to the same level as this site, which would make it impossible to lower the level within the site.	Technically possible to construct. Model demonstrates a negligible reduction in water level at the house and no reduction in flood level when the measures proposed upstream are taken into account.
	Economic Viability	Likely to fail cost benefit analysis as measure will be expensive to implement.	Should be viable subject to cost benefit analysis	Main cost is plant and labour. Over this distance (5900m), cost becomes prohibitive. Likely to fail cost benefit analysis.
	Environmental Viability	Negligible environmental impact	No environmental impact	Will require ecological impact assessment at a minimum, however, there will be minimum interference with existing channel.
	Social Acceptability	Acceptable	Acceptable	Should be acceptable. Additional land would need to be acquired. Access for fishing and machine access for maintenance etc from new bank needs to be incorporated in design.

Table 7.3 Viability Screening – Area 3 Measures (Property)

The conclusion of the above screening is that all potential measures fail on either technical or economic grounds. It is noted here that the cost of the widening of the channel from Claregalway to Curraghmore Bridge on the Headford Road would cost in the region of €4.2 million. This measure will not satisfy the cost benefit analysis criteria of 1.5 nor will it achieve a significant reduction in flood level at the property flooded in November 2009. In fact, the benefit to cost ratio here would be in the region of 0.01.

Therefore no measure can be recommended to mitigate the impact of flooding at either this house or indeed the flood risk to the neighbouring house. It is noted that the model predicts a flood level of 8.93mOD for the Design Flood event with no measures in place. In this case, the neighbouring house with a finished floor level of 8.80mOD would also be inundated. A similar conclusion can be drawn for this house ie that there is no viable flood measure available to eliminate or reduce the risk of flooding at this house. The benefit to cost ratio in the case of the Design Flood would again be in the region of 0.01. Therefore, this measure cannot be recommended.

To summarise, the following measures are recommended to proceed to more detailed viability assessment in Area 3;

- **Measure 3a – raise first section of access road**
- **Measure 3b – raise second section of access road**

A sketch of the proposed outline design relating to the proposed measures is provided in Sketch 3.1 in Appendix C.

7.2.4. Area 4 Claregalway Village

The most significant impact of the November 2009 flood event in Claregalway was the disruption caused by the closure of the N17 national road, as well as extensive flooding of housing estate roads and flooding of the castle and other properties on the castle site and a house upstream of the castle. Several commercial and residential properties were also at risk of flooding.

Eye witness reports indicate that the bridge at Claregalway acted as choke to the flow. The aflux caused by this choke is also evident in the predictions from the calibrated model. As discussed previously, there was a difference in water level of 800mm evident on the 21 November 2009 between the upstream and downstream face of the bridge.

Potential measures to be considered to eliminate or reduce the impacts described above include increasing the channel and/or flood plain conveyance, the construction of flood defences and flow diversion. The potential measures considered viable and proposed for screening are:

- Channel widening to upstream of Crusheen Bridge
- Channel re-grading in the vicinity of Claregalway Bridge
- Removal of channel constrictions
- Provision of flood bypass channel
- Construct embankments or flood walls
- Install demountable flood defences

These potentially viable measures were modelled and screened as set out in Table 7.4 overleaf;

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel	Provision of embankment or wall	Install demountable Flood Defences
Viability Screening	Technical Viability	Technically possible to construct. Model demonstrates some reduction in level upstream of Claregalway Br with the provision of a flood berm above existing bed level. Not adequate alone to reduce flood risk sufficiently.	Technically possible however the presence of rock in the river bed should be noted. The model demonstrates a significant reduction in flood level at Claregalway Br and upstream with excavation in the riverbed of up to 800mm at deepest part of channel.	The main channel constriction here is the bridge. The channel has been modelled without the bridge and a significant reduction in flood level is achieved. However, a bridge is required at this crossing and the removal of this constriction would necessitate replacement with a new bridge structure. It would be possible to provide a new bridge with a wider span and hence a larger eye which does not act as a constriction. It is noted that the existing structure appears to be structurally sound.	Technically possible. A new flood eye consisting of a portal culvert 12 x 3m (approximately 50% additional capacity) to convey moderate and high flows has been modelled and provides a significant reduction (~0.5m) in flood level. Low flows would not be affected as they would if a new bridge was to be provided. Works to the bank would be required on both upstream and downstream face to divert flows to culvert.	Technically possible and would prevent the river taking its original course through the old arch bridge and flooding the N17 as it did during Nov 2009 flood event. However, there is a risk that a barrier such as an embankment or wall may not be effective due to the karst nature of the substrata. In any case, the measure on its own would not be effective.	This would involve the provision of demountable defences at properties and critical infrastructure. May be suitable at properties but unlikely to prove feasible in protecting the N17 due to the length of barrier that would be required. Also, the erection of barriers would be dependent on a well co-ordinated emergency response team and prior warning that river levels were rising. When barriers are in place access to/from properties and housing estates would be blocked.
	Economic Viability	Main cost is plant and labour. Widening for a short distance in the vicinity of the bridge should be relatively inexpensive assuming excavated material remains on site.	Presence of rock makes the measure more expensive than might otherwise be expected. Still cost efficient when compared with structural measures.	Provision of new bridge will be costly.	Less expensive than the provision of new bridge. However, the temporary works required including temporary support, traffic management etc will add considerably to the cost.	Depends on length of barrier and whether a wall or earthen mound can be used. Earthen mound more cost effective. Some localised embanking in the vicinity of the old arch bridge would be relatively inexpensive.	Relatively inexpensive, however ongoing cost of labour etc involved in emergency response needs to be considered.

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel	Provision of embankment or wall	Install demountable Flood Defences
	Environmental Viability	Likely to require ecological impact assessment at a minimum, however, there will be little interference with existing channel.	Will require ecological impact assessment at a minimum. Works will take place in the existing channel. Extensive ecological mitigation measures are likely to be required and will be the subject of approval from Fisheries and NPWS.	Will require ecological impact assessment at a minimum. Work will most likely be required in existing channel. Extensive ecological mitigation is likely to be required and will be the subject of approval from Fisheries and NPWS.	Work will not be required in the river bed and therefore will have less environmental impact than the provision of a new bridge. Ecological impact assessment at a minimum still likely to be required.	Negligible environmental impact.	Negligible environmental impact.
	Social Acceptability	Should be acceptable. Additional land would need to be acquired. Access for fishing etc and machine access for maintenance from new bank needs to be incorporated in design.	Should be acceptable.	Temporary issues such as traffic disruption etc likely to feature.	Temporary issues such as traffic disruption etc likely to feature.	Should be acceptable although visual aspect of Nine Arches from the field will be impaired.	Should be acceptable, however, property owners will need to be given reassurances with regard to response time etc.

Table 7.4 Viability Screening Area 4 Measures

The conclusion of the above preliminary screening process is that a number of measures appear to be viable and the optimum solution would be a combination of these measures. In order to achieve a reduction in water level sufficient to eliminate or mitigate the flood risk at Claregalway, the following combination of measures is proposed;

- Provide additional flood eye at Claregalway Bridge

Flood Event	Existing Scenario	Scenario with Measure in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09 Flood	10.34	9.71	- None
Design Flood	10.76	9.97	- Flooding of N17 for 120m to a maximum depth of approx 300mm - Castle and houses on castle grounds on river bank (private residence) - Shed – next property upstream of castle
Design Flood + CC	11.30	10.49	- Flooding of N17 for 180m to a maximum depth of approx 700mm - Castle and houses on castle grounds on river bank (private residence) - Shed – next property upstream of castle - House upstream of shed at risk

Table 7.5 Impact of Additional Flood Eye at Claregalway

The brief calls for elimination of or reduction of the flood level for an event similar to the November 2009 event. The provision of an additional flood eye alone eliminates flooding for this event. However, it is recommended that in this case, measures should be examined to mitigate the Design Flood event, in consideration of the critical infrastructure and the potential disruption caused by flooding in this area. Therefore, measures in addition to the provision of the flood eye are required.

- Provide additional Flood Eye at Claregalway Bridge
- Re-grade channel in the vicinity of Claregalway Bridge
- Carry out channel widening

Flood Event	Existing Scenario	Scenario with Measures in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09	10.34	9.62	None
Design Flood	10.76	9.87	- Flooding of N17 for 85m to a maximum depth of approx 100mm - Sheds just upstream of castle
Design Flood + CC	11.30	10.35	- Flooding of N17 for 130m to approx 350mm - Shed just upstream of castle - An Mhainistir housing estate roads – minor flooding

Table 7.6 Impact of Combination of Measures at Claregalway Bridge

The most significant remaining risk following provision of an additional flood eye, re-grading and channel widening is flooding of the N17. At the Design Flood plus climate change event a part of the N17 may be impassable which could lead to closure of this primary road again.

It is therefore proposed that an embankment be constructed behind the old Nine Arches Bridge to prevent flood waters escaping onto the road. This proposed embankment is presented as Measure 4d.

To summarise, the following measures are recommended to proceed to more detailed viability assessment in Area 4;

- **Measure 4a Install additional flood eye at Claregalway Bridge**
- **Measure 4b Re-grade channel upstream and downstream of Claregalway Bridge**
- **Measure 4c Fill gap in existing flood defence wall at An Mhainistir housing estate**
- **Measure 4d Provide earthen embankment in field behind old Nine Arches Bridge**

It is noted that the channel widening recommended above is not listed as a measure here. This widening will be dealt with later in this chapter in relation to measures required at Area 8 (Caherlea/Lisheenavalla).

Measure 4c is incorporated here to address a local deficiency observed during a site visit relating to a concrete retaining wall along the northern boundary of An Mhainistir housing estate. There is a gap in this wall at the ESB sub-station kiosk. The wall stops at approximately 0.5m from either side of the kiosk. This breach needs to be filled in order for this existing retaining wall to be more effective in providing a barrier to flood water entering the estate from the river bank boundary. The wall should be completed and a pipe with a non return valve should be installed near the base of the wall to allow flood waters to escape in the event of the estate flooding from the N17. The plate below shows the ESB kiosk located in front of the breach in the wall.

Fig 7.1 ESB kiosk in front of breach in flood wall at An Mhainistir

The other measures screened including the provision of a flood barrier and demountable defences are not considered necessary if the measures proposed above are implemented.

Sketches of the proposed outline design relating to the measures recommended to proceed to more detailed viability assessment are provided in Sketch 4.1, 4.2 and 4.3 in Appendix C.

7.2.5. Area 5 Kinishka

The main impact of the November 2009 flood event in Kinishka was the inundation of the road. Three houses were also at risk of flooding. From our investigations, it is considered that this flooding was a local issue and not related to the main Clare River channel. It would appear that the flooding was caused by the overflow from a stream which is a tributary of the Clare River. This channel is OPW reference C3/5. This flooding was most likely caused by one or more constrictions on this channel. We have identified two culverts, of approximately 900mm diameter which appear to have restricted the flow and caused the stream to back up and flood the adjacent land and road. These culverts must be replaced with larger diameter culverts and general cleaning of the drain must be carried out.

To summarise, the following measures are recommended for Area 5;

- **Measure 5a Increase culvert capacity in two places**
- **Measure 5b Carry out general cleaning and maintenance**

A sketch of the proposed outline design relating to the recommended measures is provided in Sketch 5.1 in Appendix C.

7.2.6. Area 6 Lakeview

It would appear that the flooding in this area is not fluvial; rather it is caused by groundwater. Flooding is known to occur in this area during the winter months, particularly when water levels are high in the river. It would appear from the aerial video footage taken on 23 November 2009 that the flooding in this area occurs in two separate turloughs, one in the vicinity of the Corporate Park and one in the vicinity of the Cuirt na hAbhainn housing development. It is apparent from the video footage that the turlough at the Corporate Park is higher than the turlough closer to the village and the higher turlough drains to the lower turlough via a narrow neck located at the GAA pitch. This is also borne out by the photograph overleaf taken during the 2005 flood event. It is apparent from this photo that there are two separate turloughs in this area, which due to the extent of the flooding in November 2009, appeared as one. A topographical survey of the area confirms this and would suggest that the water level on the 23 November 2009 in the vicinity of the Corporate Park was approximately 11.30mOD, whereas the flood level in the lower turlough was approximately 11.00mOD. The corresponding peak water level in the Clare River at the time is predicted by the model at 11.16mOD at the upstream end of the relevant section and 10.80mOD at the downstream end of the reach. There is no surface water link between the flood water and the river evident in the video footage. There is also anecdotal evidence that this flood water took longer to recede than the flood waters around the banks of the river in Claregalway.

A search of the planning files for recent developments in the Lakeview area shows a 450mm surface water outfall from the Cuirt na hAbhainn housing development in the vicinity of cross section C79. It is recommended that a CCTV survey be carried out on this outfall to ensure that it was constructed in accordance with the planning application design.

The flood depth predicted by the model at C79 for the November 2009 event is 10.80mOD. The anecdotal flood level in the Cuirt na hAbhainn housing estate was 11.10mOD. At this level, the surface

water outfall should have been able to function; however, the capacity of the 450mm pipe may have been too small to provide any noticeable reduction in flood level in the estate.

The Corporate Park drainage system consists of infiltration trenches on site as well as a storm water holding tank with an emergency outfall to a drainage ditch along the northern boundary of the site. The infiltration trenches would not have functioned during the flood event as the groundwater storage capacity would have been fully inundated.

Fig 7.2 Lakeview Turloughs December 2005

Fig 7.3 Lakeview Turloughs November 22 2009

It is not feasible to try to eliminate this flooding; however it may be possible to reduce the magnitude of the flood by providing an outlet for a portion of the flood waters. It is proposed that a spinal drain be laid through the centre of flooded area to the N17 and then piped in the fields to the east of the road to a surface water outlet at the downstream face of the proposed flood eye at Claregalway Bridge.

Following the measures proposed at Claregalway Bridge and Crusheen Bridge (discussed later in this chapter), the predicted water level downstream of Claregalway Bridge for an event of similar magnitude to the November 2009 flood event is 9.05mOD. It is therefore expected that the proposed drain would reduce the flood level in the Lakeview area to somewhere in the region of 10.0mOD to 10.5mOD when headloss is factored in.

This drain is intended to reduce the inundation to the extent that the houses and roads in Lakeview townland will no longer be at a risk of flooding in the event of a flood of similar magnitude to that of November 2009. However, it will not eliminate flooding from this size of flood event. In fact it would not be desirable to do so, as to convey the full volume of flood water to downstream of Claregalway Bridge may increase the flood risk slightly downstream. Therefore, the maximum culvert size recommended is a 1500mm diameter pipe.

It is noted that the measures proposed at Claregalway and upstream of Claregalway will also reduce the peak water level in the Clare River in the vicinity of the surface water outfall from Cuirt na hAbhainn which will enable the runoff from this area to drain more effectively.

To summarise, the following measures are recommended for Area 6;

- **Measure 6a Provide surface water drain to river downstream of Claregalway Bridge**

A sketch of the proposed outline design relating to the recommended measures is provided in Sketch 4.3 in Appendix C.

7.2.7. Area 7 Gortatleva

The flood event of November 2009 caused one house and a hay barn on the same site to be flooded in this townland. The proposed measures at Claregalway, particularly the proposed channel widening, will eliminate the flood risk to this house for a flood event of similar magnitude to the November 2009 flood or for the design flood. There is a residual risk of flooding when climate change allowance is added to the design flood. However, there is no additional measure that viable measure that would eliminate flooding for this event.

To summarise, the same measures as for Area 4 apply to Area 7 also.

7.2.8. Area 8 Caherlea/Lisheenavalla

The most significant impact of the November 2009 flood event in the Caherlea/Lisheenavalla area was the inundation of thirteen houses to a depth of up to 700mm in some cases. The road through the townland was flooded to a depth of over 1 metre at the lowest points. These houses and the road are located some 900m from the Clare River at the nearest point. Historically, the area was a turlough; however a large manmade drain now runs through the centre of the catchment with the aim of draining standing water from

the turlough to the Clare River. This drain is within the remit of the OPW, reference number C3/7. Crusheen Bridge is located some 1.6km downstream of the area.

From eye witness accounts and video footage from locals it would appear that Crusheen Bridge acted as a choke during the flood event of November 2009 and in combination with the channel capacity downstream, caused water levels to back up to such an extent as to flood the houses in Caherlea/Lisheenavalla. The flood level was established by reference to the bridge wall; at the peak of the flood the water came to within 300mm of the top of the wall. This equates to a level of 12.45mOD at the upstream face of the bridge. The model indicates that the level upstream of the bridge at C94, the section most relevant to the houses that flooded, is 13.0mOD.

The bank level on the upstream side of the Crusheen Bridge is in the region of 11.80mOD and although these houses are located some distance from the Crusheen Bridge, there is only approximately 500mm between the bank levels in the vicinity of the bridge and the finished floor levels of the houses. The lowest part of the road is just 100mm above bank level.

In order to eliminate flooding from an event of similar magnitude to the November 2009 flood event, a reduction in water level of at least 1 metre needs to be achieved by any flood risk management measure or combination of measures.

Potential measures include increasing the channel and/or flood plain conveyance, the construction of flood defences and flow diversion. The potential measures considered viable and proposed for screening are:

- Channel widening
- Channel re-grading
- Removal of channel constrictions
- Provision of flood bypass channels
- Construct embankments or flood walls
- Install demountable flood defences

These potentially viable measures were modelled and screened as set out in Table 7.7 overleaf.

It is noted that Galway County Council was consulted in relation to Crusheen Bridge to determine if there are any plans to alter or replace Crusheen Bridge. Galway County Council has no plan in place for the bridge; however, the Council requested that the bridge be replaced for transport reasons. The replacement of the bridge is screened below in order to determine its viability in terms of flood risk management rather than traffic management. It is noted that the existing bridge appears to be in good condition structurally, however the width of the bridge in plan does not allow for two way traffic.

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel	Provision of embankment or wall	Install demountable Flood Defences
Viability Screening	Technical Viability	Technically possible to construct. However, model demonstrates that a significant reduction in level is only achieved by carrying out widening works from 900m upstream of Crusheen Bridge down to Claregalway Bridge, a distance of approx 4500m.	Technically possible however the channel gradient in this area is already close to optimum in general and therefore the reduction in level achievable is not significant.	The main channel constriction here is the bridge at Crusheen. The channel has been modelled without the bridge and a reduction in flood level in the region of 300- 400mm is achieved, which reduces flood risk to the houses but is not sufficient to eliminate the risk. A bridge is required at this crossing and the removal of this constriction would necessitate replacement with a new bridge structure. It would be possible to provide a new bridge with a larger eye which does not act as a constriction. It is noted that the existing structure appears to be structurally sound. If a new bridge was to be constructed it is likely that significant works would be required to bring the approach roads up to current road design standards.	Technically possible. A new flood eye on each bank consisting of portal culverts 6 x 3m (approximately 50% additional capacity) to convey moderate and high flows has been modelled and provides a reduction of ~0.4m in flood level. Low flows would not be affected as they would if a new bridge was to be provided. Works to the bank would be required on both upstream and downstream face to divert flows to culverts.	Technically possible, but there is a risk that a barrier such as an embankment or wall may not be effective due to the karst nature of the substrata in this area – historically the land on which the barrier would be constructed was a turlough. This measure would reduce the amount of floodplain storage available. This measure may warrant consideration as a future phase of works following monitoring of the effectiveness of other measures, subject to a hydrogeological analysis.	This would involve the provision of demountable defences at properties and critical infrastructure. Not practical in this case as properties at risk would have to be completely bunded. In addition there is a risk that the flood defences will prove ineffective due to the karst nature of the area.

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel	Provision of embankment or wall	Install demountable Flood Defences
	Economic Viability	Main cost is labour and plant. In general works will take place above rock level. The proposed length will make the total cost of this measure relatively expensive.	Presence of rock in the bed makes the measure more expensive than might otherwise be expected. Probably cost efficient when compared with structural measures.	Provision of new bridge will be more expensive than alternative measures.	Less expensive than the provision of new bridge.	Depends on length of barrier and whether a wall or earthen mound can be used. Earthen mound more cost effective.	Expensive when perimeter length requiring protection is factored in.
	Environmental Viability	Likely to require ecological impact assessment at a minimum however, there will be minimum interference with existing channel.	Will require ecological impact assessment at a minimum. Work will be carried out in existing channel. Ecological mitigation will be required and will be the subject of approval from Fisheries and NPWS.	Will require ecological impact assessment. Work will be carried out in existing channel. Electrofishing and other mitigation may be required and will be the subject of approval from Fisheries and NPWS.	Work will not be required in the river bed and therefore will have less environmental impact than the provision of a new bridge. Ecological impact assessment still likely to be required.	Negligible environmental impact.	Negligible environmental impact.
	Social Acceptability	Should be acceptable. Additional land would need to be acquired. Pedestrian access for fishing and machine access for maintenance from new bank needs to be incorporated in design.	Should be acceptable.	Temporary issues such as traffic disruption etc likely to feature.	Temporary issues such as traffic disruption etc likely to feature.	Should be acceptable.	Should be acceptable, however, property owners will need to be given reassurances with regard to response time etc.

Table 7.7 Initial Viability Screening – Area 8

The conclusion of the above screening process is that a number of measures are potentially viable and the optimum solution is a combination of these measures. In order to achieve a reduction in water level sufficient to eliminate or mitigate the impact, the combination of measures set out below is proposed.

It is noted that in the analyses of these measures, it is assumed that the measures recommended for Area 4 (Claregalway) will be implemented prior to any measures at Area 8.

- Provide additional flood eyes at Crusheen Bridge

Flood Event	Existing Scenario	Scenario with Measure in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09 Flood	12.92	12.33	- 2 houses at high risk (within 50mm of predicted flood level) - Flooding of road over 400m to a maximum depth of approx 400mm
Design Flood	13.31	12.60	- Flooding of 12 houses to a maximum depth of approx 200mm - Flooding of road over 590m to a maximum depth of approx 600mm
Design Flood + CC	13.93	13.11	- Flooding of 13 houses to a maximum depth of approx 600mm - Flooding of road over 760m to a maximum depth of approx 1000mm

Table 7.8 Impact of 2 No. Additional Flood Eyes at Crusheen Bridge

The brief calls for elimination or reduction of the flood level for an event similar to the November 2009 event. The provision of the two additional flood eyes alone does not eliminate flooding from this event and does not sufficiently reduce flooding as can be seen in Table 7.8 above. Therefore, measures in addition to the provision of the flood eye must be examined.

- Provide additional flood eyes at Crusheen Bridge
- Carry out channel widening from 900m upstream of Crusheen Bridge to Claregalway Bridge

Flood Event	Existing Scenario	Scenario with Measures in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09	13.00	11.67	None
Design Flood	13.31	11.98	- Flooding of road over 275m to a maximum depth of approx 70mm. Road should remain passable.
Design Flood + CC	13.93	12.46	- Flooding of road over 500m to a maximum depth of approx 500mm. - 2 No. houses at risk of flooding

Table 7.9 Impact of Combination of Measures at Crusheen Bridge

The most significant remaining flood risk following construction of the flood eyes and extensive channel widening is flooding of the road. At the Design Flood event there would be some flooding on the local road but it would remain passable and access would be maintained to the houses. However, when a climate change allowance is added to the Design Flood event, it is predicted that the road would flood to a depth of approximately 500mm in the lowest part. This would make the road impassable and potentially cut off access to the lowest houses. An additional future measure is therefore recommended, namely, raising of the local road in Caherlea/Lisheenavalla by 500mm over a 500m length.

To summarise, the following measures are recommended for Area 8;

- **Measure 8a Install 2 No. additional flood eyes at Crusheen Bridge**
- **Measure 8b Widen the channel from 900m upstream of Crusheen Bridge to Claregalway**
- **Measure 8c Raise the local road in Caherlea/Lisheenavalla (future measure)**
- **Measure 8d Cleaning and limited re-grading of Islandmore drain OPW C3/7 & F.799/1**

Sketches of the proposed outline designs relating to the recommended measures are provided in Sketch 8.1 to 8.11 in Appendix C.

The provision of the flood eyes (Measure 8a above) is considered to be the most cost effective in terms of mitigating the flood risk, however, if a new bridge is considered necessary at Crusheen for traffic reasons, Measure 8a could be replaced with the provision of a new bridge of with a larger cross sectional area than the existing bridge. The capital cost of a new 5m wide bridge would be in the region of €0.8 million excluding VAT.

7.2.9. Area 9 Lackagh Bridge to Corofin Bridge

The impact of the flood event of November 2009 in this area was flooding of land along the river banks. No houses or roads were impacted and therefore no measures are proposed for this area as there are none that would satisfy cost benefit analysis criteria.

7.2.10. Area 10 Ardskeaghmore

The flood event of November 2009 caused extensive flood damage in the townland of Ardskeaghmore on the Abbert River. The most significant flood impact in this area was the flooding of four houses to a level of 1.2m in one case and approximately 1m in the case of the other three houses. The peak November 2009 flood level along this reach was 27.98mOD. It would appear that the Abbert River is backwatered by the Clare River along the reach that flooded these houses. The finished floor level of the lowest house that flooded is 26.64mOD. The peak November 2009 water level in the Clare River at the Abbert confluence is 25.52mOD, just over 1m lower than the finished floor levels at a distance of 1.5km from the Clare River. Initial considerations would therefore suggest that it may not be possible to reduce this flood level significantly without reducing the peak water level in the Clare River at the confluence. Reducing the level in the River Clare channel at this point would require an extensive re-grading of the Clare River, possibly to as far downstream as Lackagh Bridge (6.5km). It is apparent without carrying out a cost benefit analysis that this level of work would not be viable. Potential measures are therefore concentrated on works that could be carried out on the Abbert River alone that may reduce the flood risk.

Potential measures on the Abbert River include increasing the channel and/or flood plain conveyance, the construction of flood defences and flow diversion. The potential measures considered viable and proposed for screening are:

- Channel widening
- Channel re-grading

- Removal of channel constrictions
- Provision of flood bypass channels
- Construction of embankments or flood walls
- Install demountable flood defences

The potentially viable measures relating to channel works were modelled and all of the potentially viable measures were screened as set out in Table 7.10 overleaf;

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel	Provision of embankment or wall	Install demountable Flood Defences
Viability Screening	Technical Viability	Technically possible to construct. Model demonstrates that a significant reduction in level is only achieved by the provision of a 10m flood berm from the field bridge at A7 to A15, a distance of 1.5km.	Technically possible however the river bed is rock in a number of areas, making any substantial re-grading expensive.	The only channel constriction here is a field bridge downstream of the flooded houses at cross section A7. The removal of the bridge has been modelled and a reduction in flood level of 250mm is achievable at Ardskeaghmore, which only slightly reduces flood risk to the houses. A bridge is required at this crossing to access farmland and the removal of this constriction would necessitate replacement with a new bridge structure. It is possible to provide a new larger span bridge with a larger eye which does not act as a constriction. The bank will have to be widened locally to facilitate a wider bridge.	Technically possible. A new flood eye on each bank consisting of portal culverts 6 x 3m to convey moderate and high flows has been modelled and provides a reduction of 250mm in flood level, which again only slightly reduces the flood risk. Low flows would not be affected as they would if a new bridge was to be provided. Works to the bank would be required on both upstream and downstream face to divert flows to culvert.	Technically possible, but there is a high risk that a barrier such as an embankment or wall may not be effective due to the karst nature of the substrata in this area. There are many karst features in the general area. This measure would also reduce the amount of floodplain storage available, which would create further flood risk upstream. An embankment or wall would have to be at least 1.5km in length to protect houses.	This would involve the provision of demountable defences at the properties at risk of flooding. Not practical in this case as properties at risk would have to be completely bunded. In addition there is a risk that defence will prove ineffective due to the karst nature of the area.

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel	Provision of embankment or wall	Install demountable Flood Defences
	Economic Viability	Main cost is labour and plant. In general works will take place above rock level (70% of works). Economic viability depends on length.	Presence of rock in the bed along 60% of proposed length makes the measure expensive.	Provision of new longer span bridge is relatively inexpensive as its function is field access. If a new bridge is to be provided it should be widened to 4m in plan to facilitate tractor access.	In this case, more expensive than provision of new bridge considering the ease with which a new bridge could be constructed in this location.	Could be expensive due to length.	Expensive when perimeter length requiring protection is factored in.
	Environmental Viability	Likely to require ecological impact assessment at a minimum however, there will be little interference with existing channel.	Will require ecological impact assessment at a minimum. Work will be carried out in existing channel. Ecological mitigation measures will be required and will be the subject of approval from Fisheries and NPWS.	May require ecological impact assessment. Work will not be required in the channel as the bridge will be founded on the rock in the bank.	May require ecological impact assessment. Work will not be required in the channel.	Negligible environmental impact.	Negligible environmental impact.
	Social Acceptability	Should be acceptable. Additional land would need to be acquired. Pedestrian access for fishing and machine access for maintenance from new bank needs to be incorporated in design.	Should be acceptable.	Should be acceptable.	Should be acceptable.	Should be acceptable.	Should be acceptable, however, property owners will need to be given reassurances with regard to response time and responsibility of erection of defences etc.

The conclusion of the above preliminary screening process is that a number of measures are potentially viable and the optimum solution is a combination of these measures. In order to achieve a reduction in water level sufficient to eliminate or mitigate the flood impact, the combination of measures set out below are examined.

- Provide new longer span field bridge at A7 and local bank widening

Flood Event	Existing Scenario	Scenario with Measure in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09 Flood	27.98	27.75	- Flooding of 4 houses to a depth of approx 1.1m at lowest house
Design Flood	27.98	27.75	- Flooding of 4 houses to a depth of approx 1.1m at lowest house
Design Flood + CC	28.27	28.02	- Flooding of 4 houses to a depth of approx 1.35m at lowest house

Table 7.11 Impact of Provision of Longer Span Field Bridge at A7

The brief calls for elimination of or reduction of the flood level for an event similar to the November 2009 event. The provision of the new bridge does not eliminate flooding from this event nor does it sufficiently reduce flooding as can be seen in Table 7.11 above, in fact the flood level is only reduced by approximately 200mm. The effect of backwatering from the Clare River is significant along the reach of the Abbert in question, which explains why the flood level is not significantly reduced by the provision of a larger capacity bridge.

Therefore, measures in addition to the provision of the flood eye are required.

- Provide new longer span field bridge at A7 and local bank widening
- Carry out channel widening from A7 to 1500m upstream of Bullaun Bridge by provision of 10m wide flood berm and re-grade the bed of the river

Flood Event	Existing Scenario	Scenario with Measures in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09	27.98	26.85	- Flooding of 1 house to a depth of approx 0.15m at lowest house
Design Flood	27.98	26.85	- Flooding of 1 house to a depth of approx 0.15m at lowest house
Design Flood + CC	28.27	27.36	- Flooding of 4 houses to a depth of approx 0.7m at lowest house

Table 7.12 Impact of Combination of Measures

As can be seen from the table above, it is possible to reduce the flood risk to three of the houses from a flood of similar magnitude to that of November 2009. However, for the Design Flood event or the Design Flood plus climate change event, the four houses will be inundated, albeit to a lower level than during the

flood of November 2009. However, it is considered that there is no other potentially viable flood risk management option available to reduce this risk further.

To summarise, the following measures are recommended to proceed to more detailed viability assessment, however it is noted here that they are unlikely to be viable when subjected to cost benefit analysis.

- **Measure 10a Provide new field bridge at A7 and**
- **Measure 10b Widen the channel from A7 to Bullaun Bridge**
- **Measure 10c Re-grade river bed from A7 to A16**

Sketches of the proposed outline designs relating to the measures proceeding to more detailed assessment are provided in Drawing 10.1 and 10.2 in Appendix C.

7.2.11. Area 11 Upstream of Bullaun Bridge

The main impact of the November 2009 flood on the areas upstream of Bullaun Bridge was land flooding to the extents of the study area at Ballyglunin and the inundation of a house adjacent to Bullaun Bridge and another house approximately 400m upstream. The properties were flooded to a depth of 0.8m and 0.6m respectively.

Potential flood risk management measures include increasing the channel and/or flood plain conveyance, the construction of flood defences and flow diversion. The potential measures considered viable and proposed for screening are:

- Channel widening
- Channel re-grading
- Removal of channel constrictions
- Provision of flood bypass channels

These potentially viable measures were modelled and screened as set out in Table 7.13 overleaf;

Potential Measure		Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel
Viability Screening	Technical Viability	Technically possible to construct. Model demonstrates that a reduction in level can be achieved by the provision of a 10m wide flood berm from Bullaun Bridge to upstream of A21, a distance of 760m. A 360mm reduction is achieved immediately upstream of Bullaun Br and a 100mm reduction at A21.	Technically possible however model demonstrates negligible reduction in flood levels as a result. Channel already efficient along this reach.	The main channel constriction here is Bullaun Bridge. The removal of the bridge has been modelled and a reduction in flood level of 360mm is achieved immediately upstream of the bridge which only reduces flood risk to the flooded house somewhat. Reduction is only approx 100mm at house 400m upstream. In any case, a bridge is required at this crossing and the removal of this constriction would necessitate replacement with a new bridge structure. It would be possible to provide a new bridge with a larger eye which does not act as a constriction. The bank will have to be widened locally to facilitate a larger bridge. The existing bridge is structurally sound.	Technically possible. A new flood eye on the southern bank consisting of a 6 x 3m portal culvert to convey moderate and high flows has been modelled and provides a reduction of 360mm in flood level immediately upstream of the bridge. A reduction in level of 100mm would be achieved at the second house 400m upstream. Low flows would not be affected as they would if a new bridge was to be provided. Works to the bank would be required on both upstream and downstream face to divert flows to culvert. Local widening required to tie in the culvert to the existing bank widths.
	Economic Viability	Main cost is labour and plant. In general works will take place above rock level (80% of works). Economic viability depends on length.	Presence of rock in the bed along the majority of proposed length makes the measure more expensive than might otherwise be expected. Still may be cost efficient for short lengths.	Provision of new bridge would be expensive particularly considering the depth of the existing bridge below road level.	Should be less expensive than the provision of a new bridge.

Potential Measure	Channel Widening	Channel Re-grading	Removal of channel constrictions	Provision of flood bypass channel
Environmental Viability	Likely to require ecological impact assessment at a minimum however, there will be little interference with existing channel.	Will require ecological impact assessment at a minimum. Work will be carried out in existing channel. Ecological mitigation measures will be required and will be the subject of approval from Fisheries and NPWS.	May require ecological impact assessment. Work will not be required in the channel as the bridge will be founded on the rock in the bank.	May require ecological impact assessment. Work will not be required in the channel.
Social Acceptability	Should be acceptable. Additional land would need to be acquired. Pedestrian access for fishing and machine access for maintenance from new bank needs to be incorporated in design.	Should be acceptable.	Temporary issues such as traffic disruption etc likely to feature.	Temporary issues such as traffic disruption etc likely to feature.

Table 7.13 Viability Screening Area 11 Measures

The conclusion of the above preliminary screening process is that a number of measures may be viable, but none on their own. Therefore, the optimum solution to achieve the maximum possible reduction in water level may be a combination of these measures.

- Provide an additional flood eye at Bullaun Bridge

Flood Event	Existing Scenario	Scenario with Measure in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09 Flood	28.95 (@ br) 30.10 (400m u/s)	28.59 30.01	- Flooding of house beside bridge by 100mm and house 400m u/s by approx 300mm
Design Flood	28.95 (@ br) 30.10 (400m u/s)	28.59 30.01	- Flooding of house beside bridge by 100mm and house 400m u/s by approx 300mm
Design Flood + CC	29.38 (@ br) 30.32 (400m u/s)	28.84 30.21	- Flooding of house beside bridge by 350mm and house 400m u/s by approx 500mm

Table 7.14 Impact of Additional Flood Eye at Bullaun Bridge

The brief calls for elimination of or reduction of the flood level for an event similar to the November 2009 event. The provision of an additional flood eye at Bullaun Bridge does not eliminate flooding from this

event nor does it sufficiently reduce flooding as can be seen in Table 7.14 above. Therefore, measures in addition to the provision of the flood eye must be examined.

- Provide an additional flood eye at Bullaun Bridge
- Carry out channel widening by provision of 10m flood berm from Bullaun Bridge to 760m upstream

Flood Event	Existing Scenario	Scenario with Measures in Place	Remaining Flood Risk post Measure
	Peak Flood Level (mOD)	Peak Flood Level (mOD)	
Nov 09	28.95 (@ br) 30.10 (400m u/s)	28.57 29.38	- House beside bridge still at risk (80mm flood predicted)
Design Flood	28.95 (@ br) 30.10 (400m u/s	28.57 29.38	- House beside bridge still at risk (80mm flood predicted)
Design Flood + CC	29.38 (@ br) 30.32 (400m u/s)	28.84 29.61	- House beside bridge flooded to 350mm

Table 7.15 Impact of Combination of Measures at Bullaun Bridge

As can be seen from the table above, it is possible to eliminate the flood risk to one of the houses from a flood of similar magnitude to that of November 2009, the Design Flood event and the Design Flood plus Climate Change event. However, for all of the events analysed, the house adjacent to the bridge remains at risk and for the Design Flood plus climate change event, the house beside the bridge will still flood. However, it is considered that there is no other potentially viable flood risk management option available to reduce this risk further.

It should be noted that the measures at Bullaun considered above, are assumed to be in addition to the proposed flood risk management measures downstream at Ardskeaghmore and the analysis above has been carried out on this basis.

Although the proposed measures are not achieving the objective of the brief, it is recommended that the following measures warrant further viability assessment in relation to the potential reduction in flood risk provided;

- **Measure 11a Provide additional flood eye at Bullaun Bridge**
- **Measure 11b Widen the channel from Bullaun Bridge to 760m upstream**

Sketches of the proposed outline designs relating to the measures proceeding to more detailed assessment are provided in Sketch 11.1 in Appendix C.

7.3. Summary of Initial Viability Screening of Measures

The table overleaf provides a summary of the measures passing the initial viability screening above and considered appropriate to satisfy the objective of elimination or reduction of flooding in the study area from a similar sized event as the November 2009 flood. It also provides further detail on the works required to implement the measures and other considerations that must be taken into account if the measures are to be implemented. These measures are the ones that will go forward to Section 7.4 for a further viability assessment including a cost benefit analysis.

SUMMARY OF INITIAL VIABILITY SCREENING OF MEASURES					
Area	**Cross Section Reference**	**Location**	**Proposed Measure from Initial Viability Screening**	**Works Required**	**Other Considerations**
CLARE RIVER					
1	C1 - C61	L Corrib to Curraghmore Br	**1a. Do Nothing**	- None	
2	C52 - C61	Miontach South (d/s Claregalway Br - south of river)	**2a. Raise access road**	- Increase road level by 700mm approx over 1000m length	- Note that road is already raised above surrounding field level. - Note presence of deep drains on both sides of road - Health & safety measures will need to be put in place for example crash barriers or railings
			2b. Increase size of culvert in conjunction with road works	- Replace existing 1.2m diameter culvert on drain with larger capacity culvert eg 3.5 x 1.2m.	- Note that this will only assist in the conveyance of flows at mean levels and is unlikely to have a significant impact at high flow as lake will influence water level here - Note that stream drains to Clare River, part of L. Corrib SAC and culvert works may require environmental mitigation measures - Size of new culvert to be confirmed at detailed design stage
			2c. Clean drain ED @ Miontagh (OPW) and other drains in vicinity	- Drain downstream of road within OPW remit – general cleaning - Drain upstream of road in private ownership – request that landowners carry out general cleaning	
3	C53 - C63	Miontach North (d/s Claregalway Br - north of river)	**3a. Raise access road**	- Increase road level by 350mm over a length of 600m	- Note that road is already raised above surrounding field level
			3b. Raise access road	- Increase road level by 1000mm over a length of 600m	- Note that road is already raised above surrounding field level
			3c. Widen Channel	- Widen channel by provision of 15m wide berm on southern bank for a distance of 5900m	- Work will be required on the bank of the Clare River which is part of L. Corrib SAC and ecological mitigation measures will be required.

SUMMARY OF INITIAL VIABILITY SCREENING OF MEASURES					
Area	**Cross Section Reference**	**Location**	**Proposed Measure from Initial Viability Screening**	**Works Required**	**Other Considerations**
CLARE RIVER					
4	C73	Claregalway Village	**4a. Install additional flood eye at Claregalway Bridge**	- Install 13m long 12 x 3.0m portal culvert to match existing bridge soffit level - Divert existing 600mm trunk watermain to facilitate culvert on upstream side - Divert existing 400mm distribution watermain to facilitate culvert on downstream side - Carry out bank works to facilitate entry and exit to/from culvert and incorporate channel widening from upstream side (part of Area 8 measures)	- Works will be required within SAC. Environmental mitigation measures will be required. - Culvert invert levels set at higher level than existing bed so as to maintain existing low flow conditions - The existing handball alley will need to be demolished to facilitate the flood eye - Proposals for a new walkway downstream of the bridge will need to be modified as a result of the flood eye - Proposals for a new pedestrian bridge on the downstream face of the road bridge will need to be modified to take account of the flood eye - Works will take place within a zone of archaeological potential. An Archaeological Impact Assessment and archaeological monitoring will be required - Detailed traffic management design will be required which may incorporate the use of a bailey bridge to facilitate two- way traffic through Claregalway - The existing trunk watermain will have to be diverted. Temporary water supply arrangements will be required for a period of up to 2 days
			4b. Regrade channel upstream of and under bridge	- Deepen channel by 1m at centre for 800m approx upstream of bridge - Underpin bridge structure using mass concrete	- Bed of the river is rock - Works within SAC. Environmental mitigation measures will be required.

SUMMARY OF INITIAL VIABILITY SCREENING OF MEASURES					
Area	**Cross Section Reference**	**Location**	**Proposed Measure from Initial Viability Screening**	**Works Required**	**Other Considerations**
CLARE RIVER					
			4c. Fill gap in wall at An Mhainistir housing estate	- Construct concrete retaining wall for a length of approx 1.5m behind ESB kiosk and tie into existing concrete retaining wall	
			4d. Provide local embankment at old Nine Arches bridge	- Construct embankment on upstream side of old Nine Arches bridge to meet retaining wall at An Mhainistir	
5	C75	Kinishka Townland (north of river)	**5a. Increase capacity of at two culverts on stream OPW C3/5**	- Replace existing 900mm culverts with larger diameter culvert	
			5b. Clean stream C3/5	- General cleaning and maintenance	
6	C78 - C80	Lakeview (south of river). Cuirt na hAbhainn housing estate to Corporate Park.	**6a. Provide surface water outlet through fields and along N17 to downstream of Claregalway Bridge**	- Construct surface water drain in fields – 920m long, approx 1m deep. Culvert the drain through Cuirt na hAbhainn housing estate and at road crossing. - Construct pipeline along N17 to river – 400m long. Preliminary sizing – 1500mm diameter - Construct surface water outfall on downstream side of bridge	- Flood risk relates to groundwater levels not fluvial flooding - Pipeline size and drain size to be confirmed at detailed design stage - Drain & pipeline route to be confirmed at detailed design stage - Culvert should be sized to reduce impact of flood rather than prevent flooding as full prevention would be both cost prohibitive and may have effect on downstream river levels - Land acquisition/wayleave required for culvert through private lands - 400m to be laid along N17 - Measures 4a and 4b will facilitate more effective drainage of Cuirt na hAbhainn surface run-off as surface water outfall to Clare River can discharge

SUMMARY OF INITIAL VIABILITY SCREENING OF MEASURES					
Area	**Cross Section Reference**	**Location**	**Proposed Measure from Initial Viability Screening**	**Works Required**	**Other Considerations**
CLARE RIVER					
7	C83	Gortatleva	**4a. Install additional flood eye at Claregalway Bridge**	- As above	- Reduction in water levels at Claregalway will lead to a reduction in flood level in Gortatleva
			4b. Re-grade channel upstream of and under bridge	- As above	
8	C91 - C94	Caherlea/ Lisheenavalla	**8a. Install additional flood eyes at Crusheen Bridge**	- Install 2 No. 8m long 6 x 3.0m portal culvert to match existing bridge soffit level – one on each bank - Divert existing small diameter group water scheme watermain to facilitate culvert installation - Carry out bank works to facilitate entry to/exit from culvert - Construct retaining wall/gabions at both faces to retain existing road between bridge and culvert and from culvert back to existing ground levels	– Culvert invert levels set at higher level than existing bed so as to maintain existing low flow conditions – Temporary water supply may be required while watermain is being diverted – Detailed traffic management design will be required which will involve closing the road for 2 weeks minimum. Diversion routes available. – Works will be required within SAC. Environmental mitigation measures will be required. – Culvert invert levels set at higher level than existing bed so as to maintain existing low flow conditions – Works will take place within a zone of archaeological potential. An Archaeological Impact Assessment and archaeological monitoring will be required – Rock present in bed and banks
			8b. Channel widening from 900m upstream of Crusheen Bridge to Claregalway	- Widen channel by provision of 15m wide berm for a distance of 4500m - Provide machine access points - Provide pedestrian access points	- Existing spoil heaps to be removed to facilitate widening - Dense vegetation in places along bank to be cleared – may result in existing bank

SUMMARY OF INITIAL VIABILITY SCREENING OF MEASURES					
Area	**Cross Section Reference**	**Location**	**Proposed Measure from Initial Viability Screening**	**Works Required**	**Other Considerations**
CLARE RIVER					
					instability - Existing bank repairs may be required. - Assume that excavated material is maintained on site
			8c. Cleaning and regrading of Islandmore drain OPW C3/7 & F.799/1	- General maintenance required including removal of farmgate and debris at outfall to Clare River	- Consider providing local embanking to Islandmore drain as potential future risk management measure following monitoring of proposed measures 8a & 8b.
			8d. Raise local road in Caherlea/Lisheenavalla	- Raise local road by 700mm for a distance of 500m	- Driveway access needs to be considered at design stage to ensure road runoff does not discharge to houses
9	C123 – C164	Lackagh Br to Corofin Br	**9a. Do Nothing**	- None	- No cost effective measure available
ABBERT RIVER					
10	A7 - A12	Ardskeaghmore	**10a. Replace existing field bridge with wider bridge**	- Remove existing field bridge and replace with 12m span bridge deck founded on rock	- Rock present in bed and bank - Use 4m wide bridge deck to facilitate tractor use
			10b. Channel widening from field bridge to Bullaun Bridge	- Widen channel by provision of a 10m wide berm over a length of 1500m	- Extensive rock in this area - Abbert drains to Clare river, part of L. Corrib SAC, therefore ecological mitigation measures will be required
			10c. Re-grading from A7 to A16	- Deepen channel over a length of 1500m	- Extensive rock in this area - Abbert drains to Clare river, part of L. Corrib SAC, therefore ecological mitigation measures will be required
11	A17 - A34	Upstream of Bullaun Br	**11a. Install additional flood eye at Bullaun Bridge**	- Install 8m long 6 x 3m portal culvert, soffit level above top of existing bridge arch - Carry out bank works to facilitate entry to/exit from culvert - Extensive vegetation clearance required to	- Watercourse drains to SAC downstream and may require environmental mitigation works - Detailed traffic management design will be required which will include a road closure at the bridge for a minimum of 2 weeks

SUMMARY OF INITIAL VIABILITY SCREENING OF MEASURES					
Area	**Cross Section Reference**	**Location**	**Proposed Measure from Initial Viability Screening**	**Works Required**	**Other Considerations**
CLARE RIVER					
				enable works	- Rock present in river bed and banks
			11b. Channel widening	- Widen channel by provision of a 10m wide berm over a length of 900m	- Extensive rock in this area - Ecological mitigation measures will be required as above

Table 7.16 Proposed Measures Emerging from Initial Viability Screening

7.4. Viability of Measures

The flood risk management measures emerging from the initial viability screening process as summarised in Table 7.16 above will now be assessed in further detail in the sections below.

The cost benefit analyses carried out for each measure compares the cost of the damages estimated in Chapter 6, "the benefit" to the cost of implementing the flood risk management measure. It should be noted that all costings are order of magnitude estimates at this outline design stage. Costs also exclude VAT at this stage.

A benefit to cost ratio of 1.5 is desirable for a potential flood risk management measure to be considered economically viable.

7.4.1. Measure 1a Do Nothing

The proposed Measure 1a Do Nothing does not require any further analysis.

7.4.2. Measure 2a & 2b

Measure 2a involves raising the road in Miontach South over a length of 1000m and Measure 2b involves the replacement of an existing undersized culvert. The peak water levels for the November 2009 flood, the Design Flood and the Design Flood plus Climate Change have been analysed. The proposed road level is set at 8.60mOD which is 130mm above the predicted level for the design flood. It is considered that the road can be raised in the future if the flood level increases as a result of climate change.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The cost of raising the road over a distance of 1000m to position it above the November 2009 flood level and the Design Flood is estimated to be in the order of €92,575. The cost of raising the road over a distance of 1000m to position it above the Design Flood plus Climate Change event is estimated to be in the order of €115,000. The cost of replacing the existing pipe with a larger culvert is estimated to be in the order of €22,281.

Flood Event	Cost of Measures	Benefit	Benefit to Cost Ratio
November 2009	€114,856	-	0.0
Design Flood	€114,856	-	**0.0**
Design Flood + Climate Change	€137,281	-	0.0

Table 7.17 Area 2 Cost Benefit Analysis

The measures do not satisfy the desirable minimum benefit to cost ratio of 1.5 for the Design Flood event, as the Multi Coloured Manual techniques for the assessment of benefit do not take account of properties at risk of flooding and it is difficult to apply the road diversion assessment techniques to local roads with no traffic data available. The measures will be incorporated into a total cost benefit analysis for the entire scheme later in this chapter and their viability re-examined based on the overall catchment.

- **Assessment in relation to environmental issues**

As the watercourse drains to the Clare River which forms part of the Lough Corrib Special Area of Conservation, the work in the watercourse to replace the drain will need to be assessed in terms of ecological impact. However, it is expected that with appropriate mitigation measures the environmental impact of these works will be negligible.

- **Assessment in relation to climate change**

The design flood has been modelled with a 20% increase in flow provided to account for potential climate change. The road would need to be raised by at least another 200mm to prevent the road from flooding in this flood event. It is considered that the further raising of the road to mitigate the flood impact from this event should be considered as a future measure.

- **Future maintenance requirements**

Maintenance requirements will remain as per the maintenance required prior to installation of the proposed measures.

- **Upstream/downstream flood risk**

The proposed measures should not have any impact on the upstream and downstream flood risk.

7.4.3. Measure 3a & 3b

Measure 3a involves raising a 460m section of road in Miontach North by up to 500mm. Measure 3b involves raising a second section of road, 785m long by up to 1.1m. The peak water levels for the November 2009 flood, the Design Flood and the Design Flood plus Climate Change have been analysed. The proposed roads levels are set at 9.00mOD which is 70mm above the predicted level for the Design Flood. It is considered that the road can be raised in the future if the flood level increases as a result of climate change.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The cost of raising the first section of road (Measure 3a) over a distance of 460m to position it above the November 2009 flood and the Design Flood is estimated to be in the order of €40,526. The cost of raising the road to position it above the Design Flood plus Climate Change allowance is estimated to be in the order of €50,025.

The cost of raising the second section of road (Measure 3b) over a distance of 785m is €80,443. If the road is to be positioned above the Design Flood plus Climate Change allowance the estimated cost is €97,348.

As discussed in Section 7.2.3, there is no viable flood risk management measure available to protect the house that flooded during the November 2009 flood event. Therefore, the benefit that would have been attributable to this house and the other houses at risk in the area has been removed from the benefit calculations below.

Flood Event	Cost of Measures	Benefit*	Benefit to Cost Ratio
November 2009	€120,969	-	0.0
Design Flood	€120,969	-	**0.0**
Design Flood + Climate Change	€147,373	-	0.0

Table 7.18 Area 3 Cost Benefit Analysis

The benefit calculated here is zero as property flooding will not be eliminated by the potential flood risk management measures and it is difficult to ascertain benefit based on flooding of local roads using the Multi Coloured Manual as explained for Area 2 above.

The measure does not satisfy the desirable minimum benefit to cost ratio of 1.5 for the Design flood. The measures will be incorporated into a total cost benefit analysis for the entire scheme later in this chapter and their viability re-examined based on the overall catchment.

- **Assessment in relation to environmental issues**

No environmental impact is envisaged.

- **Assessment in relation to climate change**

The design flood has been modelled with a 20% increase in flow provided to account for potential climate change. The road would need to be raised by at least another 200mm to prevent the road from flooding in this flood event. It is considered that the further raising of the road to mitigate the flood impact from this event should be considered as a future measure.

- **Future maintenance requirements**

The maintenance required after the installation of the measure will remain as per the maintenance required prior to installation of the proposed measures.

- **Upstream/downstream flood risk**

The proposed measures will not have any impact on the upstream and downstream flood risk.

7.4.4. Measure 4a, 4b, 4c and 4d

Measure 4a involves the provision of an additional flood eye at the Claregalway Bridge. Measures 4b, 4c and 4d are ancillary to Measure 4a and involve localised re-grading of the channel under the bridge, the filling of a gap in an existing retaining wall and the construction of an embankment in the vicinity of the Arches.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The estimated cost of installing the additional flood eye at Claregalway Bridge is €851,000. The cost of the localised re-grading and deepening of the channel in the vicinity of the bridge is estimated to be in the region of €55,603. The cost of the measures at the existing retaining wall and in the vicinity of the old arches is estimated to cost in the region of €10,750 in total.

Flood Event	Cost of Measures	Benefit	Benefit to Cost Ratio
November 2009	€917,353	€11,127,628.73	12.1
Design Flood	€917,353	€13,064,033.41	**14.2**
Design Flood + Climate Change	€917,353	€15,282,123.22	16.7

Table 7.19 Area 4 Cost Benefit Analysis

The measure satisfies the desirable minimum benefit to cost ratio of 1.5 for the Design flood.

- **Assessment in relation to environmental issues**

The works proposed in Area 4 will have an environmental impact. Some of the potential ecological impacts include the alteration of hydrological flow regimes around the bridge leading to increased scouring of the river substrate, the disturbance to vesper bats which may rest or breed in crevices under the existing bridge, the alteration of wildlife resting places such as otter holts, the release of sediment to the river during excavations, the alteration of fish spawning habitat and the risk of release of sediment to the water column. At a minimum an Ecological Impact Assessment and Appropriate Assessment under the Habitats Directive will be required.

- **Assessment in relation to climate change**

The design flood has been modelled with a 20% increase in flow provided to account for potential climate change. The proposed measures eliminate flood risk to properties and roads at the flood levels predicted by the model for this event.

- **Future maintenance requirements**

The measures proposed will not lead to a significant increase in general maintenance. The culvert must be checked for the presence of debris regularly and cleaned out if necessary.

- **Upstream/downstream flood risk**

The proposed measures, particularly the addition of a flood eye at Claregalway Bridge, will have some impact on downstream flood risk by slightly exacerbating the existing flood risk which caused one house to flood and a second house to come close to flooding in Area 3 (Miontach South) during the November 2009 flood event.

However, the implementation of the additional flood eye will also have a positive impact on downstream flood risk in that the upstream flood water will be released more gradually than during the November 2009 flood event. At the peak of the November 2009 flood event the existing bridge caused a choke and the water level upstream rose to 0.8m above the downstream level. This head of water was then released in a torrent over a relatively short period of time when the water found an alternative route downstream.

It is also considered that the volume of floodplain storage available downstream of Area 3 will significantly dampen any increase in water level caused by the addition of a flood eye.

In order to fully quantify the magnitude of the downstream risk, a 3D model and a digital terrain model (DTM) of the entire flood plain would be required. However, as stated above, the downstream impact of the measure, if any, would be to exacerbate the existing flood risk, rather than introduce a new flood risk.

The measures proposed will have a positive impact on upstream flood risk.

7.4.5. Measure 5a and 5b

Measure 5a involves the replacement of 2 No. existing culverts in the Kinishka area. Measure 5b relates to general maintenance of the watercourse. This watercourse comes within the remit of the OPW and it is therefore assumed that the cleaning will come out of a maintenance budget and as such has not been included in the cost estimate or the cost benefit analysis.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The estimated cost of replacing the two existing culverts with larger capacity culverts or field bridges is €6,210.

Flood Event	Cost of Measures	Benefit	Benefit to Cost Ratio
November 2009	€6,210	€ -	0.0
Design Flood	€6,210	€ 87,989.72	**14.2**
Design Flood + Climate Change	€6,210	€ 97,436.40	15.7

Table 7.19 Area 5 Cost Benefit Analysis

The measure satisfies the desirable minimum benefit to cost ratio of 1.5 for the Design Flood.

- **Assessment in relation to environmental issues**

The works proposed in Area 5 are not expected to have a significant environmental impact. However, this watercourse drains to the Clare River which is part of the Lough Corrib Special Area of Conservation and therefore ecological mitigation measures may need to be put in place while works are taking place to ensure no sediment etc discharges to the river downstream.

- **Assessment in relation to climate change**

It is recommended that the sizing of the culverts at detailed design stage include an allowance of 20% additional flow in the watercourse to provide for potential climate change.

- **Future maintenance requirements**

The measures proposed will not lead to a significant increase in general maintenance. The culvert should be checked for the presence of debris regularly and cleaned out if necessary.

- **Upstream/downstream flood risk**

The proposed measures will reduce the upstream flood risk but are not expected to have any effect on the downstream flood risk.

7.4.6. Measure 6a

Measure 6a relates to the provision of a surface water outlet to reduce the level of flooding from turloughs in the Lakeview area of Claregalway.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The estimated cost of providing a drain through the fields in Lakeview, discharging to a 1500mm surface water sewer constructed along the N17 and discharging to the Clare River downstream of the proposed flood eye is €301,542.

Flood Event	Cost of Measures	Benefit	Benefit to Cost Ratio
November 2009	€301,542	-	0.0
Design Flood	€301,542	€ 2,061,562.46	**6.8**
Design Flood + Climate Change	€301,542	€ 2,278,836.03	7.6

Table 7.20 Area 6 Cost Benefit Analysis

The measure satisfies the desirable minimum benefit to cost ratio of 1.5 for the Design Flood event.

- **Assessment in relation to environmental issues**

The works proposed in Area 6 are not expected to have a significant environmental impact.

- **Assessment in relation to climate change**

It is recommended that the sizing of the culverts at detailed design stage include an allowance of 20% additional flow in the watercourse to provide for potential climate change.

- **Future maintenance requirements**

There will be an increased maintenance burden on the owner of the drain and piped section of the surface water outlet. Both the drain and the pipe will need to be inspected regularly and cleaned particularly after flood events.

- **Upstream/downstream flood risk**

The proposed measure will reduce the upstream flood risk. The provision of the measure will increase the flow marginally downstream of Claregalway Bridge but this additional flow is expected to have minimal impact on the downstream flood risk.

7.4.7. Measure 8a, 8b and 8c

Measure 8a involves the provision of an additional flood eye on each bank at the Crusheen Bridge. Measure 8b relates to extensive channel widening from upstream of Crusheen Bridge to the Claregalway Bridge. Measure 8c relates to maintenance and cleaning of the Islandmore drain. This measure is not included in the cost estimate or the cost benefit analysis as it is assumed the funding will come from a maintenance budget.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The estimated cost of providing the two additional flood eyes is €408,250. The estimated cost of widening the channel by providing a 15m wide berm over 4,700m is €3,944,024. The cost of raising the road if the Design Flood plus Climate Change allowance level of protection is to be provided is €52,181.

Flood Event	Cost of Measures	Benefit	Benefit to Cost Ratio
November 2009	€4,352,273.90	€ 609,244.57	0.1
Design Flood	€4,352,273.90	€ 992,664.51	**0.2**
Design Flood + Climate Change	€4,404,455.15	€ 1,905,770.21	0.4

Table 7.21 Area 8 Cost Benefit Analysis

The measures proposed do not satisfy the desirable minimum benefit to cost ratio of 1.5 for the Design Flood.

The provision of the two flood eyes only would satisfy the cost benefit analysis criteria. However, this measure alone will not reduce the flood risk to the thirteen houses and the roads that flooded in November 2009. All but one of the houses would still be flooded to some degree as a result of the Design Flood event.

However, the reduction in flood risk that would accrue from the extensive widening would also have some benefit at Claregalway. The cost benefit analysis is therefore re-calculated below taking Area 4 and Area 8 as one;

Flood Event	Cost of Measures	Benefit	Benefit to Cost Ratio
November 2009	€5,269,626.40	€11,736,873.30	2.2
Design Flood	€5,269,626.40	€14,056,697.92	**2.7**
Design Flood + Climate Change	€5,321,807.65	€17,187,893.43	3.2

Table 7.22 Areas 4 & 8 Combined Cost Benefit Analysis

Taking Area 4 and Area 8 as one, the desirable minimum cost benefit analysis ratio of 1.5 is satisfied.

- **Assessment in relation to environmental issues**

The works proposed in Area 8 will have an environmental impact. The work involved in installing the flood eyes will have a similar impact to that at Claregalway Bridge. The channel widening works will involve some disturbance to wildlife resting places such as the obstruction of existing otter holt entrances. An Ecological Impact Statement and Appropriate Assessment will be required.

- **Assessment in relation to climate change**

The proposed measures were tested using the calibrated model by including a 20% increased flow provision to account for climate change. The resulting predicted water level would flood the local road to some degree but the road would remain passable. No houses would be flooded.

- **Future maintenance requirements**

The measures proposed will not lead to a significant increase in general maintenance. The culvert should be checked for the presence of debris regularly and cleaned out if necessary.

- **Upstream/downstream flood risk**

The proposed measures will reduce the upstream flood risk. The proposed measures are not expected to increase the downstream flood risk assuming that the measures proposed at Area 4 Claregalway are carried out prior to the measures proposed for Area 8.

7.4.8. Measure 9 Do Nothing

The proposed Measure 9 Do Nothing does not require any further analysis.

7.4.9. Measure 10a, 10b and 10c

Measure 10a involves the provision of a new field bridge downstream of Ardskeaghmore at section A7 and associated local widening. Measures 10b and 10c involve channel works comprising of the construction of a 10m wide flood berm and re-grading of the channel from A7 at the field bridge to A16 at Bullaun Bridge.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The estimated cost of providing the new field bridge is €125,000. The estimated cost of widening the channel by providing a 15m wide berm over 1,500m is €1,005,097. The works involve excavation of approximately 57,500m^3 of material. It is assumed in the costing that 20% of the material to be removed is rock.

Flood Event	Cost of Measures	Benefit*	Benefit to Cost Ratio
November 2009	€1,287,800	€148,850.00	0.1
Design Flood	€1,287,800	€148,850.00	**0.1**
Design Flood + Climate Change	€1,287,800	- -	0.0

Table 7.23 Area 10 Cost Benefit Analysis

*In order to derive the benefit to be achieved here, the total cost of damages calculated in the outline damage analysis of €201,253.19 had been reduced in consideration of the fact that with the proposed measures in place, one house still floods as a result of the November 2009 flood event and the Design Flood events and the four houses still flood at the Design Flood plus climate change event.

The measures proposed do not satisfy the desirable minimum benefit to cost ratio of 1.5 for the Design Flood.

- **Assessment in relation to environmental issues**

The works proposed in Area 10 will have an environmental impact. The re-grading works will have a significant impact and channel widening works will involve some disturbance to wildlife resting places such

as the obstruction of existing otter holt entrances. An Ecological Impact Statement and Appropriate Assessment at a minimum will be required.

- **Assessment in relation to climate change**

The proposed measures were tested using the calibrated model by including a 20% increased flow provision to account for climate change. The resulting predicted water level would flood the four houses as set out above.

- **Future maintenance requirements**

The measures proposed will not lead to a significant increase in general maintenance.

- **Upstream/downstream flood risk**

The proposed measures will reduce the upstream flood risk. The proposed measures are not expected to have any significant impact downstream.

7.4.10. Measure 11a and 11b

Measures 11a and 11b involve the provision of an additional flood eye at Bullaun Bridge and widening of the channel for 760m upstream of Bullaun Bridge to upstream of the location of the house that flooded in November 2009.

- **Preliminary Assessment of Quantities, Costs and Benefits**

The estimated cost of providing the additional flood eye is €370,300. The estimated cost of widening the channel by providing a 10m wide berm over a distance of 760m is €322,826. The work in the widening involves the excavation of approximately of 17,000m^3 of material. It is assumed in the costing that 20% of the material to be removed is rock.

Flood Event	Cost of Measures	Benefit*	Benefit to Cost Ratio
November 2009	€693,126.00	€93,807.26	0.1
Design Flood	€693,126.00	€93,807.26	**0.1**
Design Flood + Climate Change	€693,126.00	€48,718.20	0.07

Table 7.24 Area 11 Cost Benefit Analysis

*In order to derive the benefit to be achieved here, the total cost of damages calculated in the outline damage analysis of €93,807 had been reduced for the Design Flood plus Climate Change scenario in consideration of the fact that with the proposed measures in place, one house still floods.

The measures proposed do not satisfy the desirable minimum benefit to cost ratio of 1.5 for the Design flood.

- **Assessment in relation to environmental issues**

The works proposed in Area 10 will have an environmental impact. The channel widening works will involve some disturbance to wildlife resting places such as the obstruction of existing otter holt entrances. An Ecological Impact Statement and Appropriate Assessment at a minimum will be required.

- **Assessment in relation to climate change**

The proposed measures were tested using the calibrated model by including a 20% increased flow provision to account for climate change. The resulting predicted water level would flood the house adjacent to the bridge but not the house further upstream.

- **Future maintenance requirements**

The measures proposed will not lead to a significant increase in general maintenance. The culvert should be checked for the presence of debris regularly and cleaned out if necessary.

- **Upstream/downstream flood risk**

The proposed measures will reduce the upstream flood risk. The proposed measures are not expected to increase the downstream flood risk assuming flood risk management measures were also in place as set out for Area 10 above.

7.5. Recommended Programme of Measures

Based on the viability assessment carried out in Section 7.4 above, it is recommended that the programme of flood risk management measures set out in Table 7.26 overleaf are implemented to provide protection from the Design Flood.

All of the recommended flood risk management measures relate to the Clare River.

There are no flood risk management measures recommended for the Abbert River. Six houses flooded on the Abbert River during the November 2009 flood. With the measures examined in place on the river, it is predicted that two houses, one in Area 10 and in Area 11, would still be inundated as a result of a flood event similar in magnitude to the November 2009 flood, albeit to a lower level than in November 2009. At the predicted water levels resulting from the Design Flood, five houses would be flooded and similarly for the Design Flood with climate change allowance included. Therefore, at the water levels predicted for the Design Flood, only one house of the six houses flooded in November 2009, will be saved. The cost of installing the flood risk management measures to achieve this protection to one house is €1,980,925. Therefore, there are no economically viable measures that can be proposed for the Abbert River.

Although the measures for Areas 2 and 3 above proved economically unviable when analysed on a case by case basis, when combined with the other proposed measures for the Clare River, the scheme becomes economically viable, with a benefit to cost ratio of 2.8.

It is noted that when a cost benefit analysis is applied to the combined measures examined for both the Clare and the Abbert Rivers, a benefit to cost ratio of 2.1 is achieved. While this ratio would make a combined scheme seem economically viable, this option cannot be recommended based on the value for money issues associated with the Abbert River set out in the paragraph above. For information purposes only, this analysis is provided for the Design Flood event in the table below;

ANALYSIS OF MEASURES SCREENED LEVEL OF PROTECTION – DESIGN FLOOD			
	Cost	**Benefit**	**Benefit to Cost Ratio**
TOTAL - CLARE RIVER	€ 5,813,203	€16,206,250.10	2.8
TOTAL - ABBERT RIVER	€ 1,980,925	€295,060.44	0.1
TOTAL - CLARE RIVER + ABBERT RIVER	**€ 7,794,129**	**€16,501,310.55**	**2.1**

Table 7.25 Cost Benefit Analysis by River Catchment

PROGRAMME OF MEASURES STANDARD OF PROTECTION - DESIGN FLOOD					
Area	**Location**	**Proposed Measure**	**Capital Cost**	**Benefit**	**Benefit to Cost Ratio**
CLARE RIVER					
2	**Miontach South**	**2a. Raise access road** **2b. Increase size of culvert in conjunction with road works** **2c. Clean drain ED @ Miontagh (OPW) and other drains in vicinity**	**€ 114,856**	**€ -**	**0.0**
3	**Miontach North**	**3a. Raise access road** **3b. Raise access road**	**€ 120,969**	**€ -**	**0.0**
4	**Claregalway**	**4a. Install additional flood eye at Claregalway Bridge** **4b. Regrade channel upstream of and under bridge** **4c. Fill gap in wall at An Mhainistir housing estate** **4d. Provide local embankment at old Nine Arches bridge**	**€ 917,353**	**€ 13,064,033**	**14.2**
5	**Kinishka**	**5a. Increase capacity of at two culverts on stream OPW C3/5** **5b. Clean stream C3/5**	**€ 6,210**	**€ 87,990**	**14.2**
6	**Lakeview**	**6a. Provide surface water outlet through fields and along N17 to downstream of Claregalway Bridge**	**€ 301,542**	**€ 2,061,562**	**6.8**
8	**Caherlea/Lisheenavalla**	**8a. Install additional flood eyes at Crusheen Bridge** **8b. Channel widening from 900m upstream of Crusheen Bridge to Claregalway** **8c. Cleaning and regrading of Islandmore drain OPW C3/7 & F.799/1** **8d. Raise local road in Caherlea/Lisheenavalla**	**€ 4,352,274**	**€ 992,665**	**0.2**
TOTAL - CLARE RIVER			**€ 5,813,203**	**€16,206,250**	**2.8**

Table 7.26 Recommended Programme of Measures

It is noted that planning costs, such as site investigation, preparation of an environmental reports, archaeological reports, design costs etc are not included in the costs for the measures above. It is recommended that an allowance of 15% of the capital costs be budgeted for these items. It is also noted that VAT is not included in the capital costs set out above.

Therefore, the total costs and benefits are as follows;

Item	Cost	Benefit	Benefit to Cost Ratio
Capital Cost of Proposed Flood Risk Management Scheme excl VAT	**€5,813,203**	**€16,206,250**	**2.8**
Add VAT @ 13.5%	**€784,782**	**-**	**-**
Capital Cost of Proposed Flood Risk Management Scheme incl VAT	**€6,597,985**	**€16,206,250**	**2.5**
Add 15% for Planning Costs	**€989,698**	**-**	**-**
Total Cost of Proposed Flood Risk Management Scheme incl VAT	**€7,587,683**	**€16,206,250**	**2.1**

Table 7.27 Total Cost of Recommended Programme of Measures

It is noted that the costs in Table 7.27 above do not include for the cost of land acquisition.

7.6. Environmental Impact

The various potential ecological impacts have been discussed in previous sections in relation to each measure's viability. It is clear from the viability assessment that the recommended programme of measures will have an environmental impact, particularly as the work is located in or adjacent to the Lough Corrib Special Area of Conservation.

The Planning and Development Regulations of 2001 require that certain categories of projects be subjected to Environmental Impact Assessment, as detailed in Schedule 5. The following categories of projects listed in the schedule are relevant to the recommended programme of measures;

- *"Inland waterway construction not included in Part 1 of this Schedule which would extend over a length exceeding 2 kilometres."*
- *"Canalisation and flood relief works, where the immediate contributing sub-catchment of the proposed works (i.e. the difference between the contributing catchments at the upper and lower extent of the works) would exceed 1,000 hectares or where more than 20 hectares of wetland would be affected or where the length of river channel on which works are proposed would be greater than 2 kilometres"*

Any works falling into the above categories will require full Environmental Impact Assessment.

As the Clare River forms part of the Lough Corrib cSAC, all proposed channel and drainage works potentially impacting on the aforementioned protected sites and species will also need to be screened in relation to an Appropriate Assessment. If the outcome of this screening exercise cannot completely exclude the potential for impacts on the qualifying interests of the site, a full Habitats Directive Assessment will need to be carried out and the resultant Natura Impact Statement published. The assessment will also

consider potential cumulative impacts to the cSAC when taken in combination with other works, developments, abstractions and inputs to the Clare catchment.

As the Clare and Abbert Rivers are key salmonid spawning rivers in the region, in-stream works must be constrained to a time window between May 1st and September 30th, following consultation with the Western Regional Fisheries Board. Under Section 40 of the Wildlife Act, vegetation clearance may only be carried out between October 1st and March 31st, though the exclusion in Subsection 2(c) may apply in this case, namely *"the cutting, grubbing or destroying of vegetation in the course of any works being duly carried out for reasons of public health or safety by a Minister of the Government or a body established or regulated by or under a statute"*.

It is noted that impacts associated with the proposed flood risk management scheme may not all necessarily be negative; protection of various habitats is likely to be an outcome of such works, as the impact of major flood events is likely to be reduced.

7.7. Archaeological Impact

There are several sites of archaeological interested located close to the proposed works. It is recommended that prior to detailed design stage, an Archaeological Impact Assessment, at a minimum, be carried out by a qualified archaeologist in relation to potential impacts.

7.8. Outline Design of Proposed Measures

Appendix C contains sketches of the proposed outline design of the recommended programme of measures. It also contains sketches of the measures not recommended to proceed which were produced in order to further inform the viability screening process.

8. Conclusions and Recommendations

8.1. Conclusions

The flood event of November 2009 had severe consequences for the southern part of the Clare River catchment, particularly in the vicinity of Claregalway and surrounding townlands. The rainfall that fell in the weeks and particularly just prior to the peak of the floods was statistically significant with 300% of normal rainfall falling in November 2009 and estimated return periods of 134 years for the 2 day rainfall, 293 years for the 4 day rainfall, 306 years for the 8 day rainfall, 272 years for the 16 day rainfall and 131 years for the 25 day rainfall ending on 26 November 2009.

The peak water level at Claregalway Bridge was recorded on Sunday 22 November 2009. The level at this time was 360mm higher than the previous highest water level recorded in December 2006.

The flooding caused by the peak water levels in the River Clare and its major tributary, the Abbert River, high groundwater levels and high lake levels had severe impacts throughout the study catchment, but particularly in the following areas, where the high water levels resulted in houses being flooded, access roads becoming impassable and extensive flooding of agricultural land;

- Area 1 — Lough Corrib to Claregalway Bridge — Land flooding
- Area 2 — Miontach South — Access road, land flooding
- Area 3 — Miontach North — House, access road, land flooding
- Area 4 — Claregalway — N17 national route, access roads
- Area 5 — Kinishka — Access road, land flooding
- Area 6 — Lakeview — Access roads, land flooding
- Area 7 — Gortatleva — House, land flooding
- Area 8 — Caherlea/Lisheenavalla — 13 houses, access road, land
- Area 9 — Lackagh Bridge to Corofin — Land
- Area 10 — Ardskeaghmore (Abbert River) — 4 houses, land flooding
- Area 11 — Upstream of Bullaun Bridge (Abbert River) — 2 houses, access road, land

The estimated economic cost of the damages consequent to the flood of November 2009 amount to €12.1 million. The damages in the Claregalway region were particularly severe, mainly as a result of the closure of the N17 for six days, and amount to approximately €11.8m alone.

In order to determine the technical viability of potential flood risk management measures to eliminate or reduce flooding, from an event of similar magnitude to November 2009, a HEC-RAS model of the Clare and Abbert River was constructed. This model was calibrated using anecdotal information regarding peak flood levels. Various potential flood risk management measures were then tested using this calibrated model. All of the potential flood risk management measures were subjected to an initial viability assessment on technical, economic, environmental and social acceptability grounds. The flood risk management measures emerging from this process as potentially viable were then subjected to a further more detailed viability assessment which included a cost benefit analysis, assessment in relation to climate change, maintenance costs etc.

The conclusion of the study is a programme of viable measures to eliminate or reduce flooding from a similar sized flood event to November 2009. This programme of measures is set out in Section 8.2 below.

It is noted that the elimination or reduction of flooding from an event such as November 2009 was not possible in all areas.

In Area 3 (Miontach North), flood risk management measures are proposed to eliminate the flood risk to access roads, however, there is no available viable measure to eliminate or reduce flood risk to the house that flooded and to the neighbouring house that came close to flooding. In the case of the flooded house, the water emerged from the ground and entered the house through the floor. It is therefore considered that the provision of local protection measures to the two houses at risk would be ineffective as the water is likely to flow under any barrier and emerge at the other side under pressure from the head of water. There is no channel conveyance measure available that will reduce the water level in the channel and consequently the water level in the vicinity of the houses sufficiently to eliminate or mitigate flood risk to the two houses.

In Areas 10 and 11, adjacent to the Abbert River, it is concluded that there are no flood risk management measures available that satisfy economic criteria or indeed technical criteria. There were six houses flooded in the flood event of November 2009. It would cost in the region of €2m to install flood risk management measures which would only protect four of the houses from an event of similar magnitude to November 2009. When water levels resulting from the Design Flood plus Climate Change event are examined using the calibrated model, it is predicted that five houses would still flood. For this reason, no flood risk management measures can be recommended for Areas 10 and 11.

8.2. Recommendations

It is recommended that the following programme of measures be implemented to eliminate or reduce the impact of flooding from an event of similar magnitude to that of November 2009;

- Area 2 Miontach South
  - Raise access road
  - Increase size of culvert
  - Clean drain

- Area 3 Miontach North
  - Raise 2 sections of access road

- Area 4 Claregalway
  - Install flood eye and associated local widening downstream
  - Re-grade channel upstream and under bridge
  - Fill gap in retaining wall at An Mhainistir estate
  - Provide local embankment at old Nine Arches Bridge

- Area 5 Kinishka
  - Increase capacity of two culverts
  - Clean stream

- Area 6 Lakeview
  - Provide surface water outlet to Clare River

- Area 8 Caherlea/Lisheenavalla
  - Install 2 No. flood eyes at Crusheen Bridge
  - Channel widening from 900m upstream of Crusheen Bridge to Claregalway

The cost of the proposed measures and the benefits accruing from the implementation of the proposed measures are as follows;

Area	Capital Cost	Benefit	Benefit to Cost Ratio
Area 2 Miontach South	€ 114,856	€ 0	0.0
Area 3 Miontach North	€ 120,969	€ 0	0.0
Area 4 Claregalway	€ 917,353	€13,064,033	14.2
Area 5 Kinishka	€ 6,210	€ 87,990	14.2
Area 6 Lakeview	€ 301,542	€ 2,061,562	6.8
Area 8 Caherlea/Lisheenavalla	€ 4,352,274	€ 992,665	0.2
Total Capital Costs of Flood Risk Management Scheme excl VAT	**€5,813,203**	**€16,206,250**	**2.8**
Total Cost of Flood Risk Management Scheme incl VAT & Planning Costs	**€7,587,683**	**€16,206,250**	**2.1**

It is noted that Area 2 Miontach South, Area 3 Miontach North and Area 8 Caherlea/Lisheenavalla do not satisfy the desirable benefit to cost ratio of 1.5 when analysed on a stand alone basis. However, when the individual measures are combined as a programme of works for a single scheme, a benefit to cost ratio of 2.8 is achieved when capital costs alone are considered. When planning costs and VAT are added to the capital costs, the benefit to cost ratio is 2.1.

8.3. Phasing

If the programme of measures is to be implemented on a phased basis, it is recommended that the measures proposed for each area are prioritised as follows;

1. Area 4 Claregalway
2. Area 6 Lakeview
3. Area 8 Caherlea/Lisheenavalla

The local measures proposed in Area 2 Miontach South, Area 3 Miontach North and Area 5 Kinishka do not need to be implemented in any particular order as the recommended measures have no upstream or downstream affects.

It is likely that the result of a separate study into flooding issues in the Carnmore catchment, will be to recommend that overflow from the Carnmore catchment be discharged to Clare River catchment. It must be noted that this potential flood risk management measure for the Carnmore area cannot be implemented prior to the flood risk management measures recommended for Area 4 and Area 8 being carried out.

8.4. Other Recommendations

It is recommended that a documented Environmental Impact Assessment Screening exercise be carried out in relation to the proposed programme of measures in order to determine the level of ecological assessment required.

On foot of this study, informal consultation should take place with the National Parks and Wildlife Service and the Western Regional Fisheries Board as soon as possible. Galway County Council and the National Roads Authority should also be consulted in relation to the works on the local roads and the N17. The

comments of the Development Applications Unit (DAU) of the Department of Environment, Heritage and Local Government (DEHLG) should be sought as soon as possible in relation to the archaeological impacts of the proposed measures.

The proposed measures should proceed to detailed design as soon as possible.

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