Office Of Public Works

Study to identify practical measures to address flooding on the Dunkellin River including the Aggard Stream

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REPORT

PROJECT: **Study to identify Practical Measures to address Flooding on the Dunkellin River and Aggard Stream**

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1 EXECUTIVE SUMMARY

Following the invitation to tender from the Office of Public Works, dated 8th February 2010 and the submission of a Tender proposal on 19th February 2010, TOBIN Consulting Engineers in association with Royal Haskoning Ireland, were commissioned on 10th March 2010 to undertake a Study to :

"Identify Measures to address flooding on the Dunkellin River from Craughwell to Kilcolgan to include the Aggard Stream and its tributaries up to Cregaclare".

Following on from this study, Tobin Consulting Engineers in association with Royal Haskoning have proposed a costed package of flood remediation works along the Dunkellin River and the Aggard Stream to Cregaclare, which will accommodate the 100 Year Flood, with an allowance for climate change.

These works are based on a developed hydraulic model of the Dunkellin River and the Aggard Stream, which includes the various bridge structures, culverts, and other hydraulic controls, and which has been used to test the proposed measures, in two Strategic Schemes, against the expected benefits of including these measures in the overall package of works.

The Report describes the catchment topography, and the channel profile, from the headwaters, through Craughwell, into the Rahasane/Rinn Turlough system, and downstream to the sea at Kilcolgan. It recognises the karstic nature of the limestone bedrock, and draws upon previous work in describing its impact on Rahasane Turlough in particular.

The flood events of January 2005 and November 2009 are described, to define the extent of flood damage, traffic and social disruption, and the flood plain extent.

The flow records covering more than 50 years at the five Hydrometric Gauging Stations along the catchment have been extensively analysed, so that the flood likely to be exceeded on average, once in 100 years, can be calculated, and so that the extreme flood experienced in November 2009 can be placed in its proper context of extremity and probability of recurrence. While it would have a return period in excess of 200 years in the mid-catchment, when allowance is made for Climate Change impacts, the November 2009 event will be likely to recur at a lower frequency of around 100 year in future.

Two broad modelling or Strategic Schemes have been examined.

The first examines a package of coherent, effective works, concentrating on channel improvements and reconstruction of those structures whose removal would be essential in an effective scheme of works.

This Strategic Scheme No 1 examines the impact of works associated with :

a. deepening particular lengths of the channel between bridge structures,
b. the use of flood eyes or bypass/over culverts at the Dunkellin Bridge and Rinn Bridge
c. removal of the old N6 stone arched bridge crossing in Craughwell and
d. deepening of the bed level at the Railway Crossing and N6 bridge in Craughwell Village.

The second Strategic Scheme examines the incremental benefit of more extensive bridge replacement, including :

1. the impact of channel widening, in lieu of deepening as examined under Strategic Scheme No.1,
2. the complete replacement of the Killeely Beg and Dunkellin Bridges,
3. the use of bypass culverts at the Railway Bridge
4. removal of the old N6 stone arched bridge crossing and
5. the complete replacement of the N6 bridges with larger span structures.

The hydraulic models of the Strategic Schemes, combined with consultation with the OPW, indicate that a particular selection of flood alleviation measures, from each of these schemes, would produce an overall Preferred Scheme which would provide optimum flood relief whilst also controlling the overall capital investment required.

Other flood alleviation measures, considered under the Strategic Schemes, such as additional and more extensive bridge replacement and channel deepening, produce such minor incremental benefits that they would not be cost-effective.

The proposed works strike a delicate balance at Rahasane Turlough cSAC. Extreme floods would be safely and effectively passed through the Turlough, by adaptations at Rinn Bridge, which would deliberately not change the flow control at the ecologically critical normal water level range in average years.

The cost of flood damage, disruption to traffic, and social disruption is estimated, and compared to the estimated cost of the recommended package of works, and the Report closes with a recommendation that sanction be given to proceed immediately with these works, with necessary stakeholder consultation proceeding in parallel.

2 INTRODUCTION

2.1 BACKGROUND AND SCOPE OF THIS STUDY

Following the invitation to tender from the Office of Public Works, dated 8th February 2010 and the submission of a Tender proposal on 19th February 2010, TOBIN Consulting Engineers in association with Royal Haskoning Ireland, were commissioned on 10th March 2010 to undertake a Study to :

"Identify Measures to address flooding on the Dunkellin River from Craughwell to Kilcolgan to include the Aggard Stream and its tributaries up to Cregaclare".

The overall scope of the study, contained in the Clients Brief, as shown in Figure 3.1 and Drawing No.5968-1000 in Appendix No. 1, can be summarised as follows.

To examine existing data, including longitudinal sections, cross sections, OPW Arterial Drainage Designs, hydrometric data and to complement this data with on-site surveys with a view to developing a mathematical hydraulic model of the Dunkellin Study Area and examining the possible benefit of the following flood alleviation measures.

a. Works Upstream of Kilcolgan to Killeely Bridge (Refer to Figure 3.1 & Drawing No. 5968-1000 in Appendix No.1)

- Localised bank widening downstream of Killeely Bridge and an examination of the flood risk at this bridge and its possible replacement.

b. Works from Killeely Bridge to Dunkellin Bridge (Refer to Figure 3.1 & Drawing No. 5968-1000 in Appendix No.1)

- Examination of the flood risk at Dunkellin Bridge including the reopening of "flood eyes" with remedial measures for boundary designation and stock control.
- Examination of the flood risk downstream of Dunkellin Bridge with a view to including berms and a two stage channel.
- Examination of the effectiveness of possible channel maintenance or width increases including improvements to river/structure alignments and roughness coefficient with regard to the overall conveyance capacity of the channel.

c. Works from Dunkellin Bridge to Rinn Bridge (Refer to Figure 3.1 & Drawing No. 5968-1000 in Appendix No.1)

- Examination of the flood risk at Rinn Bridge including the provision of "flood eyes" or the complete replacement of the bridge whilst minimising or eliminating the potential risks and consequential impacts on the Rahasane Turlough cSAC.
- Examination of the effectiveness of possible channel maintenance or width increases including improvements to river/structure/weir alignments and roughness coefficient with regard to the overall conveyance capacity of the channel.

d. Works from Rinn Bridge to Aggard Stream excluding the Rahasane Turlough cSAC (Refer to Figure 3.1 & Drawing No. 5968-1000 in Appendix No.1)

- Examination of the effectiveness of possible channel maintenance including above channel or bank maintenance. Works are not proposed within the Rahasane Turlough cSAC.

e. Works from Aggard Stream to Craughwell (Refer to Figure 3.1 & Drawing No. 5968-1000 in Appendix No.1)

- Examination of the effectiveness of possible channel and bed profile realignment, including the assessment of works required at a number bridges in Craughwell village (N6, Old N6 Multi-arch Bridge, the Railway Bridge and the bypass channel).

f. Works along the Aggard Stream (Refer to Figure 3.1 & Drawing No. 5968-1000 in Appendix No.1)

- Examination of the effectiveness of possible channel maintenance including bank maintenance with regard to the overall conveyance capacity.
- Assessment of the possible impacts of the Certified Aggard Stream Drainage Scheme as detailed in the EIS dated July 2001.

The preparation of this report involved the collation of a large body of existing data held by the OPW and this data was supplemented by extensive on-site topographical surveys carried out in March 2010. This topographical survey proved to be valuable in establishing the overall physical characteristics of the Dunkellin River and Aggard Stream and all of this data has been used in the development of the 1 Dimensional Hydraulic Model of the channels.

2.2 EXTENT, LOCATION AND DESCRIPTION OF THE CATCHMENTS

The extent of the study area, as shown in Figure 2.1, has been divided into two distinct channels. These channels are :

1. the Dunkellin/Craughwell River from approximately 200m upstream of Craughwell Village, through the Rahasane Turlough cSAC, to the sea at Kilcolgan,

and

2. the Aggard Stream and Monksfield River from the townland of Cregaclare (near Ardrahan) to its outfall at the confluence of the Dunkellin and Craughwell Rivers.

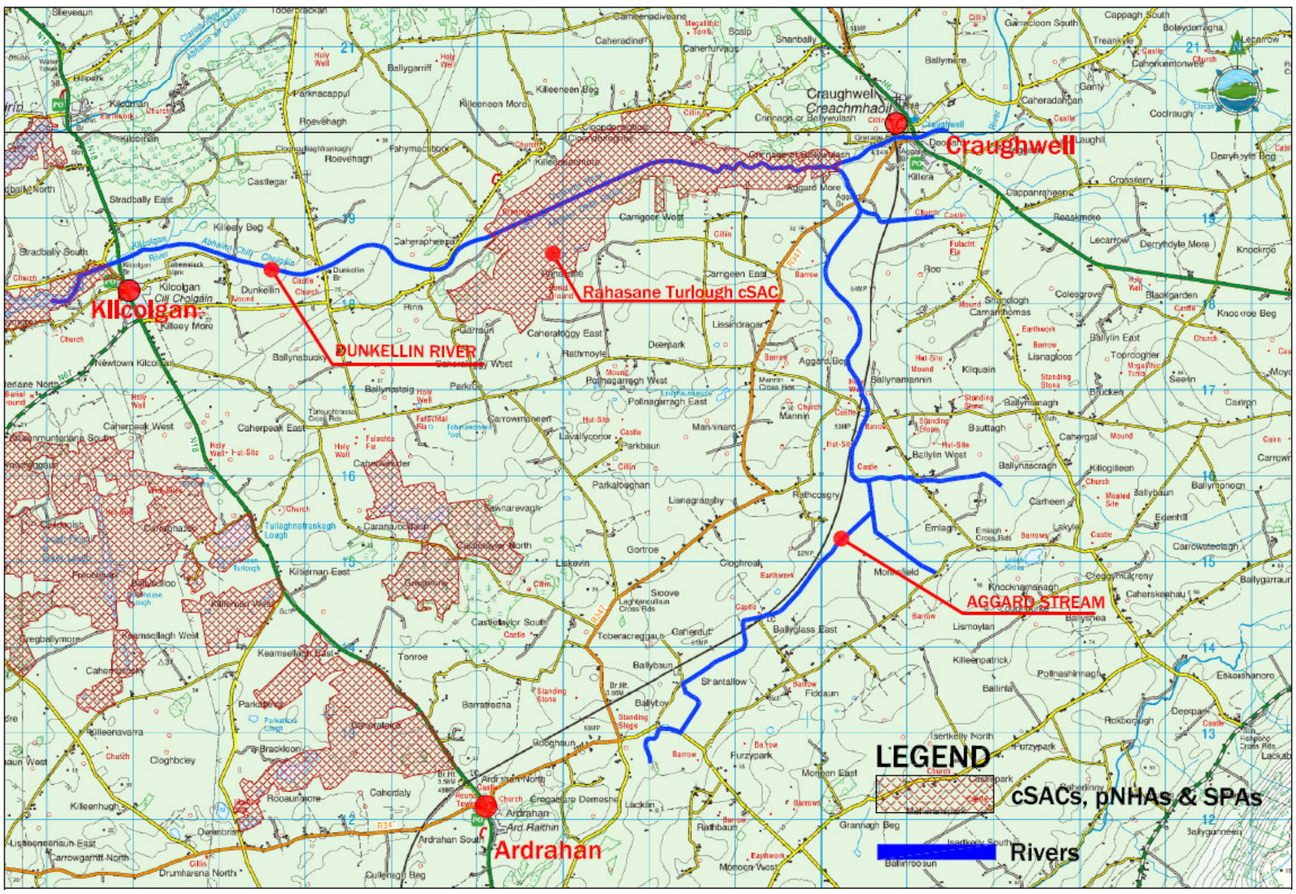

Figure 2.1 – Extent of the Study Area

The Craughwell River and Dunkellin River, together with the Aggard Stream to the south of Craughwell, form part of the Dunkellin Drainage District, where the length of the main channel within this district from its source to its estuary, is approximately 45km, encompassing a total catchment area of approximately 373km².

Whilst the Dunkellin River drains a significant area of lands to the east, northeast and south of Craughwell village (>200km^2), the particular reach of river under review in this study is approximately 11km in length and runs in a western direction from Craughwell Village to the sea at Kilcolgan.

The Aggard Stream discharges into the main Dunkellin channel at the confluence of the Craughwell and Dunkellin rivers, approximately 1,000m downstream of Craughwell Village. This tributary rises in the townland of Cregaclare where water entering the channel, via surface contributions and ground water springs, flows in a northerly direction for a distance of approximately 4km in the townland of Monksfield. At this location the channel discharges into the Monksfield River which, after a further 3.5km, enters the Aggard Stream.

3 EXISTING CATCHMENT CHARACTERISTICS

3.1 TOPOGRAPHY & HYDRAULIC CONTROLS ALONG THE DUNKELLIN RIVER

The Dunkellin River and its tributaries, rise at a number of locations to the east of Craughwell, and drain a number of population centres, including Woodlawn (Raford or Dooyertha River) and New Inn (Craughwell River), Cappataggle and Lough Rea (St Cleran's River) to name a few. Flows from each of the upper catchment areas, combine to form the main channel reach at Craughwell Village, where the discharge is recorded at a gauging station (Station No. 29007) on the main N6 Road Bridge.

Figure 3.1, shows the extent of the Dunkellin River from Craughwell Village to Kilcolgan and the positions of the major hydraulic controls along this particular stretch of river.

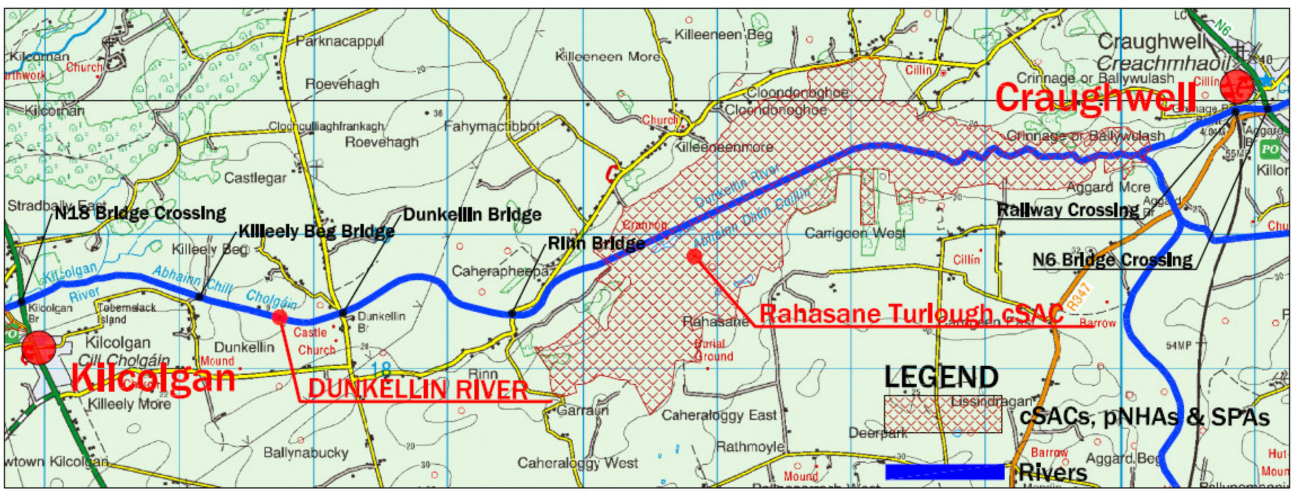

Figure 3.1 – Dunkellin Catchment from Craughwell to Kilcolgan

Figure 3.2, shows the longitudinal section of the Dunkellin River from Craughwell Village to Kilcolgan and also details the predicted surface water profile for the 100 Year Return Flood (1%AEP). Further detailed drawings are included in Appendix 1 of this report.

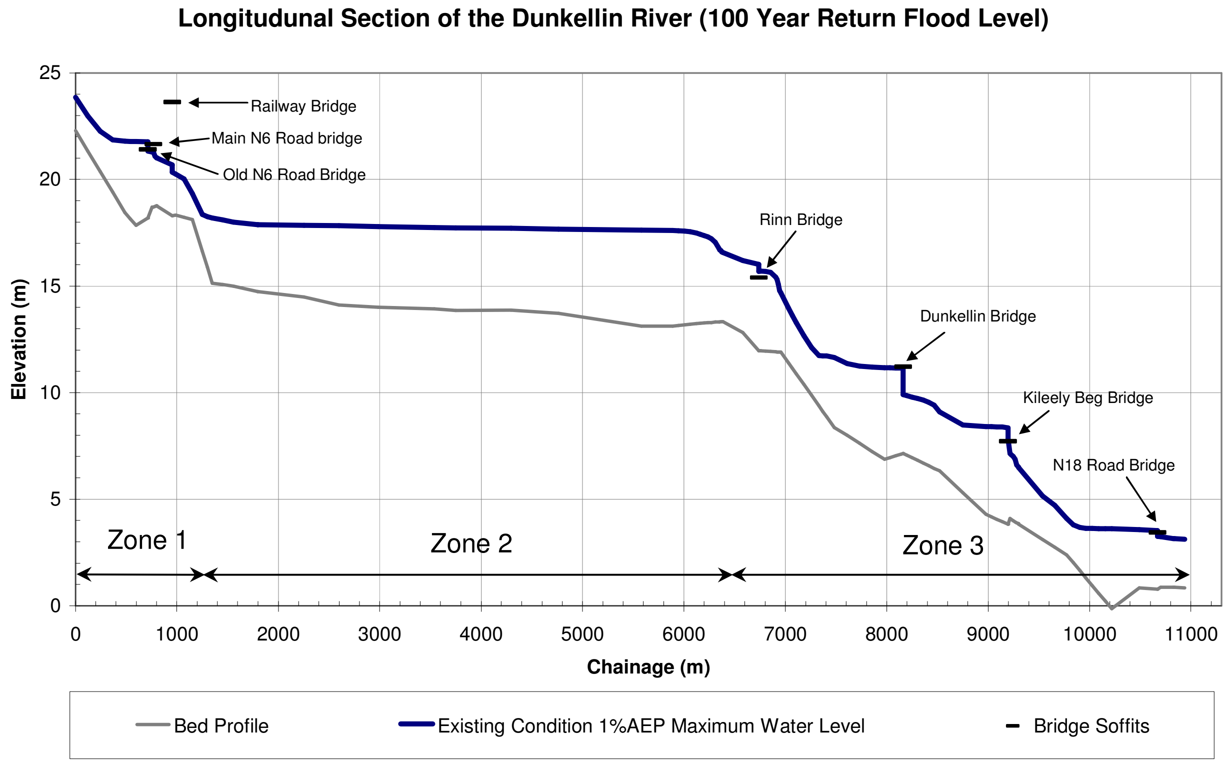

Figure 3.2 – Longitudinal Section of the Dunkellin River from Craughwell to Kilcolgan. (Extract from ISIS Model)

The depth of the main channel varies quite considerably throughout its course. Natural river bank, embankments formed from excavated spoil, significant rock cuts and large flat flood plains are predominant physical features of this channel.

The bed profile of the Dunkellin River, from Craughwell to Kilcolgan, as shown in Figure 3.2, ranges from a height of 22.29mOD (Malin Head) in Craughwell village, to 0.88mOD at Kilcolgan Bridge, and has three (3) general zones along its length.

Zone 1 – Craughwell River which has a relatively steep gradient in bed level at Craughwell Village.
Zone 2 – Rahasane Turlough cSAC which has a gentle undulating bed level.
Zone 3 – Lower reach of the Dunkellin River which has steep gradients in bed level from Rinn Bridge to the sea at Kilcolgan.

These zones are described in more detail in the following sections.

3.1.1 Zone 1 – Craughwell River

This particular stretch of the Craughwell River consists of two distinct channels, namely,

a. the main channel and
b. the bypass or overflow channel.

During normal flow conditions, surface water flows are restricted to the main Craughwell River, as shown in blue in Figure 3.3, and pass under two bridge crossings namely; the main N6 Bridge and Old N6 Bridge.

However, when flow conditions dictate excess surface water flow is directed around the main N6 Bridge Crossing via an overflow channel and a further bridge crossing of the N6, highlighted in red on Figure 3.3. The effectiveness of this overflow channel (bypass channel) is limited, as it is not fully connected to the Craughwell River at its upstream location. High flows must follow a short section of overland flow before entering the overflow channel.

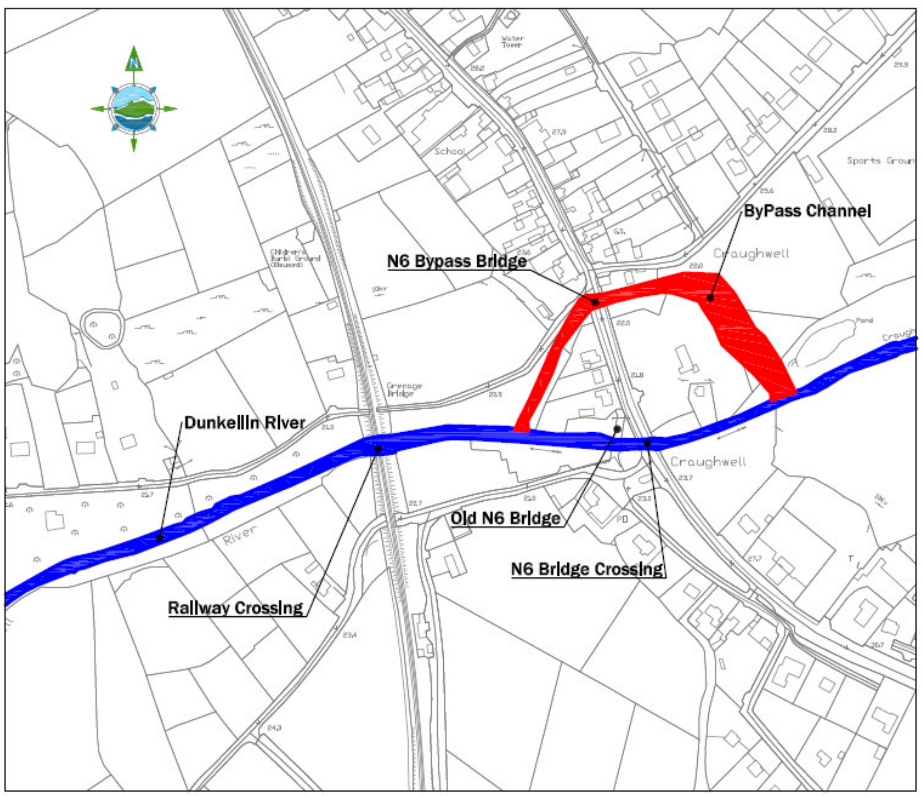

Figure 3.3 – Zone 1 Craughwell River at Craughwell Village

The channel along this stretch of river, is of the order of 1.4m to 2.0m deep and the bed level gradient varies considerably with a significant change in bed level occurring within Craughwell Village at the three bridge crossings.

There are a number of hydraulic controls along this stretch of the river. These controls are shown in the following photography and are :

a. The overflow or bypass channel within Craughwell Village (Photograph No. 1).
b. The three N6 road bridges (Photograph No's. 2, 3 and 4) and
c. The railway bridge (Photograph No. 5).

Photograph No. 1

Overflow or Bypass Channel looking upstream from the N6 bridge crossing

Photograph No. 2

N6 Bridge along the main channel looking upstream from the old N6 (Stone Arched) Bridge crossing shown in Photograph No. 3

Note : Full span of bridge available for flow and the water main located on the downstream face does not impede flows.

Photograph No. 3

Old N6 Bridge looking downstream from the main N6 Bridge Crossing shown in Photograph No. 2

Note : Low Flows generally restricted to the main arches on the right of the photo. Only in times of high flows are the arches on the left utilised due to high bank levels.

Photograph No. 4
N6 Bridge along the Bypass Channel looking upstream towards the channel shown in Photograph No. 1

Note : Unlike the Main N6 Bridge, this structure has a central pier/support which reduces the overall effectiveness of the bridge.

The water main is located on the downstream face of the bridge and does not impede flows.

Photo No. 5
Railway Bridge looking downstream through the stone arch.

Note : Water marks on the bridge abutments indicate that the full capacity (arch height) of this bridge is not hydraulically used.

3.1.2 Zone 2 – Rahasane Turlough

Water passing downstream of Craughwell Village, flows in a westerly direction for a distance of approximately 1km, where the Craughwell River and Aggard Stream combine to form the Dunkellin River.

During low flow conditions, surface water flows are restricted to the main Dunkellin River, which following an Arterial Drainage Scheme in the 1850's, can be described as being "canalised" for a significant portion of its length. Along this particular stretch of the Dunkellin, the gradient of the channel bed is relatively flat, approximately 1 in 3,000.

During low flows, the channel varies in width from 10.0m to 30m. However, during periods of high flow, the Dunkellin River overflows its banks and floods the adjoining lands to form the Rahasane Turlough cSAC. The Rahasane Turlough cSAC is considered to be one of the largest turloughs in Europe and is of particular significance in an ecological context in that it is "one of only two large turloughs which still function naturally" (Site 000322 – Site Synopsis). The Rahasane Turlough cSAC is a rare habitat type of major conservation importance. This habitat type (turloughs) is listed in Annex 1 of the Habitats Directive.

The Rahasane Turlough (circa 4km in length) lies in gently undulating land and consists of two basins which are connected at times of flood but separated as the waters decline (Drew & Daly, 1996). These basins are detailed in Figure 3.4.

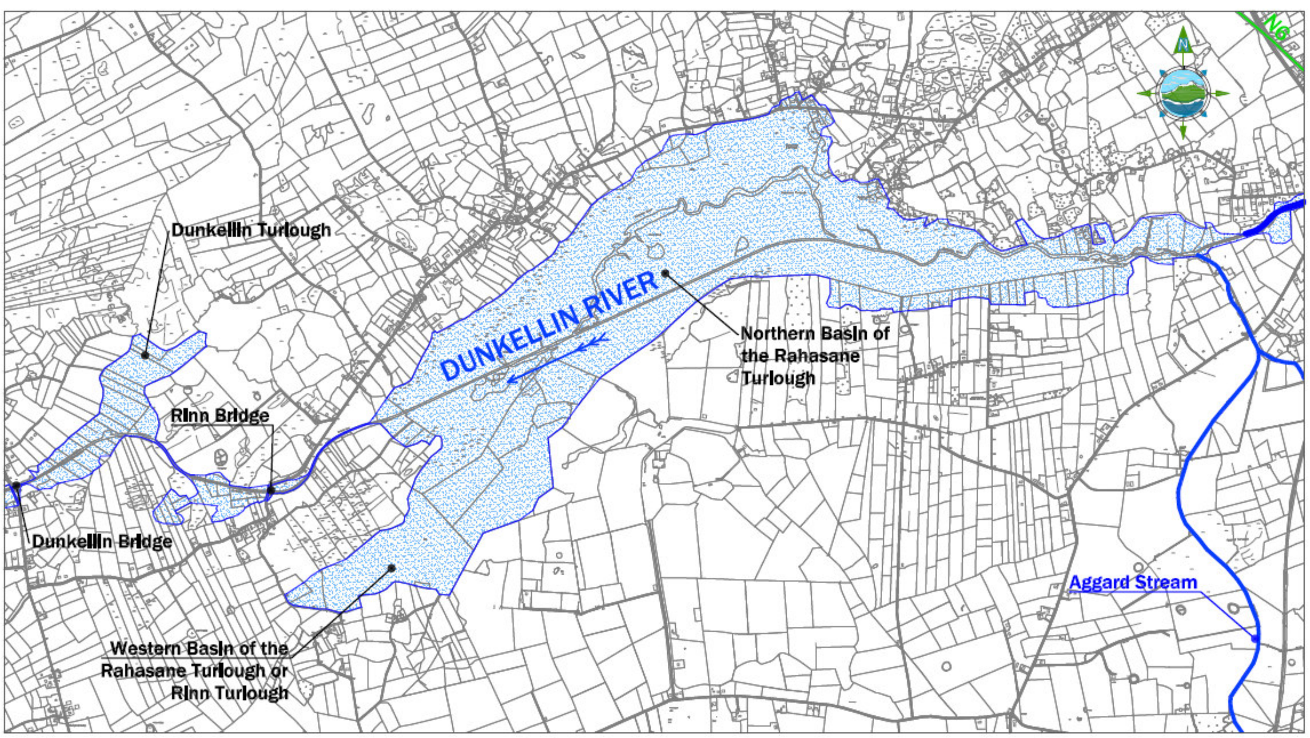

Figure 3.4 – Zone 2 Rahasane, Rinn & Dunkellin Turlough Complex

The larger of these, the northern basin, is described as the Rahasane Turlough. Rahasane was formerly the natural sink of the Dunkellin River, but now an artificial channel takes some of the water further downstream. Water escapes the artificial channel to flood the northern basin where it flows into an active swallow hole system (NPWS, Site : 000322 - Site Synopsis).

The second of these basins, the western basin, known as the Rinn Turlough, is orientated north-south and is connected to the main Rahasane Turlough by a raised channel (circa 0.5m above the floor of the Rahasane Turlough). This Rinn Turlough is an overspill basin to the main turlough (Drew, 1986).

During flood conditions the width of the "Dunkellin River" or the flood plain increases quite significantly as can be seen in Photograph No. 6. In a number of locations along Rahasane Turlough cSAC, the flood plain can be >1km wide and at its highest levels can extend to cover an area of over 300ha.

Photograph No. 6
Rahasane Turlough

Taken in November 2009 looking northwards

The Rinn Turlough (Western Basin) is in the foreground.

The Rahasane Turlough (Northern Basin) is shown in the upper portions of the image.

Typical floor levels within the Rahasane Turlough cSAC are of the order of 13.0mOD Malin Head (TOBIN Topographical Survey 2010) with other localised depressions or sinkholes having levels of 11.0m OD Malin Head (Drew 1986).

Downstream of the Rahasane Turlough cSAC, surface water flows, westerly toward Rinn Bridge, through a well defined canalised channel measuring up to 3.3m in depth and 15 to 20m in width. The section of channel downstream of the turlough is shown in Photograph No. 7. This section of the channel is formed in a rock cut, for a significant portion of its length, and the gradient of the channel bed is typically 1 in 200.

Photograph No. 7
Dunkellin River looking upstream from Rinn Bridge

The banks of the existing channel are overgrown and bush/tree cutting will be required along this stretch of the river to improve conveyance.

3.1.3 Zone 3 – Rinn Bridge to Kilcolgan

The main channel exiting the Rahasane Turlough (Photograph No. 7) and the Rinn Bridge (Photograph No. 8), which is located approximately 800m downstream of the turlough, are the main downstream features impacting on the hydraulic control of the river.

Downstream of the Rinn Bridge, and during low flow conditions, surface water flows are restricted to the main Dunkellin River, which again, following the Arterial Drainage Scheme completed in the 1850's, can be described as being "canalised" for a significant portion of its length. During these low flows this particular stretch of the river varies in width from 10.0m to 15m and the gradient of the channel bed is approximately 1 in 300.

Photograph No. 8
Rinn Bridge taken from the upstream left bank

Note the central pier dividing the two spans The removal of the central pier is modelled later in Section 6.2.2.7 of this report.

The bed level at this structure and the upstream channel control the normal flood levels in the Rahasane Turlough.

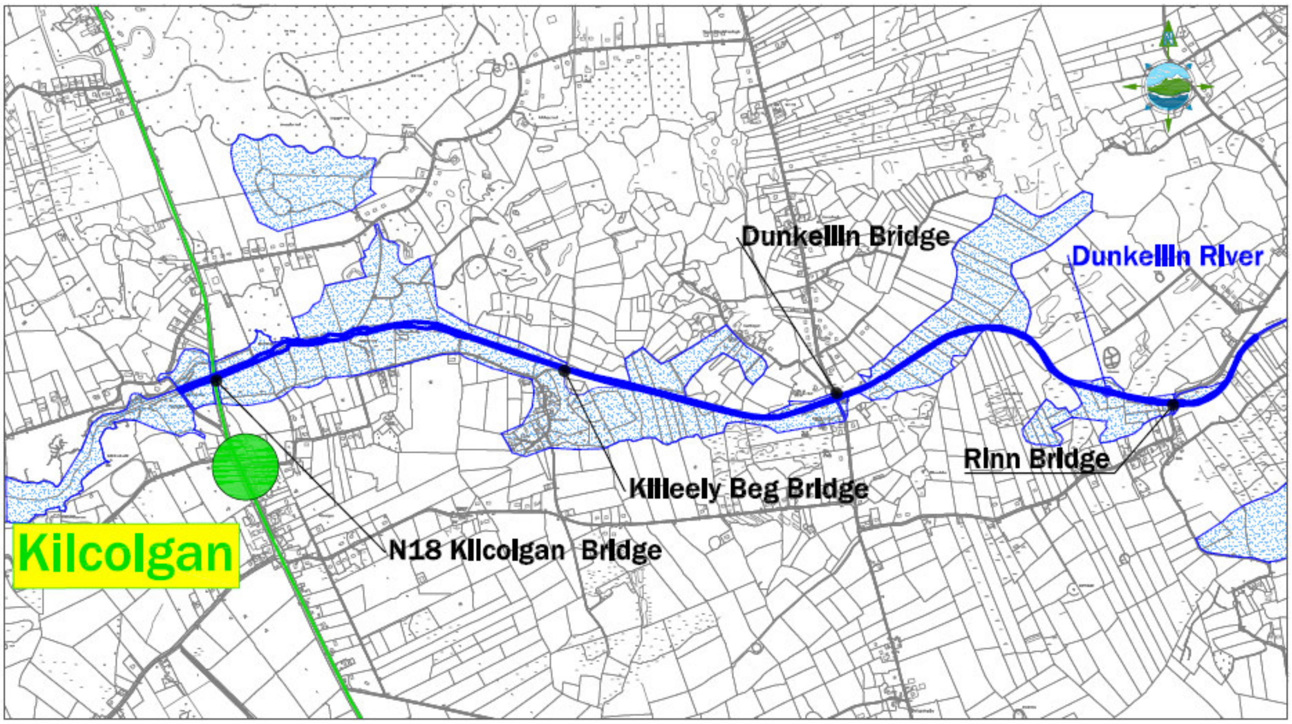

Figure 3.5 – Zone 3 Rinn Bridge to Kilcolgan

During high flows, the Dunkellin River overtops its banks and water enters another flood plain approximately 750m downstream of the Rinn Bridge.

This flood plain is shown on Photograph No. 9 and is known as the Dunkellin Turlough. Water level within this turlough is controlled by the downstream Dunkellin Bridge shown in Photograph No. 10.

Photograph No. 9
Dunkellin Turlough

Facing upstream with the Dunkellin Bridge in the centre of the image with a cluster of houses on each of the right and left banks

Note : the narrow flood plain just upstream of the bridge which is visible as the left bank in Photograph No. 10

Photograph No. 10
Upstream face of the Dunkellin Bridge showing the main arch and flood eyes on the left bank

Low Flows at this location are restricted to the main channel and stone arch visible on the right of the photograph.

High flows overtop the channel and pass under the roadway via the three visible (smaller) arches.
However, restrictions, such as the trailer and piles of stone reduce the effectiveness of these flood eyes.

Downstream of this multi-arched bridge, the Dunkellin River continues for a further 2.5km to the sea via the Killeely Beg Bridge, the Kilcolgan Road (N18) Bridge and a local road bridge (stone arch). The lands and main channel within the vicinity of the Kilcolgan Road Bridge are tidal. Downstream of Dunkellin Bridge, the Dunkellin River continues to follow a well defined canalised channel with gradients of between 1 in 11 and 1 in 20 and widths ranging from 10.0 to 15.0m, until it reaches the sea at Kilcolgan.

3.2 TOPOGRAPHY & HYDRAULIC CONTROLS ALONG THE AGGARD STREAM

As noted earlier in this report, the Aggard Stream, as shown in Figure 3.6, discharges into the main Dunkellin channel at the confluence of the Craughwell and Dunkellin rivers approximately 1,000m downstream of Craughwell Village. The stream rises in the townland of Cregaclare where, water entering the channel, via surface contributions and ground water springs, flows in a northerly direction for a distance of approximately 4km in the townland of Monksfield. At this location, the channel discharges into the Monksfield River which, after a further 3.5km, enters the Aggard Stream. The channel flows almost parallel to the western railway corridor and crosses this railway at three locations.

Unlike the Dunkellin River, there are no designated sites (cSAC's, NHA's or SPA's) along the route of the Aggard Stream and Monksfield River.

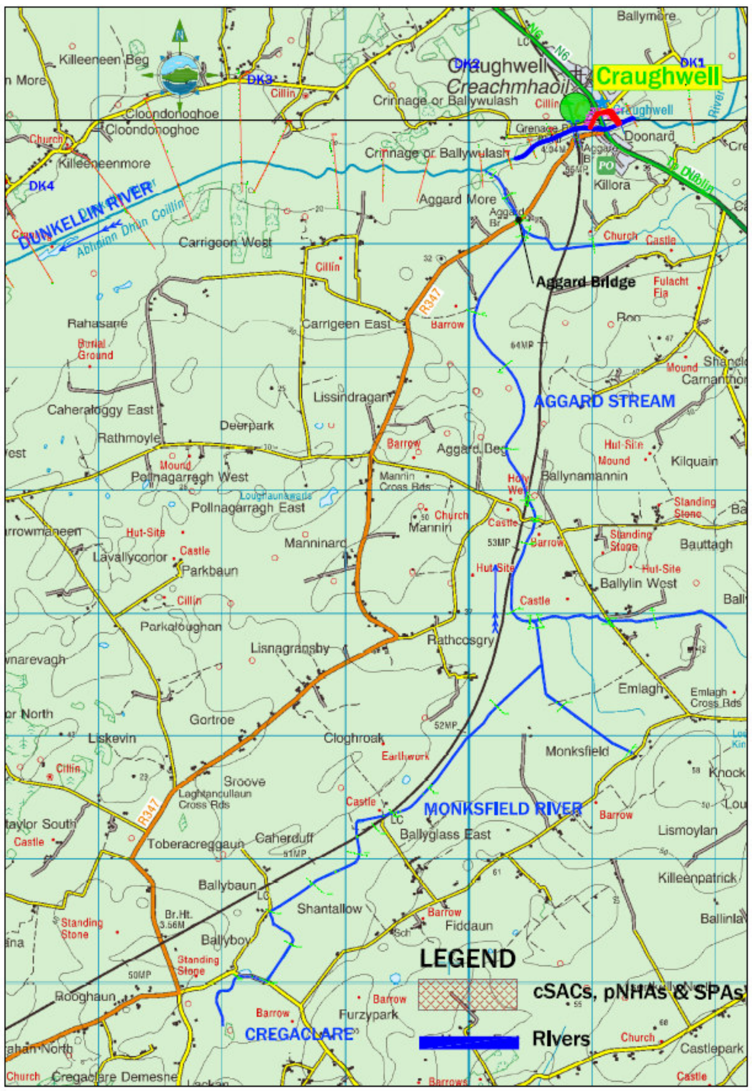

Figure 3.6 – Aggard Stream & Monksfield River

The bed profile and right/left bank levels along the Aggard Stream and Monksfield River from the townland of Cregaclare to the Dunkellin River are shown in Figure 3.7. Further detail and drawings are included in Appendix No. 1 of this report.

Along this channel, the bed profile ranges from a height of 32.5mOD (Malin Head) in its upper reaches, in the townland of Cregaclare, to 16.6mOD at the confluence with the Dunkellin River approximately 1,000m downstream of Craughwell.

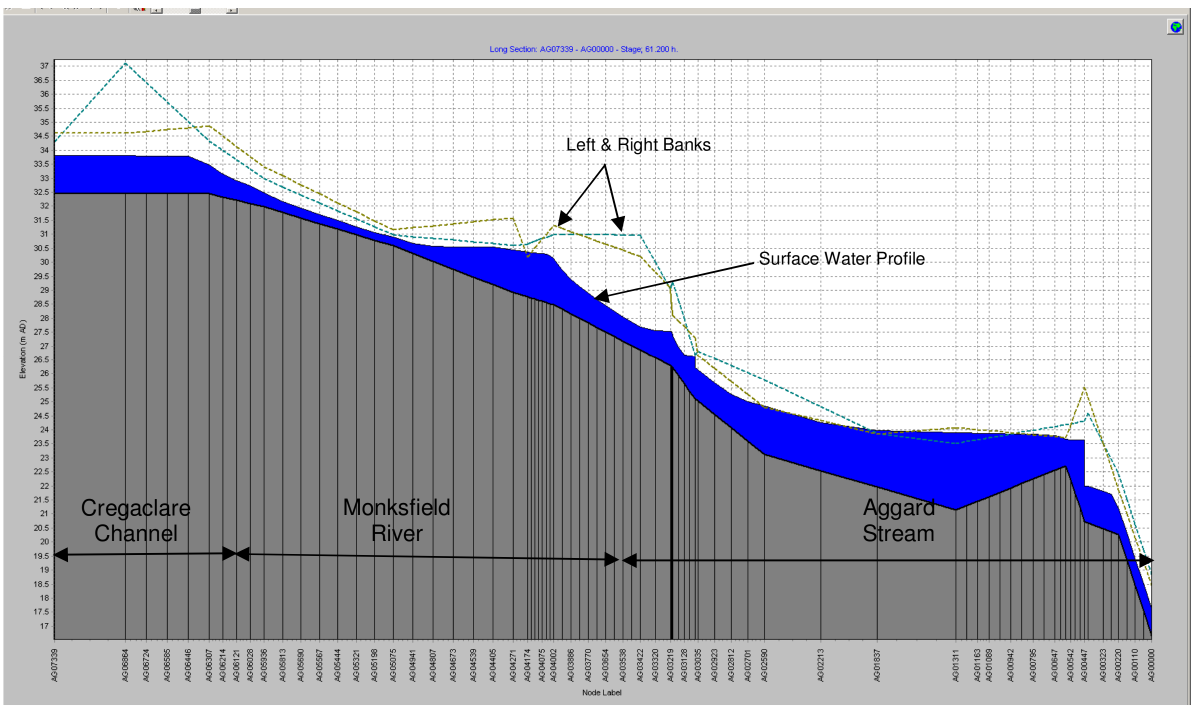

Figure 3.7 – Long Section of the Aggard Stream. Extract from the ISIS Model

The base width and side slopes of the Monksfield River and Aggard Stream are quite variable throughout its length.

In its upper reaches, along the Cregaclare Channel, the width of the stream is relatively narrow with some sections being 2.0 to 2.5m wide where the water depth is also quite shallow and stagnant as a result of the very flat gradient in bed level. Along this stretch of the channel, field boundaries and local access crossings, as shown in Photographs 11 and 12 , also impede the flow in the channel.

Photograph No. 11
Typical Boundary Crossing along the Aggard Stream in Cregaclare

Note : boundary wall traverses the channel without any pipework crossing to improve conveyance

Photograph No. 12
Typical Field Crossing along the Aggard Stream in Cregaclare

Dense weedy growth is also a significant feature of the upper reaches of this channel

Downstream of the Cregaclare Channel, in the townland of Ballyglass and Monksfield, the channel width becomes more pronounced and is typically 3.0 to 5.0m. The bed profile also steepens to a gradient of approximately 1 in 500. Along this stretch of the Monksfield River, the hydraulic control features are also more defined with concrete culverts and stone arch bridges used to traverse the railway line.

Photograph No. 13
Railway Crossing along the Aggard Stream in Ballyglass

Note : The channel banks at each railway crossing have been cleaned in recent years due to works at each railway crossing

Photograph No. 14
Railway Crossing along the Aggard Stream in Monksfield

Note : The channel banks at each railway crossing have been cleaned in recent years due to works at each railway crossing

Downstream of the Monksfield River, along the Aggard Stream, the channel width is typically 5.0 to 7.0m and the bed profile is variable including a localised rise in the bed level as the channel approaches the Aggard Bridge.

The final hydraulic control on the Aggard Stream is the Aggard Bridge where the R347 Ardrahan Road traverses the channel. This structure is shown in Photograph No. 15.

Photograph No. 15
Downstream face of the Aggard Bridge

The bridge consists of two stone arches the second of which is not visible at his location due to trees and bush growth on the channel banks

3.3 EXISTING CONDITION OF THE DUNKELLIN RIVER AND AGGARD STREAM

The conditions encountered along the length of the Dunkellin River and Aggard Stream are quite variable.

The Dunkellin River can be characterised as having :

1. a "Canalised" channel with steep banks in rock cut,
2. Overgrown river banks where natural vegetation, such as trees and bushes impact on the conveyance capacity of the channel.

Photographs 16 and 17 show typical examples of these two main channel conditions.

Photograph No. 16
Typical section of "canalised" channel along the Dunkellin River

This image was taken upstream of the Dunkellin Bridge

Photograph No. 17
Typical overgrowth along the Left and Right Banks of the Dunkellin River

This image was taken downstream of Rinn Bridge

The Aggard River can be characterised as having :

1. a natural channel with flat gradients resulting in significant weedy growth in its upper reaches, and
2. Overgrown river banks where natural vegetation, such as trees and bushes impact on the conveyance capacity of the channel.

Photographs 18 and 19 show typical examples of these two main channel conditions.

Photograph No. 18
Typical flat gradients and weedy growth along the upper reaches of the Aggard Stream

Photograph No. 19 (Aggard Bridge)
Typical natural bank overgrowth along the lower reaches of the Aggard Stream

3.4 HISTORICAL FLOODING WITHIN THE CATCHMENTS

3.4.1 Flood Event in January 2005

One of the most recent, and prior to November 2009, the highest recorded flooding event on the Dunkellin River, recorded by the gauging station in Craughwell (Station No. 29007), took place on the 10th of January 2005.

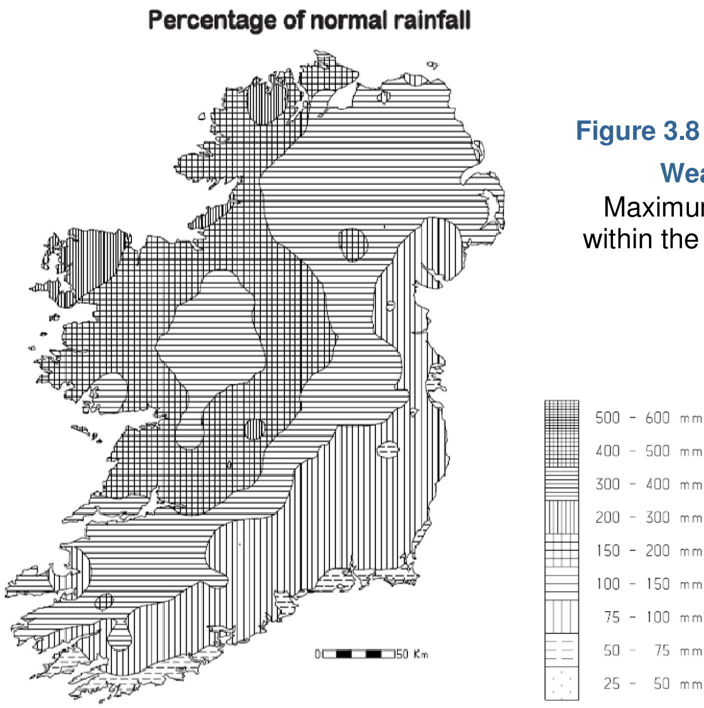

Figure 3.8 Extract from Met Eireann Monthly Weather Bulletin January 2005

Maximum Recorded Percentage Rainfall within the Dunkellin catchment ranged from 100% to 150%

The maximum level recorded on 10th January 2005 corresponded to a staff gauge reading of 2.85 m or a water level of 21.577mOD Malin Head. It has been estimated that this staff gauge reading represents a peak flow of 44m³/s.

Digital records, along with aerial photography for this flooding event, were documented by the OPW and the following photographs highlight some of the flooded lands, to the west of Craughwell, a number of days after the event has passed.

Photograph No. 20
January 2005 Event
Looking to the west of Craughwell towards the Rahasane Turlough on 12th Jan 2005

Note : the narrow channel width at foreground, due to tree and bush growth,

Photograph No. 21
January 2005 Event
Looking Upstream towards Craughwell from the Rahasane Turlough on 12th Jan 2005

The width of the flood at this location was approximately 375m

3.4.2 Flood Event in November 2009

A number of weather events occurred across Ireland, during the first three weeks of November 2009, which resulted in record rainfall and high water levels being recorded in many parts of Galway. The flooding which occurred at Craughwell, and downstream at Rinn Bridge, Dunkellin Bridge and Killeely Beg Bridge, was as a result of several days of persistent rain over the country which, when possibly combined with high winter water tables, resulted in water levels which exceeded those normally encountered in many rivers during the same period.

During November 2009, the weather station at NUI Galway recorded a monthly total of 329.4mm of rain, which represents 286% of the average November rainfall for the period 1961 to 1990. Leading up to this flooding a peak daily rainfall of 60.8mm was recorded at NUI Galway on the 17th November 2009.

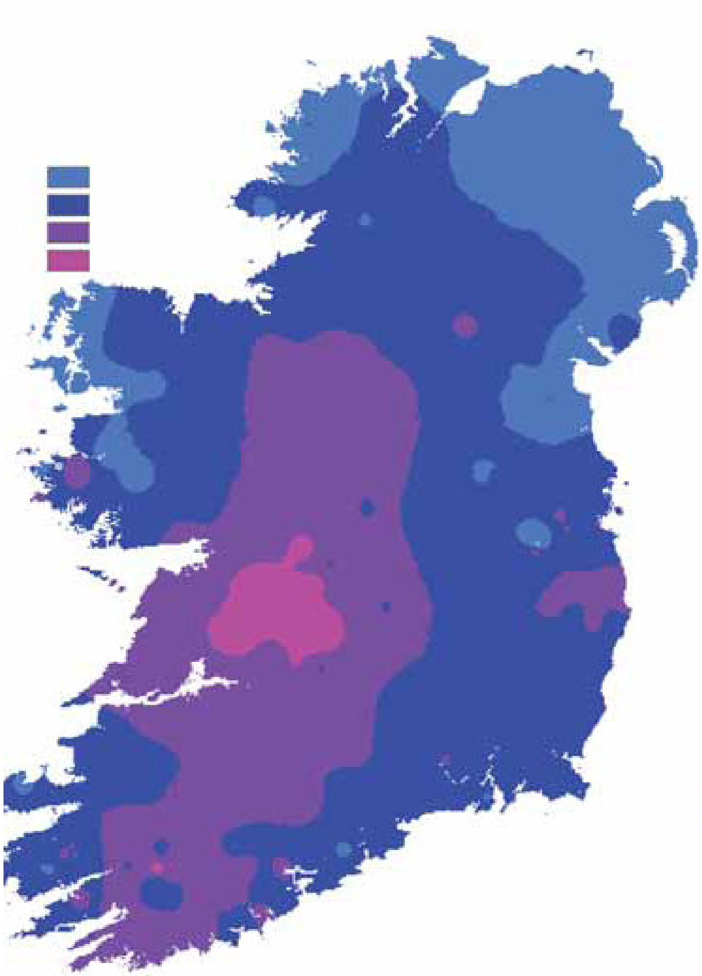

Figure 3.9 Extract from Met Eireann Monthly Weather Bulletin November 2009

During the period 17th to 24th November 2009, daily rainfall amounts on Wednesday 19th were recorded as 26.7mm and 29.4mm at the Shannon and Claremorris Weather Stations, respectively, but based on the rainfall data recorded at NUI Galway, it is clear that localised heavier rainfalls occurred in the Galway Area. This peak rainfall was followed by peak flood levels :

a. upstream of Craughwell village along the R349 (Loughrea to Athenry Road) at approximately midday on Thursday 20th November,
b. at the Craughwell River/N6 road crossing during Thursday afternoon (road closed in afternoon resulting in significant traffic disruption), and
c. downstream of Craughwell at Rahasane Turlough during Friday 21st November.

The following photography, taken by the OPW & Central Fisheries Board, during the period Thursday 20th to Saturday 22nd November 2009, shows the extent of flooding which occurred in late November 2009.

Photograph No. 22 Flooding in Craughwell at the Main N6 crossing on 20th Nov 2009

The extent of dwellings flooded, or at risk from flooding, in the village is evident .

Turbulent flow crossing the N6 is also evident in the lower left foreground where both the bypass (lower left) and main N6 bridge crossing (centre) were overtopped.

The N6 Road was closed for 4 days during this event.

Photograph No. 23 Rahasane Turlough downstream of Craughwell on 23rd Nov 2009

The Kilcolgan Road with ribbon development is visible in the upper portions of the photograph. This road was closed for 10 days during this event and 10 houses were flooded along this stretch of the Dunkellin River

Photograph No. 24
Flooding at Dunkellin Bridge on 23rd Nov 2009

View facing upstream with the Dunkellin Bridge in the centre of the image with a cluster of houses on each of the right and left banks

The Dunkellin Turlough is also visible in the background

Photograph No. 25
Flooding in townland of Killeely Beg on 23rd Nov 2009

The “canalised” Dunkellin River is a straight section of channel in this location. The channel breaks its banks and follows the natural contours of the adjacent lands and ultimately bypasses the Killeely Beg Bridge in the centre of the photo (surrounded by trees).

Note : extent of dwellings flooded, or at risk from flooding, in this location

Following a review of aerial photography of the November 2009 event and by establishing an account of local anecdotal evidence, the estimated flood plain during the November 2009 event can be established. This flood plain is shown in Figure 3.10.

Figure 3.10 – Estimated Flood Plains along the Dunkellin and Aggard Stream based on Photography of the Nov 09 Event and local anecdotal evidence

From the recorded hydrographs of the event (Appendix No. 3), aerial photography, measured wrack levels, direct observation from local residents and the estimated flood plain contained in Figure 3.10 it can be observed that:

1. Flooding upstream of Craughwell along the R349, (Athenry to Loughrea Road) north of Craughwell, occurred in advance of the flooding on the N6 within the village. However, any future proposals to prevent flooding in these locations, and their implications on increased surface water flows, have not been considered in this report.

2. The N6 road bridges (2 No. flat deck concrete structures and 1 No. old stone arched bridge) are significant hydraulic restrictions, as both the main bridge and the additional "bypass/overflow" were overtopped.

3. The railway bridge (Photograph No. 5), with a smaller effective cross sectional area, is also a significant restriction and an influencing factor on the upstream flooding within Craughwell.

4. The main channel downstream of the railway bridge, and upstream of the Aggard/Dunkellin confluence, despite its steep bed gradient is also causing a restriction on flow (narrow flood plain with dense tree growth evident in Photograph No. 20).

5. The channel exiting the Rahasane Turlough cSAC and the Rinn Bridge have insufficient capacity to cater for this event.

6. The Dunkellin Bridge and Killeely Beg Bridge (Photographs 24 & 25), and the channel upstream and downstream of these structures, also have insufficient capacity to cater for this event.

These observations, further analysis of the recorded river flow data, possible flood alleviation measures, and the mathematical modelling of these measures are discussed later in this report.

The following aerial photography details a number of locations where dwellings and commercial properties were flooded during the November 2009 event.

Photograph No. 26 Craughwell Village

Three dwellings were flooded in Craughwell, located in the centre of the photo and to the left of the N6 roadway. The N6 was also closed for 4 days during this event.

Two commercial properties were also flooded including the underground car park of the new development in the top left hand portion of the image.

Whilst the dwelling on the right of the photo was not flooded the surrounding gardens were inundated with flood waters.

Photograph No. 27 Rahasane Turlough

A total of 12 dwellings were flooded at a number of locations along the northern shores of the Rahasane Turlough.

Whilst this image was taken after the flood had subsided, the threat to the Kilcolgan road is evident in this image.

Photograph No. 28 Killeely Beg Townland

A total of five dwellings were threatened by flood waters in the townland of Killeely Beg when the Dunkellin River broke its left bank and travelled along what appears to be the natural contour of an old channel.

3.5 HISTORICAL FLOWS REGIMES, PREVIOUS STUDIES & PROPOSED ARTERIAL DRAINAGE DESIGNS

3.5.1 Historical Flow Regimes and Previous Studies

Numerous studies have been undertaken along this particular stretch of the Dunkellin River, from Craughwell to Kilcolgan, particularly within the confines of the Rahasane Turlough cSAC, which primarily relate to the ecology of the designated site.

Additionally, a number of papers have been prepared with regard to the geology, ground water movement and the surface drainage systems in the area.

One of these papers, *Ground Water and Karstification in Mid-Galway, South Mayo and North Clare (Drew & Daly, 1993)* pays particular regard to the hydrogeology of the East Galway Bay Area which includes two main river systems, namely; the Lavally (Clarin) and Dunkellin Rivers.

With regard to the Dunkellin River Drew & Daly (1993) noted that :

"the Dunkellin River originally sank in the large Rahasane Turlough west of Craughwell, the waters reappearing, in all but the lowest stage conditions, at two further turloughs between Rahasane and Galway Bay".

With specific regard to the historic Arterial Drainage Scheme, implemented in the 1850's Drew & Daly (1993) also noted that :

"Extensive arterial drainage undertaken in the Dunkellin basin has had the effect of increasing the volume and rate of surface water runoff, decreasing the recharge of groundwater by approximately 93Mm^3/year and also lowering of the summer water table by 1 to 2m"

"For 75% of the year on average, inflows to the turlough exceed outflows (by up to 15m^3/s). For the remainder of the year, outflows exceed inflows by up to 7m^3/s – this when ground water levels are close to the level of the turlough floor.

Drew (1986) in a separate document entitled, *Dunkellin/Lavally Catchments Ground Water Investigation – Report to the Office of Public Works,* and following detailed investigation between 1982 and 1986, noted that :

"The effects of the nineteenth century arterial drainage appear …. to have little influence on winter flooding of the 3 Dunkellin Turloughs".

"There are a series of springs close to the Dunkellin – Raford channel, that become operative during high water conditions……..It is not possible to measure the combined flow from the springs but it is estimated at 3 to 6 cumecs".

Drew (1986) also analysed the nature of the aquifer recharge following two particular rainfall events in 1984 and noted as follows.

Event 1 (29th July to 6th August 1984). 27mm of Rain occurred over 10 hours when the Rahasane Turlough was dry and all rivers were sinking.

While flow upstream of the turlough increased tenfold (x10) the event did not result in an outflow from the turlough but did show ground water response and aquifer recharge.

Event 2 (27th August to 10th September 1984). 42mm of Rain occurred over 11 hours when all turloughs were dry and all rivers were sinking.

During this event the Rahasane Turlough filled to winter levels within 24 hours and while ground water responded within 5 to 10 hours the ground water levels did not "quite" reach the level of the Rahasane Turlough floor.

3.5.2 Formerly Proposed Arterial Drainage Schemes

Following on from Arterial Drainage Works completed, along the Dunkellin River, in the mid 1850's and later in the early 1920's, the Office of Public Works prepared an Arterial Drainage Design for the Dunkellin/Lavally Catchments in the mid 1900's (circa 1950). This Arterial Drainage Scheme, as detailed on the original design drawings, included for alterations to the channel widths, channel regrading (bed level) and deepening of a number of the bridges/structures.

In March 2000, the Office of Public Works also commissioned a Design Review Report of the Aggard Stream (Cregaclare) Certified Drainage Scheme and following on from the publishing of this report, an EIS was also prepared. This Certified Drainage Scheme recommended three (3) main bodies of work along the Monksfield River, Aggard Stream and Cregaclare Channel. The proposed works included channel clearance (maintenance) for the lower 3750m of the Aggard Stream, regrading of 3,550m of the central reaches of the channel (Monksfield River) and further channel clearance of the Cregaclare Channel.

These Arterial Drainage Schemes have not been implemented.

4 FLOOD FREQUENCY ANALYSIS

4.1 HYDROMETRIC STATIONS AND DATA USED IN THIS STUDY

A significant amount of Hydrometric Data was received from the OPW for several hydrometric gauges within the study area. Figure 4.1 shows the location of the OPW hydrometric stations used in this study.

The OPW Hydrometric Section based in Headford, County Galway has provided data for five hydrometric stations, namely Rathgorgin 29001, Rahasane Turlough 29002, Craughwell 29007, Aggard Bridge 29010 and Kilcolgan 29011.

The data consists of:

- Annual maximum series of recorded water levels and estimated flows for the Data Logger Stations, on the Dunkellin Catchment listed above, for the period of records dating from the commissioning of the hydrometric station to January 2010.

- Instantaneous 15 minute water level and flow data for the flood period 01/11/2009 to 15/01/2010 for each hydrometric station listed above, with the exception of Rahasane Turlough Station where the data logger was inundated during the November 2009 flooding event resulting in no data being available beyond 07:30hrs on the 19/11/09.

- Station rating equations and rating periods

The Environmental Protection Agency, Hydrometric Office, Castlebar has also provided data of measured flow for the November 2009 flooding event at Craughwell Station 29007, where measurements were carried out on the 21/11/2009 one day after the peak of that flood event.

Daily Tidal Gauge Data from Galway Port for November 2009 was also received from the Marine Institute, Galway.

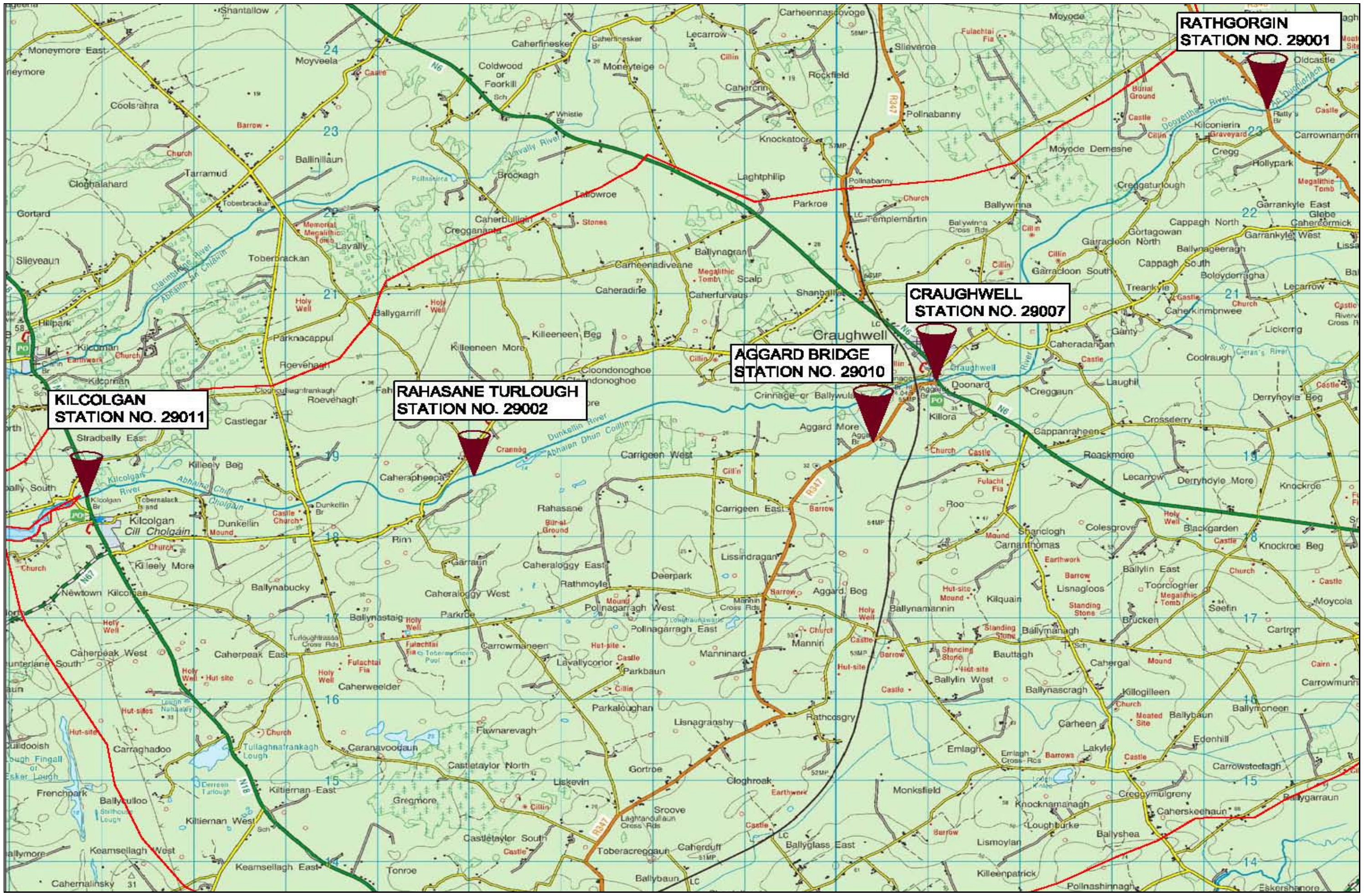

Figure 4.1 – Location of Hydrometric Stations in Dunkellin Catchment

4.2 METHODOLOGY

As extensive and continuous hydrometric records are being maintained in this section of the Dunkellin Catchment, a statistical analysis of the recorded data is used in estimating the design Annual Exceedance Probability (AEP) flow. This method will also incorporate any hydrogeological influences that may have affected flooding in the Dunkellin Catchment.

Frequency analysis calculations for hydrometric stations, Rathgorgin 29001, Rahasane Turlough 29002, Craughwell 29007, Aggard Bridge 29010 and Kilcolgan 29011, have been carried out using the Extreme Value Type 1 (EV1) Distribution Method and the EV1 (Gumbel) Method of Moments.

A theoretical assessment based on catchment characteristics, as described in the Flood Studies Report, will not be considered as part of our assessment since results from such methods are statistically equivalent to calculations carried out on less than 3 years of recorded flow data. However, a Flood Index Method was used as a check to verify the results of the EV1 (Gumbel) methods. The Flood Index Method applies the national growth curve factor to the derived index flood estimate (QBAR) from the annual maximum flow series data for each of the hydrometric stations.

A comparison between the estimated flow that occurred in November 2009 and the predicted 1% AEP flow will be carried out at each hydrometric station.

For the purpose of this hydrological report, data from five hydrometric stations operated and managed by the OPW will be examined. A summary of the stations statistical data based on the EPA Register of Hydrometric Stations in Ireland 2007, the OPW hydro-data website and the EPA Hydrological Data report entitled ‘A listing of water level recorders and summary statistics at selected gauging stations’ published in 1995, is given in Table 3.1.

The annual maximum data series for the hydrometric stations detailed in Table 4.1, are contained in Appendix 3.

Table 4.1 – Summary of the statistical data of each Gauging Station within the Study Area

Station Statistics Data	Rathgorgin Station	Craughwell Station	Aggard Bridge Station	Rahasane Turlough Station	Kilcolgan Station
Station Number	29001	29007	29010	29002	29011
Station Type	Autographic Level Recorder Velocity Area Station with natural control.	Autographic Level Recorder Velocity Area Station with natural control.	Autographic Level Recorder Velocity Area Station with natural control.	Autographic Level Recorder Velocity Area Station with natural control.	Autographic Level Recorder Gauge affected by tidal levels
River Name	Rathford	Dunkellin	Aggard	Dunkellin	Dunkellin
Location	Ratty's Bridge	N6 Craughwell Bridge	Aggard Bridge on the R347	Dunkellin River	N18 Kilcolgan Bridge
NGR	M 546 232	M 510 199	M 504 191	M 460 187	M 418 185
Catchment Area to Station	119km²	278km²	45km²	357km²	373km²
Approx. u/s dist. of AR Station to River outlet at Galway Bay	16.3km	10.3km	475m upstream from the confluence with the Dunkellin River	4.7km	140m
Period of Continuous Hydrometric Records	1957 to 2010	1983 to 2010	1983 to 2010	1971 to 2010	1983 to 2010

Table 4.1 continued – Summary of the statistical data of each Gauging Station within the Study Area

Station Statistics Data	Rathgorgin Station	Craughwell Station	Aggard Bridge Station	Rahasane Turlough Station	Kilcolgan Station
Rating Curve Equation, **where** **Q = flow (m^3/s)** **x = stage (m)**	$Q= 4.1*(x + 0.2)^{1.544}$ Equation No. 1	$Q= 10*(x -0.27)^{1.55}$ Equation No. 2	$Q= 5.2*(x -0.1)^{2.52}$ Equation No. 3	$Q= 3.2*(x -0.505)^{2.1}$ Equation No. 4	$Q= 13*(x -0.06)^{1.96}$ Equation No. 5
Rating Curve Upper Limit	13.0 m^3/s	55.0 m^3/s	2.4 m^3/s	39.0 m^3/s	46.7 m^3/s
Stability and Quality of Rating Curve **(As quoted in EPA Hydrological Data report)**	Stable control. Very good rating over entire flow range.	Stable control. Very good rating over entire flow range.	Unstable control due to severe weed growth. Unreliable ratings.	Pre'92 very good ratings over the entire flow range. Station still being rated post 1992 following dredging of the river.	
Station comments / notes **(As quoted from OPW hydro website)**	Poor quality low and flood flow data – to be used for indicative purposes only.	Poor quality low and flood flow data – to be used for indicative purposes only.	Poor quality low and flood flow data – to be used for indicative purposes only.	Low flow ratings truncated.	Poor quality low and flood flow data – to be used for indicative purposes only.

4.3 STATISTICAL METHODS

4.3.1 Extreme Value Distribution Type 1

The Extreme Value Distribution Type1 (EV1) method was selected as an appropriate statistical analysis for the data set presented by the OPW at Hydrometric Stations, Rathgorgin 29001, Rahasane Turlough 29002, Craughwell 29007, Aggard Bridge 29010 and Kilcolgan 29011. EV1 analysis is carried out on annual maximum discharge values where events are assumed to be independent and identically distributed.

The annual maximum flow for each of the above hydrometric stations is presented in Appendix 3.

The reduced variant for each station was calculated and the plotting positions determined by the application of the Gringorten formula. The frequency growth factor for each given return period was calculated using the EV1 reduced variant equation. The estimated flow for each return period was calculated by applying the generated trendline equation for each hydrometric station based on the Annual Maximum Flow Probability Plot.

4.3.2 Extreme Value Distribution Type 1 (Gumbel)- Method of Moments

The EV1 Gumbel Method of Moments is used in flood estimation to obtain the magnitude of a given return period. The method of moments estimators of the Gumbel maximum distribution are:

$$\alpha = 0.7797\, s \qquad \text{Eqn No. 6}$$

$$u = \mu - 0.5772\, \alpha \qquad \text{Eqn No. 7}$$

Where, α is the scale parameter, s is the standard deviation, μ is the sample mean of the annual maxima series and u is the location parameter.

The Hyfran (Hydrological Frequency Analysis) computer programme was used in calculating Gumbel's Method of Moments for hydrometric stations, Rathgorgin 29001, Rahasane Turlough 29002, Craughwell 29007, Aggard Bridge 29010 and Kilcolgan 29011. The results from the analysis presents estimated Moment Design Flows with an upper and lower 95% confidence interval.

4.3.3 Index Flood Method

The index flood method was applied to all hydrometric stations to check estimated return period flow against the EV1 Distribution Method and the EV1 Method of Moments. For this method the mean flow or QBAR was not estimated by applying Catchment characteristics but rather by using the annual maximum flow series at each of the hydrometric stations. The Flood Studies Report calculates the flood discharge for any given return period by applying national growth factor coefficients to the mean flow for a range of return periods. The Irish national growth factor curve provides an alternative estimate for the frequency return period flow based on pooled data derived from a large quantity of catchments.

4.3.4 Results of the Statistical Analysis

The estimated flows for a given return period using statistical analysis at hydrometric stations Rathgorgin 29001, Craughwell 29007, Aggard 29010, Rahasane Turlough 29002 and Kilcolgan 29011 are presented in Table 4.2 and in graphical format in Figures 4.2 to 4.6 inclusive and discussed in detail in Section 4.4 of this report.

Based on the gauged data analysis contained in Table 4.2 and Figures 4.2 to 4.6, recommended 100 year and 200 year designs flows, for each hydrometric station, have been estimated and these are presented in Table 4.3.

Table 4.2: Estimated Flow at each Station for a given return period

Return Period	Rathgorgin 29001			Craughwell 29007			Aggard Stream 29010			Rahasane Turlough 29002			Kilcolgan 29011		
	EV1[1] m³/s	EV1 Gumbel MOM[2] m³/s	Flood Index Method m³/s	EV1 m³/s	EV1 Gumbel MOM m³/s	Flood Index Method m³/s	EV1 m³/s	EV1 Gumbel MOM m³/s	Flood Index Method m³/s	EV1 m³/s	EV1 Gumbel MOM m³/s	Flood Index Method m³/s	EV1 m³/s	EV1 Gumbel MOM m³/s	Flood Index Method m³/s
200	26.27	26.00	31.39	64.71	64.90	63.11	19.53	20.00	13.32	74.29	73.8	62.84	71.22	73.5	67.56
100	24.57	24.40	28.75	59.54	59.70	57.80	17.58	18.00	12.20	67.68	67.2	57.56	65.39	67.3	61.88
50	22.85	22.70	25.97	54.34	54.40	52.20	15.61	16.00	11.02	61.05	60.6	51.98	59.54	61.1	55.88
25	21.13	20.40	23.47	49.11	49.10	47.19	13.64	13.90	9.96	54.37	54	46.98	53.65	54.9	50.51
10	18.80	18.70	20.10	42.06	42.00	40.40	10.97	11.10	8.53	45.36	45.1	40.23	45.71	46.4	43.25
5	16.96	16.90	17.60	36.47	36.40	35.39	8.86	8.93	7.47	38.24	38	35.24	39.43	39.8	37.88
2	14.1	14.20	13.94	28.04	27.90	28.02	5.67	5.61	5.91	27.47	27.4	27.90	29.94	29.7	29.99

[1]EV1 = Extreme Value Type 1 Distribution Method

[2]EV1 (Gumbel) MOM = Extreme Value Type 1 Method of Moments

Table 4.3: Recommended Design Flood Flow for 100year and 200year return periods

	Rathgorgin 29001	Craughwell 29007	Aggard Stream 29010	Rahasane Turlough 29002	Kilcolgan 29011
	EV1	EV1 Gumbel Method Of Moments	EV1 Gumbel Method Of Moments	EV1	From Rahasane Turlough Station
100 Year Return Period	24.57m³/s	59.70m³/s	18.00m³/s	67.68m³/s	67.68m³/s
200 Year Return Period	26.27m³/s	64.90m³/s	20.00m³/s	74.29m³/s	74.29m³/s

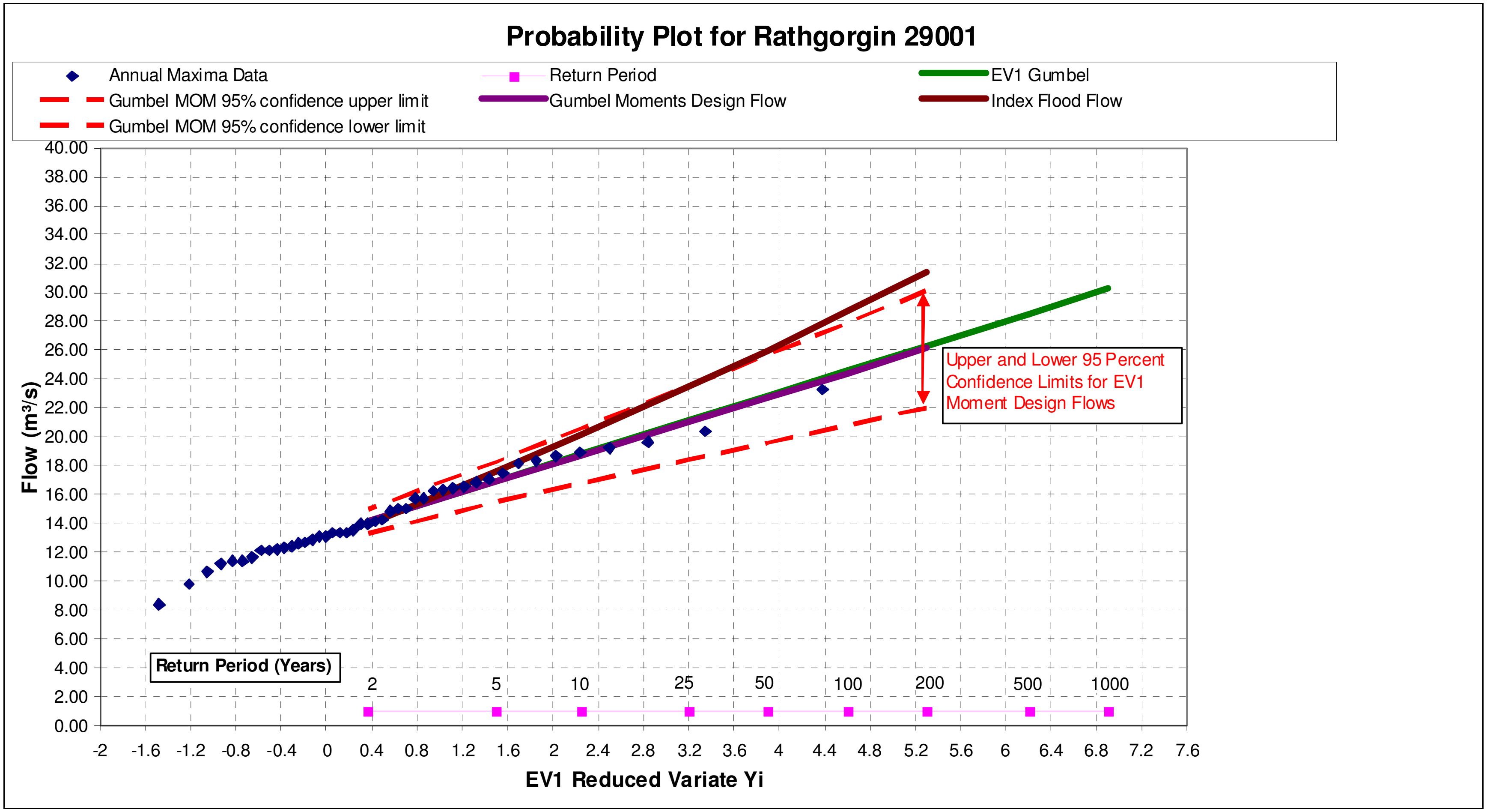

Figure 4.2 – Frequency Analysis Probability Plot

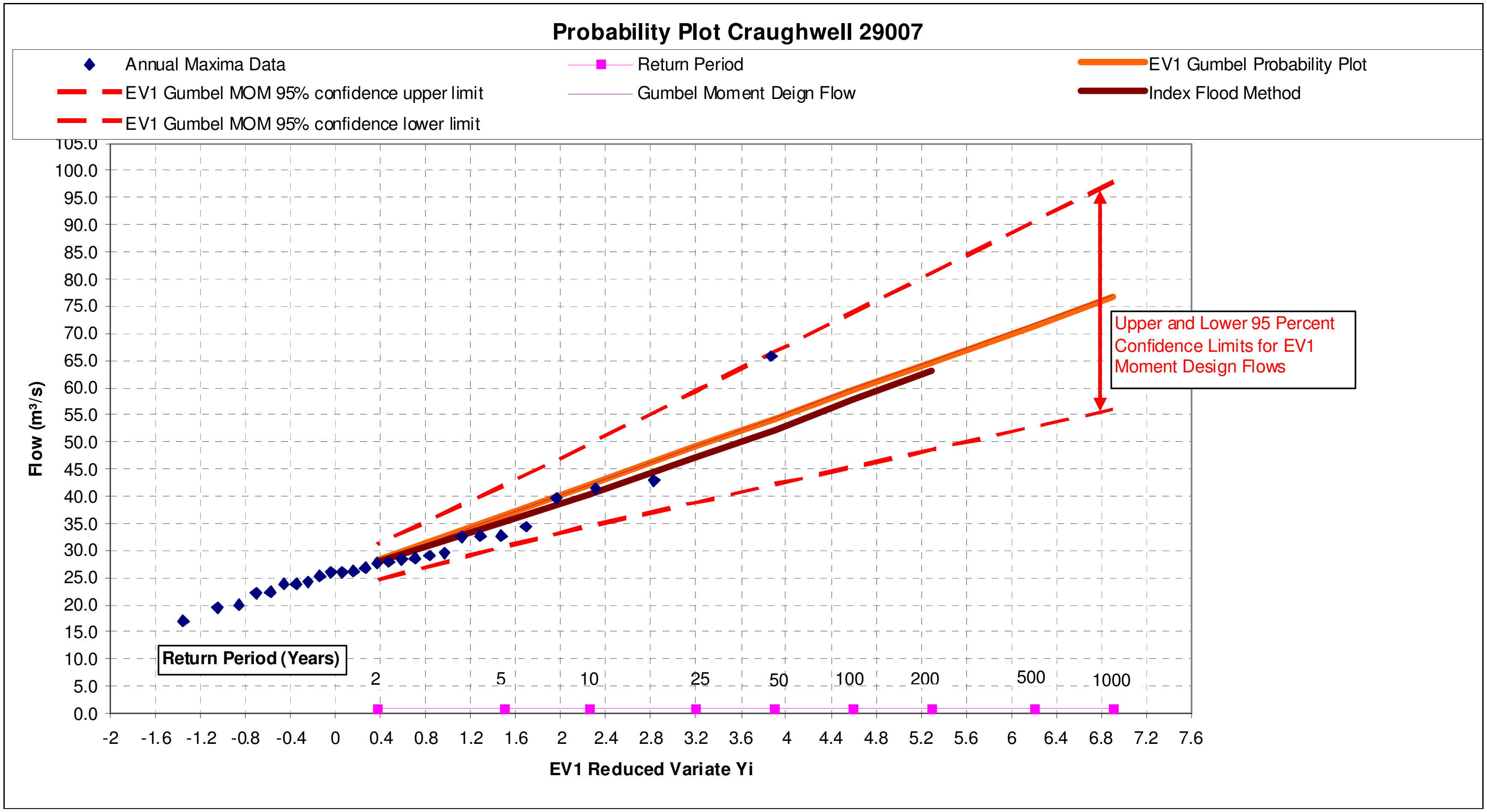

Figure 4.3 – Frequency Analysis Probability Plot

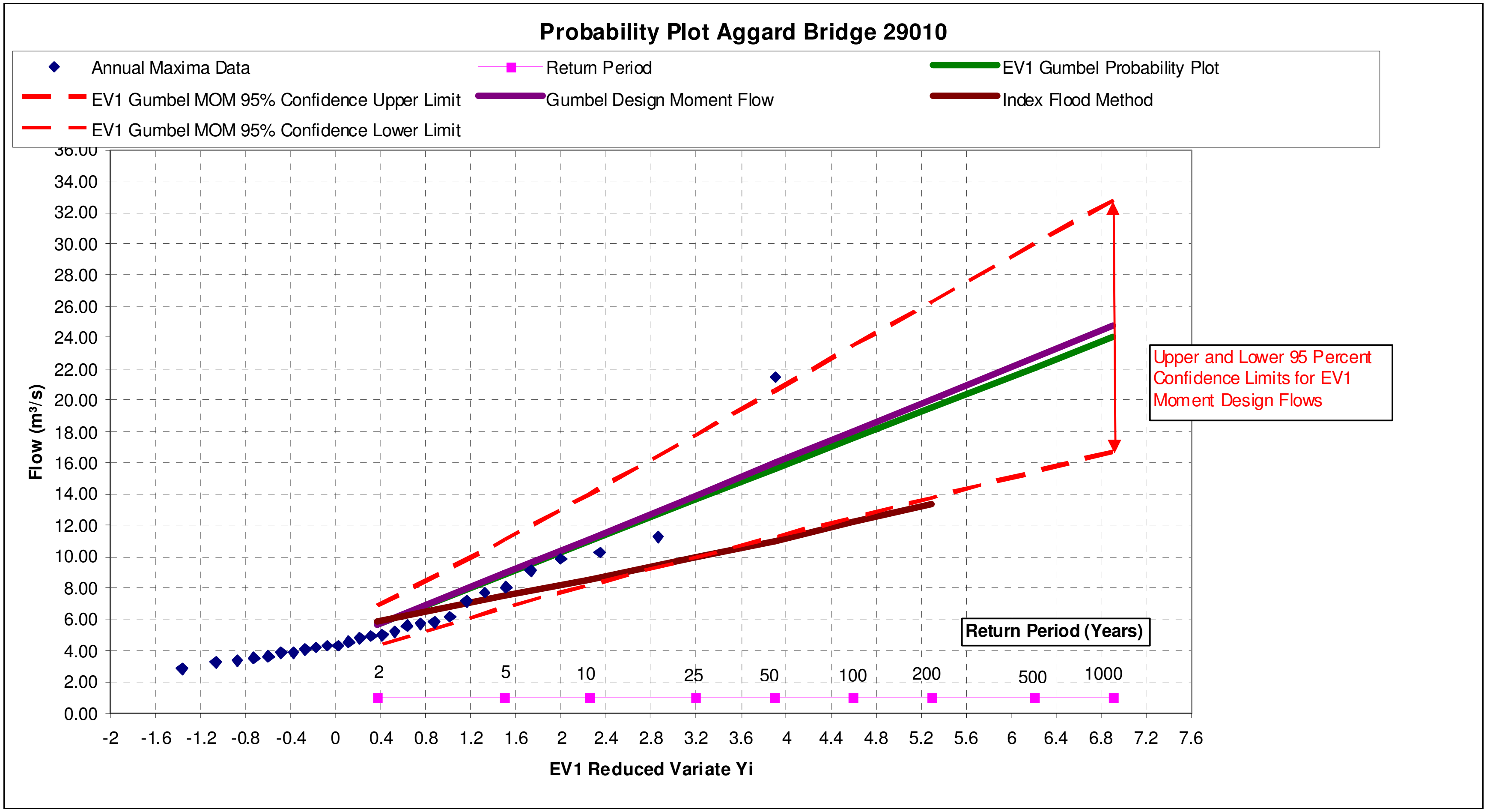

Figure 4.4 – Frequency Analysis Probability Plot

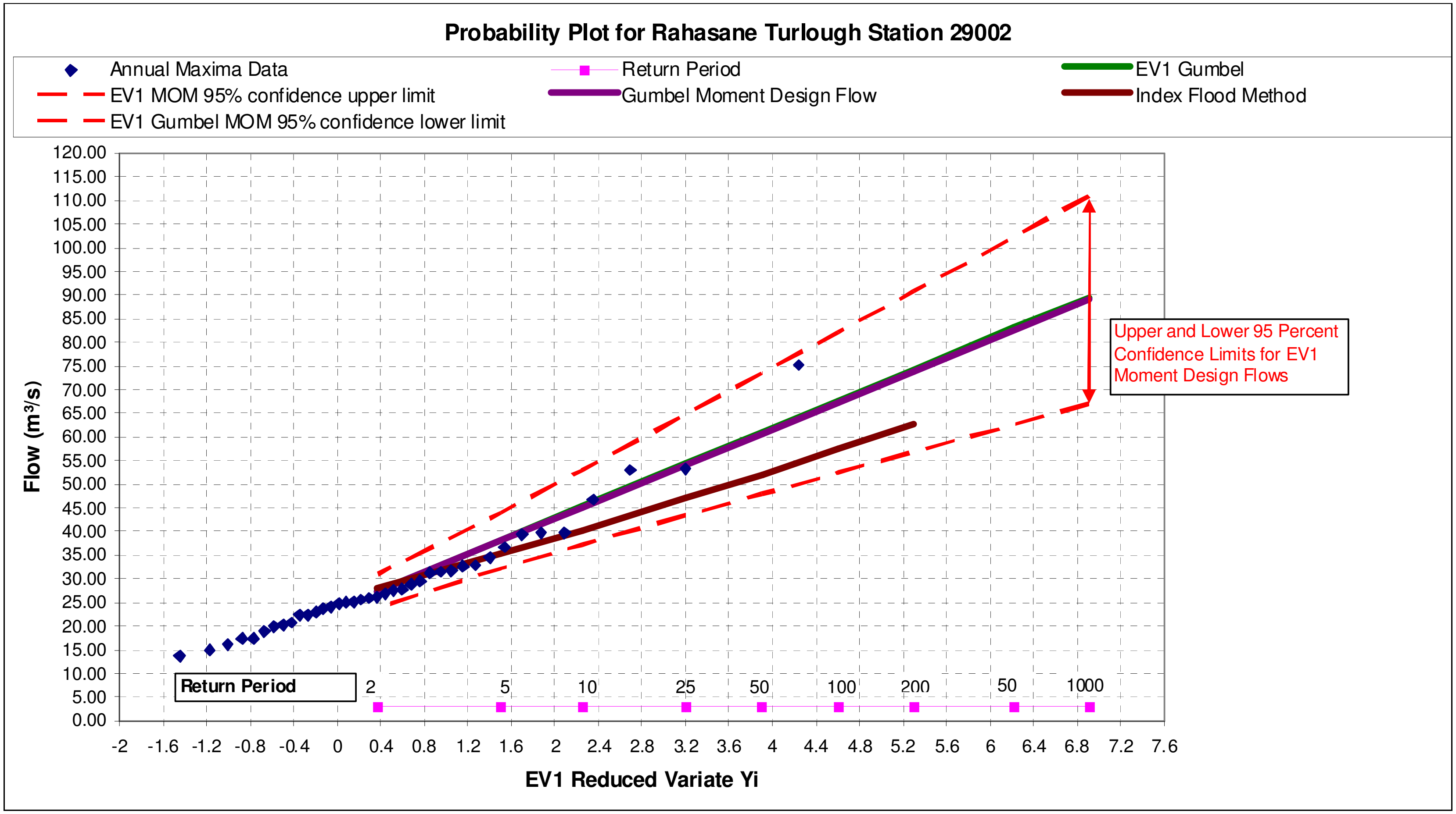

Figure 4.5 – Frequency Analysis Probability Plot

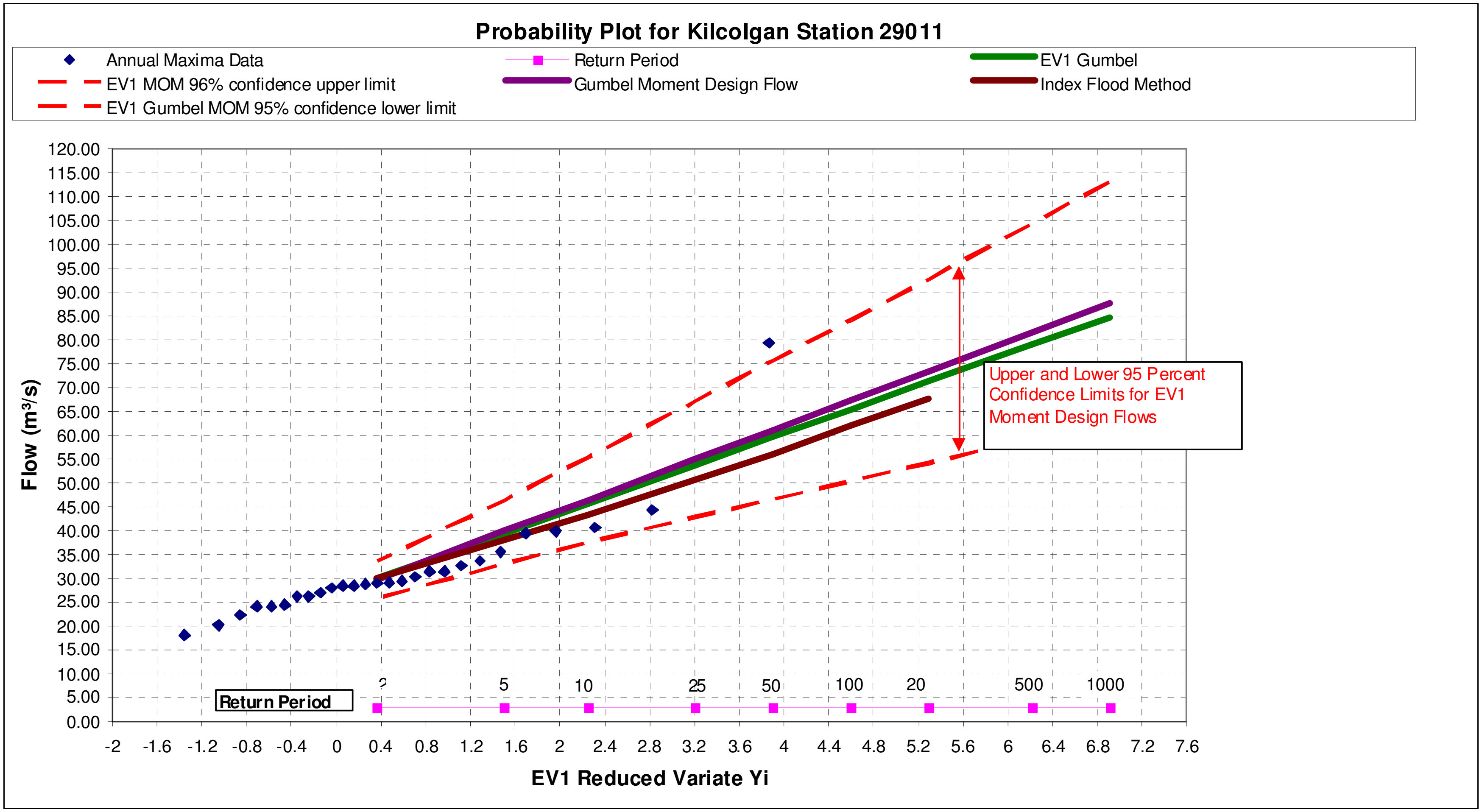

Figure 4.6 – Frequency Analysis Probability Plot

4.3.5 Discussion of Statistical Results at each Hydrometric Station

4.3.5.1 Rathgorgin Gauging Station 29001

The statistical probability plot for the Rathgorgin Station (Station No. 29001) is presented in Figure 4.2. From Figure 4.2 it can be seen that there is negligible difference between the trendlines of the Gumbel Moments Method (and the EV1 Distribution Type Method. The November 2009 flooding event does not appear as an outlier at this station and this is reflected in our estimation of the return period for the 2009 flooding event of 1 in 59 years.

Based on the location of the Rathgorgin Station 29001, it is unlikely that backwater effects impact the recorded flows as the nearest hydraulic structure (the road bridge at Caherdangan) is located approximately 4.6km downstream of the station.

The EV1 and Gumbels Moment Design flow trendlines generated appear to best fit the data spread. From looking at the positioning of the AM data spread and the Flood Index method growth curve, the Flood Index method overestimates the Q100 flood.

The Q100 flow value can reasonably be expected to lie within the confidence interval 95% confidence limits of the Gumbel Moments Design Flow.

The Q100 value at the Rathgorgin Station 29001 as adopted for the purpose of this report is 24.57 m^3/s.

4.3.5.2 Craughwell Gauging Station 29007

The AM plotting positions for the Craughwell Station are presented in Figure 4.3 where it can be seen that the November 2009 flooding event has an unusually high value compared to the previous maximum flow values.

EPA hydrometric officers noted that, during the 21st November 2009, the bridge at Craughwell acted as a hydraulic constraint on the Dunkellin River with water levels on the upstream face of the bridge being higher than water level on the downstream face.

However, the OPW data logger station at the Craughwell Station (Station No. 29007) is located on the downstream face of Craughwell Bridge and therefore it can be assumed that recorded water levels were not affected by a backwatering effect.

We have estimated the return period for the November 2009 flooding event at this station as 1 in 224 years.

The outlier value of the 2009 flooding event has been incorporated into the statistical analysis calculations and this has had the effect of increasing the predicted return period flow estimates over and above the values expected if this outlier value was not included.

The Gumbel Moments method and the EV1 Distribution Type trendlines plots are almost identical, while the Index Flood method appears to slightly underestimate the predicted return period flow.

The Q100 value for the Craughwell Station (Station No. 2007) adopted for the purpose of this report is 59.70 m^3/s.

4.3.5.3 Aggard Stream Gauging Station 29010

The Aggard Stream Station (Station No. 29010) is located on the Aggard Stream which forms one of the largest tributaries to join the Dunkellin River downstream of Craughwell Village. This is the only OPW station located within the study area that is not located on the Dunkellin River.

The AM plotting positions for the Aggard Steam Station (29010), as presented in Figure 4.4, show the November 2009 flooding event as having an extremely high flow when compared to the maximum flow values recorded in other years.

Considering the location of the Aggard Stream Station (29010) and confluence of the Dunkellin River and Aggard Stream, (i.e., approximately 475 meters upstream of the confluence), it is possible that this station was effected by backwatering, which may have contributed to the elevated flood water levels recorded during the November 2009 flooding event.

The return period of the November 2009 flooding event at this station has been estimated to be a 1 in 324 year flooding event.

The 2009 AM value has been included in our statistical analysis, but as can be seen from Figure 4.4, the inclusion of this value has resulted in an upward shift of the trendline position for the EV1 and Gumbel methods. The Index Flood Method does not appear as a good fit to the data set for this station.

The Q100 value for the Aggard Stream Station (Station No. 29010) adopted for the purpose of this report is 18.00 m^3/s.

4.3.5.4 Rahasane Turlough Gauging Station 29002

The Rahasane Turlough Station (Station No. 29002) is located along the canalised Dunkellin River just downstream of Rahasane Turlough and upstream of the Rinn Bridge. The November 2009 flooding event appears as an outlier at this station and this is reflected in our estimation of the return period for this flooding event of 1 in 220 years.

All three flood estimation methods plot within the 95% confidence limits with the EV1 method producing the most conservative estimate for the 100 year return flow of 67.68m^3/s.

4.3.5.5 Kilcolgan Gauging Station 29011

The Kilcolgan Station (Station No. 29001) is the last hydrometric station located on the Dunkellin River prior to it discharging into Galway Bay. Tidal levels affect the lower reaches of the Dunkellin River particularly on the river reach downstream from Dunkellin Bridge to Kilcolgan. In providing the annual maxima series at Kilcolgan Station the OPW has removed tidal component and hence all estimated flows provided are based on the fluvial flood peaks alone. It is worth noting at this station that water levels provided by the OPW are frequently exceeded, particularly if high tide levels occur instantaneously with peak fluvial levels.

By comparing the statistical calculations for the Kilcolgan Station (29001) in Figure 4.6 and Rahasane Turlough Station (29002) in Figure 4.5, it can be seen that that the flow estimates for the predicted 100 year return flood flow at Kilcolgan is slightly less than that of Rahasane Turlough.

It is unlikely that there would be a reduction in flood flow between the two stations however it is possible that the flow may be restrained to some extent by the bridge structures located between these two hydrometric stations. It is more likely that the annual maximum flow estimates for the Kilcolgan station may be underestimated due to the tidal component of the flow being removed.

For this report we are taking the conservative approach of assuming that the 100 year and 200 year predicted flow estimates for the Kilcolgan Station will be equal to that of Rahasane Turlough Station.

The flow estimates for the 100 year and 200 year return periods for Kilcolgan Station are 67.68m^3/s and 74.68m^3/s respectively.

It is also worth noting that by comparing the hydrograph from the Kilcolgan Station (29001) with the tidal hydrograph during November 2009, as contained in Appendix 3 of this report, the peak flood on the Dunkellin River did not coincide with the high tide level.

Similar to the previous upstream hydrometric stations, located on the Dunkellin River, the November 2009 flooding event appears unusually high when examining the AM data spread for the Kilcolgan Station (29001).

The estimated return period for the November 2009 flooding event at this station is 1 in 341 year.

4.4 ESTIMATED RETURN PERIOD FOR THE NOVEMBER 2009 EVENT

The OPW have estimated the November 2009 flood flow at the Rathgorgin 29001, Craughwell 29007, Aggard 29010, Rahasane Turlough 29002 and Kilcolgan 29011 hydrometric stations by examining the rating curve equation for each station.

In an email sent by the OPW hydrometric section to Tobin Consulting Engineers on the 19/03/10 it was noted that the largest measured flow and corresponding water level recorded by OPW hydrometric staff at each hydrometric station was exceeded by the November 2009 flooding event.

The various flow estimates for the November 2009 event have been derived by extrapolating the Rating Curve Equation and this method of estimation should be treated with caution as it may result in the possible underestimation of the flood flow.

By comparing the November 2009 estimated flood flow at each hydrometric station with the statistical flow estimates, a return period corresponding to the November 2009 flooding event is estimated and these results are presented in Table 4.4.

Table 4.4: Estimated Return Period of the November 2009 flooding event at OPW Hydrometric Stations

	Rathgorgin 29001	Craughwell 29007	Rahasane Turlough 29002	Kilcolgan 29011	Aggard Stream 29010
Maximum Recorded Water Level (mOD Malin)*	31.78m	22.31m	18.08m	3.70m	19.84m
Estimated Flow	23.25 m^3/s	65.74 m^3/s	75.14 m^3/s	79.37 m^3/s	21.46 m^3/s
Estimated Return Period	1 in 59 year	1 in 224	1 in 220 year	1 in 341 year	1 in 324 year

*Conversion from Poolbeg to Malin Head Datum carried out by applying conversion factor of 2.73m

4.5 CLIMATE CHANGE & FUTURE FLOW SCENARIOS

Allowances for future changes in design input data have also been reviewed as part of the data collection for this project.

The document entitled *"Assessment of Potential Future Scenarios for Flood Risk Management"* and published by the OPW in August 2009 has been reviewed.

This document states that :

"To provide an adequate understanding of the potential implications of the predicted impacts of climate change and other future changes, with due consideration of the significant uncertainty associated with such predictions, the OPW recommends that a minimum of two potential future scenarios are considered."

The two minimum scenarios are referred to as the :

"Mid-Range Future Scenario (MRFS) which it is intended to represent a 'likely' future scenario, based on the wide range of predictions available and with the allowances for increased flow, sea level rise, etc. within the bounds of widely accepted projections."

And

"High-End Future Scenario (HEFS), is intended to represent a more extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictions available, and with the allowances for increased flow, sea level rise, etc. at the upper the bounds of widely accepted projections."

The allowances, in terms of numerical values, for future changes which should typically be used for each of these scenarios, are set out in Table 4.5.

Table 4.5 Allowances for Future Scenarios (100 year time horizon)

	Mid-Range Future Scenario MRFS	High-End Future Scenario HEFS
Extreme Rainfall Depths	+ 20%	+ 30%
Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500 mm	+ 1000 mm

In developing the ISIS model for the study area, the Mid Range Future Scenario (MRFS) has been adopted to establish the possible impact that the increases may have on the recommended flood alleviation measures.

The estimated 100 year return flow at each gauging station, the allowance for future scenarios and the November 2009 event are summarised in Table 4.6.

Table 4.4: Estimated Return Period of the November 2009 flooding event at OPW Hydrometric Stations

	Rathgorgin 29001	Craughwell 29007	Rahasane Turlough 29002	Kilcolgan 29011	Aggard Stream 29010
Estimated 100yr Return Flow from Table 4.3	24.57m³/s	59.70m³/s	67.68m³/s	67.68m³/s	18.00m³/s
Allowance for Mid-Range Future Scenario	4.91 m³/s	11.94 m³/s	13.58 m³/s	13.58 m³/s	3.6 m³/s
Estimated Future Scenario	**29.48m³/s**	**71.64m³/s**	**81.46m³/s**	**81.46m³/s**	**21.6m³/s**
Peak Flow November 2009 Event (Table 4.4)	23.25 m³/s	65.74 m³/s	75.14 m³/s	79.37 m³/s	21.46 m³/s

5 DEVELOPMENT OF THE HYDRAULIC MODEL

The Dunkellin River was modelled to investigate the effects of channel improvements on water levels for extreme flood events. This was investigated following the flood event of November 2009.

The channel improvements take the form of two Strategic Schemes, with the most effective elements of each scheme being taken forward for detailed analysis under the Preferred Scheme. Full details of the two Strategic Schemes and the Preferred Scheme are provided in detail in Section 6.0 of this report.

5.1 MODEL BUILD

The modelling software used for the purposes of this study is ISIS v3, a 1 dimensional (1D) hydraulic model. The model is based on cross-sections of the water course, surveyed as part of this study and supplemented with additional cross sectional information from the original OPW Arterial Design which was completed in the mid 1950s. All of the topographical information, particularly level information, is based on the Malin Head datum. The extent of the survey cross sections used in the hydraulic model were determined by analysing the November 2009 flood event and selecting critical locations where flood level information was available from automatic gauging stations and anecdotal evidence from local representatives.

The modelled reach of the Dunkellin River is approximately 10.8km long, and starts approximately 780m upstream of the Main N6 bridge Crossing in Craughwell.

The modelled reach starts with an elevation of approximately 24 m.OD Malin, in Craughwell and ends with an elevation of 0.8 m.OD Malin, in Kilcolgan.

The downstream extent of the model is approximately 125m downstream from the N18 Bridge Crossing at Kilcolgan and this downstream boundary is in a tidal reach. However variable tidal inputs have not been considered in the development of the model. The downstream boundary used in the hydraulic model is a normal depth boundary.

Model parameters for the base model are summarised in Table 5.1 and a schematic of the base model is shown in Figure 5.1.

Table 5.1 Summary of base model parameters.

Dunkellin Base Model Summary 1D model element (ISIS)		
Total Modelled Length		10,856m
Upstream Boundary	**Location**	Approximately 780m upstream from N6 bridge (551778,719995)
	Type	ReFH boundary unit
Downstream Boundary	**Location**	Approximately 125m downstream from N18 Road bridge at Kilcogin (541546,718439)
	Type	Normal depth boundary unit
Model Units	**Channel sections**	71
	Bridge units	9
	Spill units	10
	Weir units	1
	Interpolates	72
	Junction units	22
Roughness values (Manning's '*n*')		0.04
Initial conditions		.ief file for each return period Initial conditions are included in the data file.
Time step		Initial timestep: 4 seconds Minimum timestep: 0.5 seconds
Duration		206 hours

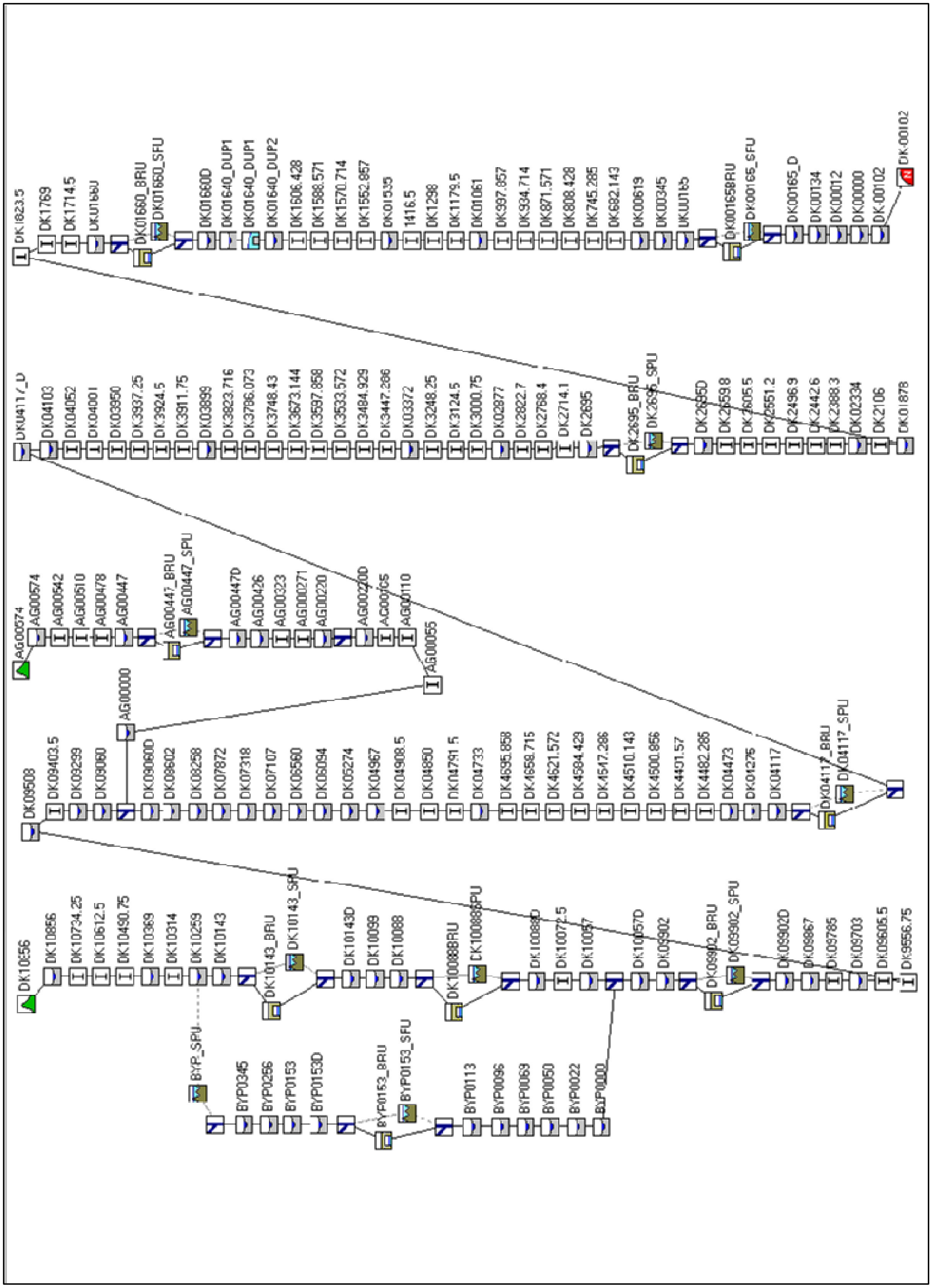

Figure 5.1 Base Model – Existing condition model schematic

5.2 KEY FEATURES OF THE MODEL

There are eight bridges on the modelled reach of the Dunkellin River, a bridge bypass scheme around the N6 road bridge, a salmon count structure and the Aggard Stream tributary joining the watercourse via the left bank at approximately 1,000m downstream of Craughwell.

A summary of key features on the watercourse and how they were modelled is shown in Table 5.2.

Table 5.2 Key Features on modelled reach of Dunkellin River

Feature	Label	Chainage (m)	Model unit	Comments
N6 road bridge	DK1043_BRU	10143	USBPR 1978 bridge	Single arched concrete bridge, flat soffit.
Old N6 road bridge	DK10088BRU	10088	USBPR 1978 bridge	6 arched structure
Railway Bridge	DK09902_BRU	9902	USBPR 1978 bridge	Single arched stone structure
Aggard Stream	DK09060	9060	Junction	574m of Aggard Stream modelled
Rinn Bridge	DK04117_BRU	4117	USBPR 1978 bridge	Twin arched concrete bridge, flat soffit.
Dunkellin Bridge	DK02695_BRU	2695	USBPR 1978 bridge	Multiple arched stone bridge. One main arch and 5 flood arches.
Kileely Beg Bridge	DK01660_BRU	1660	USBPR 1978 bridge	Single arched bridge
Salmon Counter	DK01640_DUP1	1640	General purpose weir	No comment
N18 road bridge at Kilcogan	DK00165BRU	165	USBPR 1978 bridge	Double arched concrete bridge, flat soffit.
N6 bridge for bypass channel	BYP0153_BRU	153*	USBPR 1978 bridge	Double arched concrete bridge, flat soffit.
Aggard Bridge	AG00447_BRU	447*	USBPR 1978 bridge	Double arched stone bridge.

* from confluence with Dunkellin river

5.3 MODEL ASSUMPTIONS & ROUGHNESS CO-EFFICIENT

5.3.1 Model Assumptions

A number of assumptions have been made with regard to the model build for this study. These are summarised as follows :

- The proposed bypass channel for Rinn Bridge is theoretical and may not be feasible due to topographic or engineering reasons.
- Flood relief arches in the Dunkellin Bridge were modelled as blocked in the base model – this was the situation when the structure was surveyed following the November 2009 flood event.
- Surface features such as walls, buildings, isolated trees, fences and hedges have not been included in the model. These features may affect flows along the floodplain that are not accounted for in the model.
- Default weir, culvert and bridge loss coefficients have been used.
- All structures included in the model have been assumed to be in good condition and will withstand a flood event without damage.

The model used in this study is a one-dimensional mathematical model, which has some limitations. Allowances should be made for super-elevation (where the water surface is raised on the outside of a bend), wind stresses creating waves and variations in velocity with depth.

5.3.2 Model Roughness Coefficient

Roughness co-efficients were based on Manning's '*n*' values as derived from Chow (*Open-Channel Hydraulics*, McGraw-Hill, 1959). A value of 0.03 was used for the main channel with values for the banks and floodplain sections varying from 0.04 to 0.055. The Rahasane Turlough cSAC has been represented with a roughness coefficient of zero. In ISIS this creates standing water in the floodplain and mimics the behaviour of the turlough quite well. Table 5.3 shows the values used with their corresponding descriptions.

Table 5.3 Roughness coefficients used in the Dunkellin River model.

Description	Value	Range
Natural Streams		
Clean, straight, full stage, no rifts or deep pools	0.03	Normal
Floodplains		
Light brush and trees	0.04	Minimum
Pasture, no brush, high grass	0.05	Maximum

5.3.3 Sensitivity Tests

The model was tested for sensitivity to a variation in roughness coefficient of ±20% along the length of the model. The purpose of this test is to highlight any areas where the maximum depth varies by greater than 20% indicating an area where roughness values need to be chosen with care. Figure 5.2 shows how sensitivity to a change in roughness co-efficient varies along the length of the model.

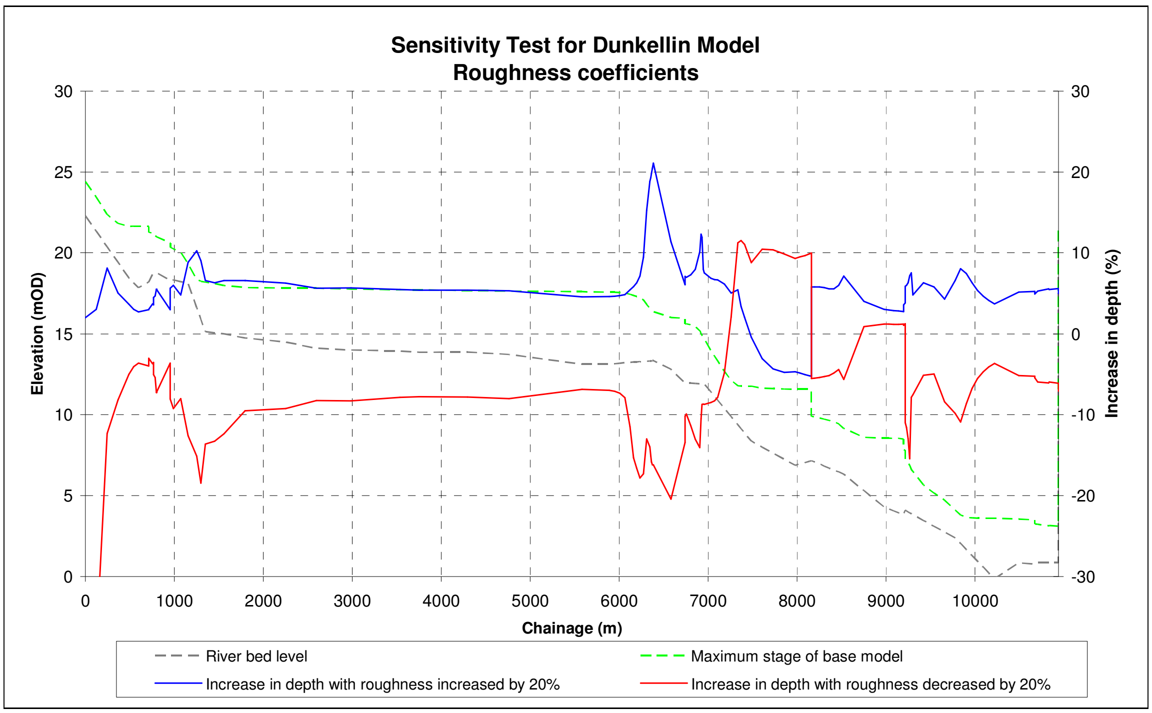

Figure 5.2 Sensitivity test results for Dunkellin model (Note: zero chainage in this figure is at the upstream boundary of the model at Craughwell)

The model shows no exceptional sensitivity along most of its length. In general the maximum depth varies by less than 10%.

The exception to this is at the outlet end of the Rahasane Turlough cSAC, between chainages 6,000 and 7,000m, where the depth varies by up to ±20%.

It should be noted that decreasing the roughness does not always decrease the water level as is seen in Figure 5.2, between chainages 7,200 to 8,000m where decreasing the roughness has led to increased water levels. This is probably caused by increased conveyance upstream.

The channel within Craughwell Village, at chainage 500m, is particularly sensitive to a decrease in roughness coefficient, however increasing the roughness does not have a significant effect.

5.4 MODEL CALIBRATION

The hydraulic model was calibrated using the November 2009 event. This event was well recorded and has also been estimated to be greater than a 1% AEP (i.e., 1 in 100 year return period) event.

The base model used the flow recorded at the Craughwell gauge as a Q-T (flow-time) input, and compared the model's calculated flow with the recorded flow at the at the N18 Bridge Crossing at Kilcolgan. The flow recorded at Aggard Bridge was also included in the model build and calibration.

Figure 5.3 shows the results of the final model calibrations, where the recorded flow, the initial modelled output and the final calibrated output have been shown.

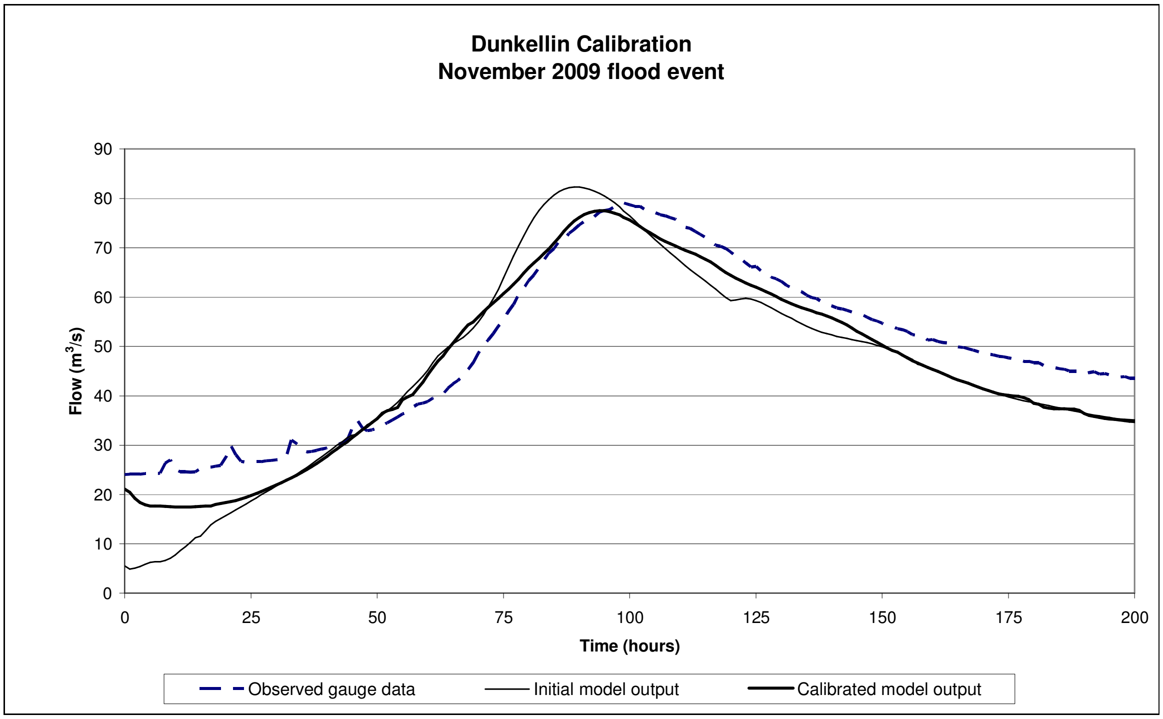

Figure 5.3 Calibration results for Dunkellin model

The initial model showed a peak of 82m^3/s at 89 hours, whereas the gauge showed a peak of 79m^3/s at 98hours. Improvements to the model resulted in a peak of 77m^3/s at 94 hours. Considering the complexities of the geology in the area, this is satisfactory.

5.5 STRATEGIC SCHEME MODELLING

The Strategic Schemes were developed using a hydrograph based on the November 2009 flood event, scaled to 1% AEP (1 in 100 year) flood event peak flow levels, as described in Section 4.

Two Stragegic Schemes have been modelled, each containing 11 proposed flood alleviation measures which have been changed in the base model.

The changes required for each Strategic Scheme are detailed in Section 6.0.

The preferred flood alleviation measured considered under each of the Strategic Schemes have been incorporated into the final Preferred Scheme. The schematic for this model is shown in Figure 5.4.

Table 5.4 summarises the in puts used in the model of the Preferred Scheme.

Table 5.4 Summary of preferred option model parameters

Dunkellin Preferred Option Model Summary 1D model element (ISIS)		
Total Modelled Length		10,856m
Upstream Boundary	**Location**	Approximately 780m upstream from N6 bridge (551778,719995)
	Type	ReFH boundary unit
Downstream Boundary	**Location**	Approximately 125m downstream from N18 Road bridge at Kilcogin (541546,718439)
	Type	Normal depth boundary unit
Model Units	**Channel sections**	71
	Bridge units	8
	Spill units	10
	Weir units	1
	Orifice units	1
	Conduits section	2
	Interpolates	72
	Junction units	22
Roughness values (Manning's '*n*')		0.03 (channel)
Initial conditions		.ief file for each return period Initial conditions are included in the data file.
Time step		Initial timestep: 4 seconds Minimum timestep: 0.5 seconds
Duration		206 hours

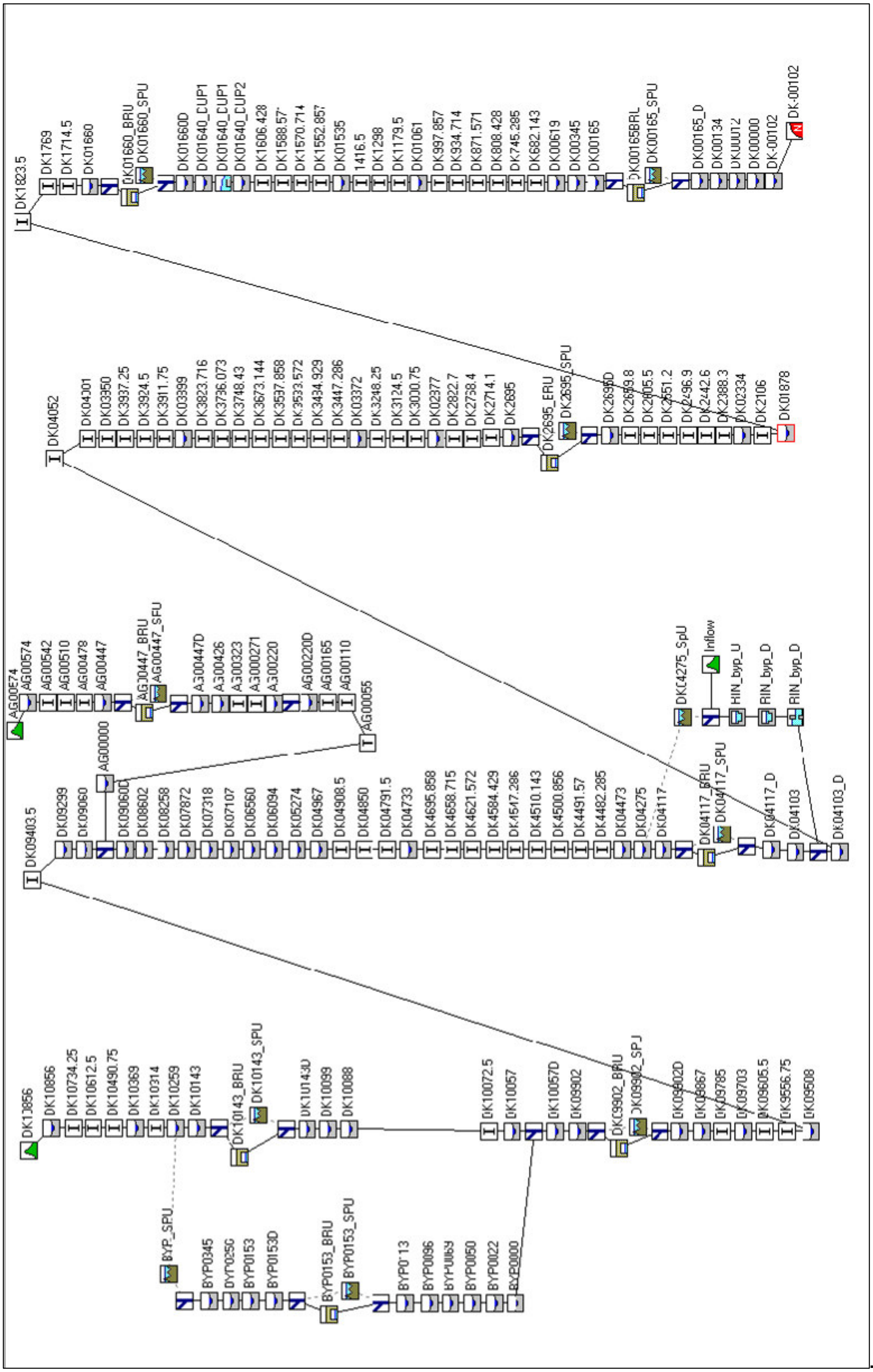

Figure 5.4 Preferred option model schematic

6 TESTING OF POSSIBLE FLOOD ALLEVIATION MEASURES

As noted earlier in this report, the overall scope of the study, contained in the Clients Brief, can be summarised as follows:

1. to examine existing data, including longitudinal sections, cross sections, OPW Arterial Drainage Designs, hydrometric data and complement this data with on-site surveys,
2. develop a mathematical hydraulic model of the Dunkellin Study Area and
3. examine the possible benefit of a number of proposed flood alleviation measures.

To facilitate the development of this report and the examination of the estimated benefits gained from the proposed flood alleviation measures, a three stage approach process was undertaken. The three stages are presented in Figure 6.1 and are :

Stage 1 Generic Review of possible flood alleviation measures.
Stage 2 Development of 2 No. Strategic Schemes made up of a package of flood alleviation measures reviewed under Stage 1.
Stage 3 Development of the Recommended Scheme.

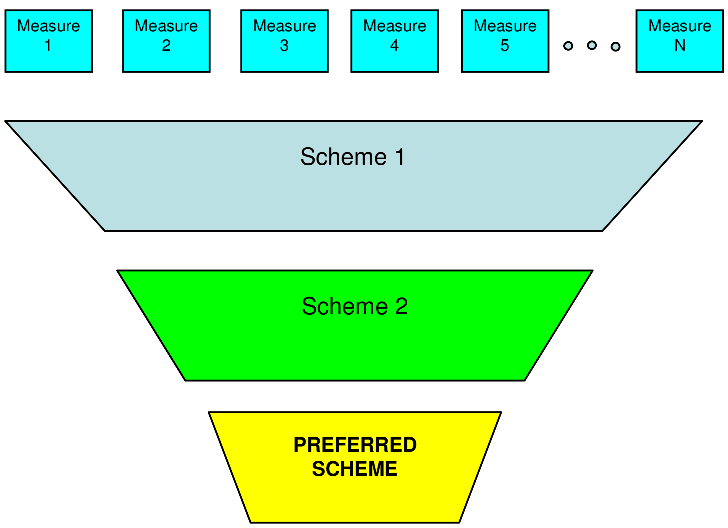

Figure 6.1 Development of Flood Alleviation Measures

6.1 STAGE 1 - OVERVIEW OF POSSIBLE FLOOD ALLEVIATION MEASURES

A series of possible flood alleviation measures have been reviewed as part of this study and each of the main measures are summarised in Table 6.1 and discussed in further detail in the following sections. The impact or benefit of the proposed flood alleviation works considered, at the eleven locations detailed in Table 6.1, are discussed in Section 6.2.

Table 6.1: Matrix of Possible Flood Alleviation Measures

Location No.	Description of Location	Scheme No. 1	Scheme No. 2
1	Works at Kilcolgan & N18 Bridges	No Measures Considered at the N18 Crossing in this Model Build	Increased bridge opening at the N18 Crossing – Extra opening on left bank, same size as existing openings.
2	Channel Works from the N18 Bridge to Killeely Beg Bridge	Widen channel by 50% for each cross section.	Remove weir representing salmon counter
3	Works at Killeely Beg Bridge	Widen opening by approx 50%. Same soffit & springing levels utilised, and adjust cross section to suit.	Use reservoir unit to initially represent bypass channel and to check flow and volume. Aim to use sensible sized culvert, 3m x 1.5m
4	Channel Works from Killeely Beg Bridge to Dunkellin Bridge	Widen channel by 50%	Reduce the roughness of the channel by removing vegetation
5	Works at Dunkellin Bridge	Block flood eyes in base model, then represent as unblocked in 5 flood eyes only. Main aperture is unblocked.	Model with 2 spans, one for main arch and one for the flood eyes. Use a square bridge with the same soffit.
6	Channel Works from Dunkellin Bridge to Rinn Bridge	Deepen channel only by 0.5m between bridges. The bed level at the bridges must stay the same.	Widen channel by 50%
7	Works at Rinn Bridge	Bypass culvert adjacent to Rinn Bridge.	Model with New Bridge. Open bridge completely.
8	Channel Works from Rinn Bridge to the Rahasane Turlough *Works at Rahasane Turlough*	Deepen channel. Base model will have high Mannings on banks, reduce to channel Mannings. *It is Not Proposed to Complete any Works within the Rahasane Turlough cSAC*	Widen channel to match u/s and d/s widths *It is Not Proposed to Complete any Works within the Rahasane Turlough cSAC*
9	Channel Works from Aggard Stream to the Railway Bridge	Deepen Channel Locally by 1.0m and reduce Mannings N	Widen Left Bank by 50% and reduce roughness
10	Railway Bridge in Craughwell	Lower bed by up to 0.7m, tied in with channel deepening from detailed in Item 10	Add flood relief culvert size 3m x 1.5m. Invert level to be just above initial river level.
11	Channel & Bridge Works in Craughwell	Remove old N6 bridge (Multi Arch Bridge) & Deepen channel by up to 1.0m.	Remove old N6 bridge (Multi Arch Bridge) and put new bridge in for New N6 Crossing.

6.2 STAGE 2 - TESTING OF POSSIBLE FLOOD ALLEVIATION MEASURES

Strategic Scheme No. 1, on a general basis, examines the impact of works associated with deepening particular lengths of the channel, the use of flood eyes or bypass/over culverts at the Dunkellin Bridge and Rinn Bridge, and deepening of the bed level at the Railway and N6 bridges in Craughwell Village.

This differs from Strategic Scheme No. 2 which examines the impact of channel widening, in lieu of deepening, the complete replacement of the Killeely Beg and Dunkellin Bridges, and the use of bypass culverts at the Railway Bridge and the replacement of the N6 bridges.

The results from the model runs for each Strategic Scheme are presented in graphical format in the following sections.

Each of the figures, which document the predicted model results, as contained in the following sections, provide a graphical representation of :

1. the bed level of the channel (coloured black).
2. the baseline surface water profile resulting from the 100 year return flows under existing channel conditions (coloured blue & dotted),.
3. the predicted surface water profile for Strategic Model No. 1 (coloured red).
4. the predicted surface water profile for Strategic Model No. 2 (coloured green).

The graphs as presented, show the predicted (100 Year Return) surface water after all of the proposed measured have been added to each model.

The predicted water level for more extreme events such as the November 2009 Flood Event, are modelled in later in Section 6.4 of this report.

6.2.1 Impact of Flood Alleviation Measures considered

6.2.1.1 Location No. 1, Works at Kilcolgan Bridge

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is not proposed to make any changes to the N18 Bridge Crossing at Kilcolgan or the old Stone Arch Bridge on the Stradbally Road.

Under **Strategic Scheme No. 2**, it is proposed to increase the overall size of the existing N18 Kilcolgan Bridge Crossing by providing an additional opening or bridge on the left bank which is equivalent in size to the existing bridge. The existing bridge consists of a double span flat concrete decked bridge. Each span measures 7m and with an effective depth of 2.6m the total cross sectional area of the existing bridge opening is $37m^2$. Therefore an additional bridge with an additional cross sectional area of $37m^2$ has been included in this model run.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.2.

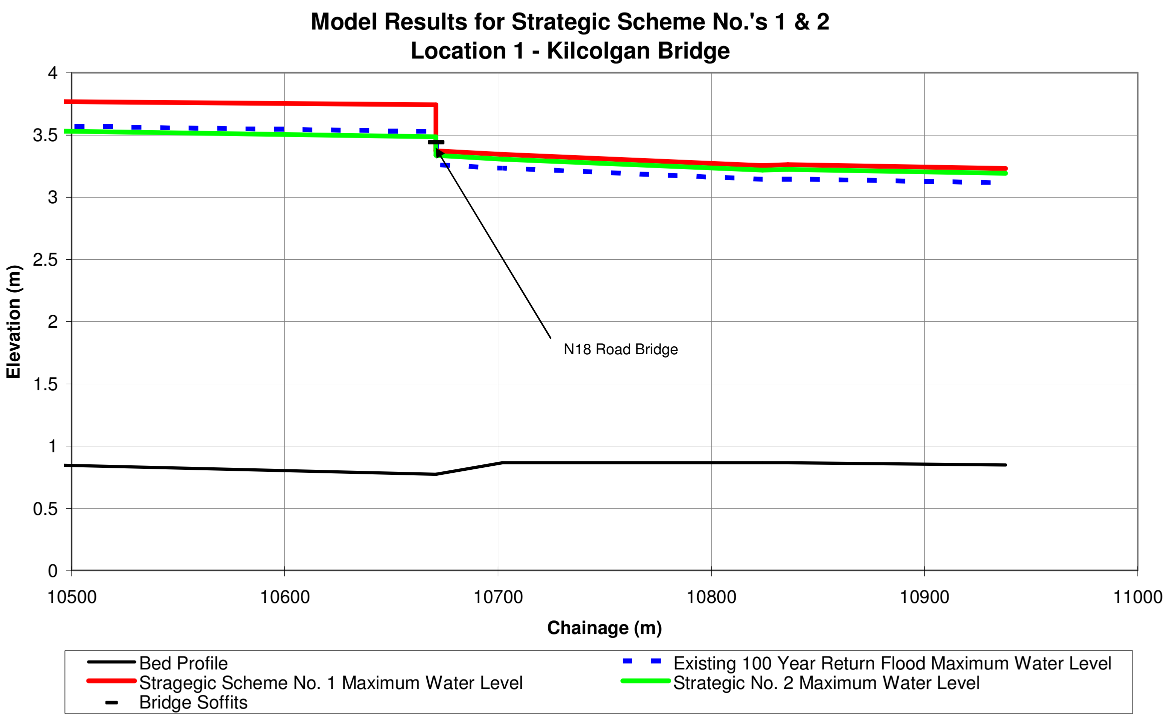

Figure 6.2 Predicted Model Results for Location No 1

From Figure 6.2, it can be seen that the overall effect, from the 100 Year Return Flood, under both Strategic Schemes, is to increase the level of the predicted surface water profile downstream of the N18. This increase is of the order of 0.15m. This small increase in water level can be explained by the fact that the conveyance, and hence river flows, are increased upstream of this location.

Under Strategic Scheme No. 2, where it is proposed to increase the size of the bridge crossing, there is a decrease in the level of the predicted surface water profile (green line), at the 100 Year Return Flood. However, due to the coastal location of this structure, this predicted change in the surface water profile would be ineffective under high tidal conditions and the potential cost benefits or flood protection offered would not be effective under such tidal conditions.

However, it must also be noted that with works now progressing on the development of the M18 from Oranmore to Gort, the benefit of this additional bridge crossing in reducing the risk of road closures along the N18, would be minimal.

The predicted water level for extreme events such as the November 2009 Flood Event, are modelled later in Section 6.4 of this report.

6.2.1.2 Location No. 2, Channel Works from the N18 Bridge Crossing at Kilcolgan to Killeely Beg Bridge

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is proposed to widen this particular stretch of the channel by 50% along its full length (circa 1,400m) and to leave the salmon counter (weir) in place.
>
> Under **Strategic Scheme No. 2**, it is also proposed to widen this particular stretch of the channel by 50% along its full length (circa 1,400m) from upstream of the N18 Kilcolgan Bridge Crossing to the Killeely Beg Bridge but to also remove or demolish the existing salmon counter (weir).

Proposed works at the Killeely Beg Bridge are discussed in Section 6.2.1.3.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.3.

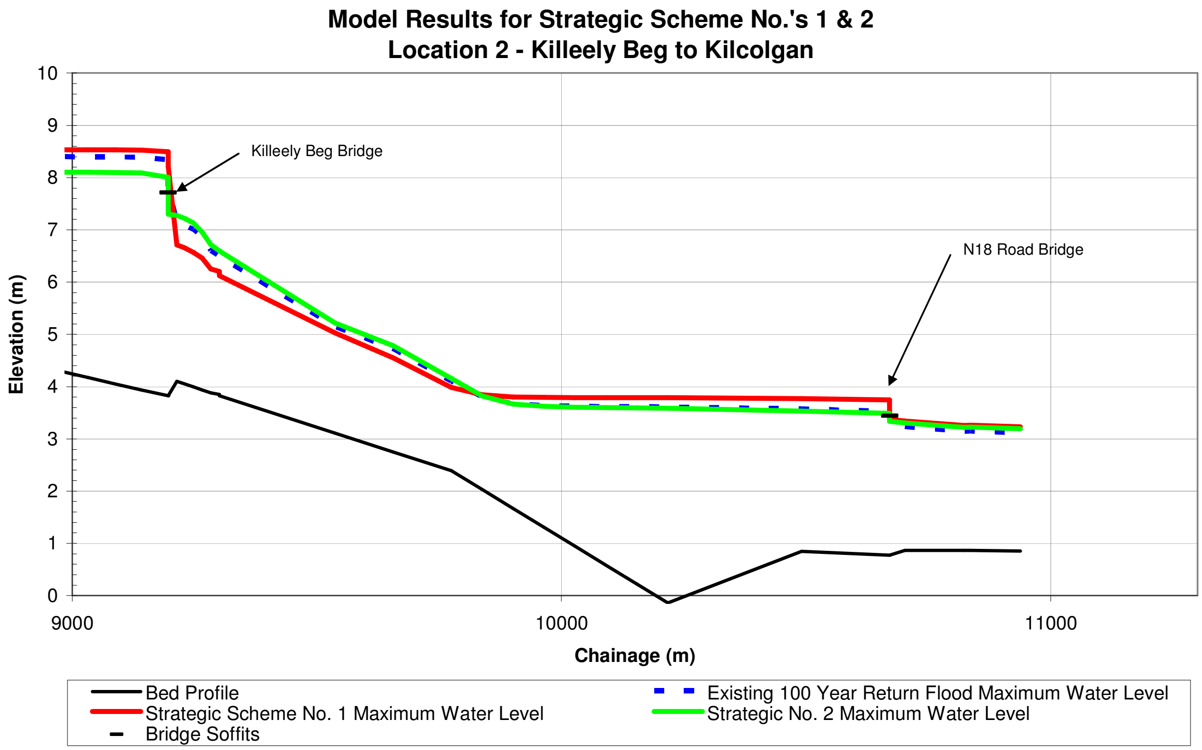

Figure 6.3 Predicted Model Results for Location No 2

From Figure 6.3, it can be seen that the removal of the salmon counter, as considered under Strategic Scheme No. 2 (green), offers minimal benefit over the baseline flood (blue). The structure becomes drowned out, and represents no significant restriction to flow during an extreme event.

However, the change in level of the predicted surface water profile, for the 100 Year Return Flood, by widening the channel by 50%, as considered under Strategic Scheme No. 2, is of the order of 0.45m just downstream of the bridge, and is gradually reducing over the following 500m stretch of river.

Based on the aerial photography taken along this stretch of river, downstream of Killeely Beg, in November 2009 (Photograph No. 21), it is predicted that this 0.45m decrease in the predicted 100 year return flood level, would offer protection to five dwellings, three of which were flooded and the remaining two of which were threatened, but not inundated by, flood waters.

Further analysis of the potential flood alleviation cost benefits are detailed in Section 7 of this report.

6.2.1.3 Location No. 3, Structural Works at the Killeely Beg Bridge

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is proposed to examine the impact of widening the Killeely Beg Bridge structure by 50%, but leaving the down stream salmon counter (weir) in place and maintaining the existing bridge soffit level of 3.975mOD Malin Head.
>
> Under **Strategic Scheme No. 2**, it is proposed to provide a bypass channel adjacent to the Killeely Beg Bridge, but leaving the down stream salmon counter (weir) in place. For the purposes of this study, a channel size similar to the existing channel and a culvert, measuring 3.0m x 1.5m, have been adopted.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.4.

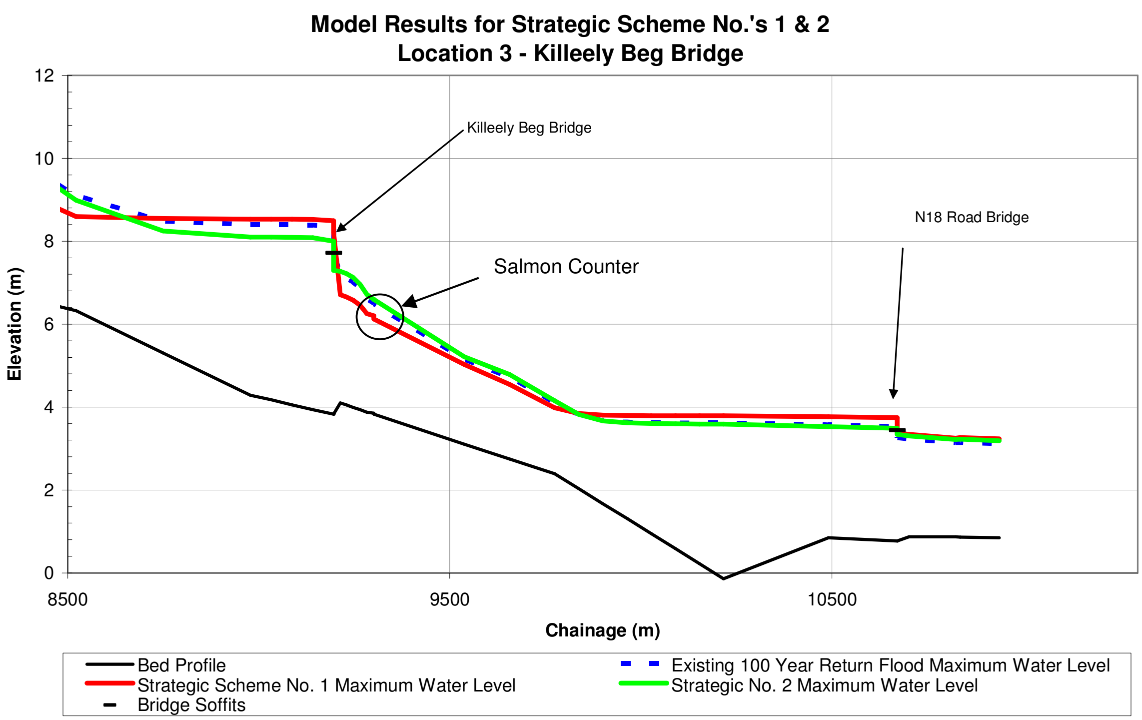

Figure 6.4 Predicted Model Results for Location No 3

From Figure 6.4, it can be seen that the difference in the predicted surface water profile for the proposed bypass channel (green), is lower than the profile for the proposed 50% increase in the bridge opening. The resultant 50% increased span on the Killeely Beg Bridge, has resulted in a minimal change of the 100 Year Return Flood level.

From Figure 6.4, it can be seen that there is a predicted change in the surface water profile, from the 100 Year Return Flood, as a result of the new bypass channel around Killeely Beg Bridge. This change is predicted to be 0.34m.

Based on the aerial photography taken within the townland of Killeely Beg, in November 2009 (Photograph No. 21), it is predicted that the combination of this decrease in the 100 year return flood level of 0.34m and the downstream reduction of 0.45m would offer protection to the five dwellings in that townland which were threatened or inundated by the flood waters.

Analysis of the impact of more extreme events such as in November 2009 is discussed in Section 6.5 and the potential flood alleviation benefits are detailed in Section 7 of this report.

6.2.1.4 Location No. 4, Channel Works from Killeely Beg Bridge to Dunkellin Bridge

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is proposed to examine the impacts of widening the channel by 50% along its full length (circa 1,000m) from just upstream of Killeely Beg Bridge to just downstream of Dunkellin Bridge
>
> Under **Strategic Scheme No. 2**, it is proposed to examine the impacts of reducing the roughness of the channel by removing vegetation.

Proposed works at Dunkellin Bridge are discussed in the following Section 6.2.1.5.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.5.

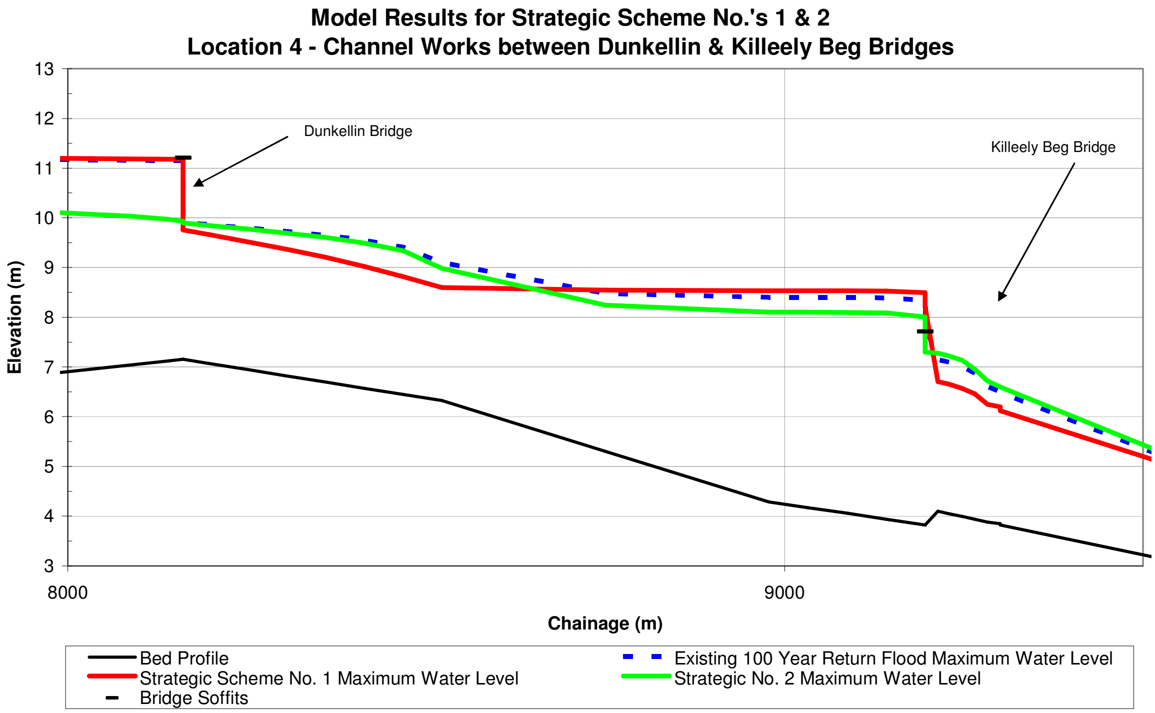

Figure 6.5 Predicted Model Results for Location No 4

From Figure 6.5, it can be seen that the two strategic schemes offer varying degrees of flood alleviation along this stretch of the Dunkellin River. The model results from the combination of channel widening upstream of Killeely Beg Bridge and the bypass channel at the bridge itself, predicts that in general the level of the 100 year return surface water profile would be reduced in the townland of Killeely Beg.

However, it is also evident that works at Dunkellin, as considered in the following section have a significant impact on the surface water profile along this stretch of river.

Analysis of the impact of more extreme events such as in November 2009 are discussed in Section 6.5 and the potential flood alleviation benefits are detailed in Section 7 of this report.

6.2.1.5 Location No. 5, Structural Works at the Dunkellin Bridge

The following works were examined at this location :

> Under **<u>Strategic Scheme No. 1</u>**, it is proposed to maintain the existing main arch and unblock all five existing flood eyes.
>
> Under **<u>Strategic Scheme No. 2</u>**, it is proposed to replace the Dunkellin Bridge with a twin spanned flat decked bridge. The existing soffit level has been retained in the model.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.6.

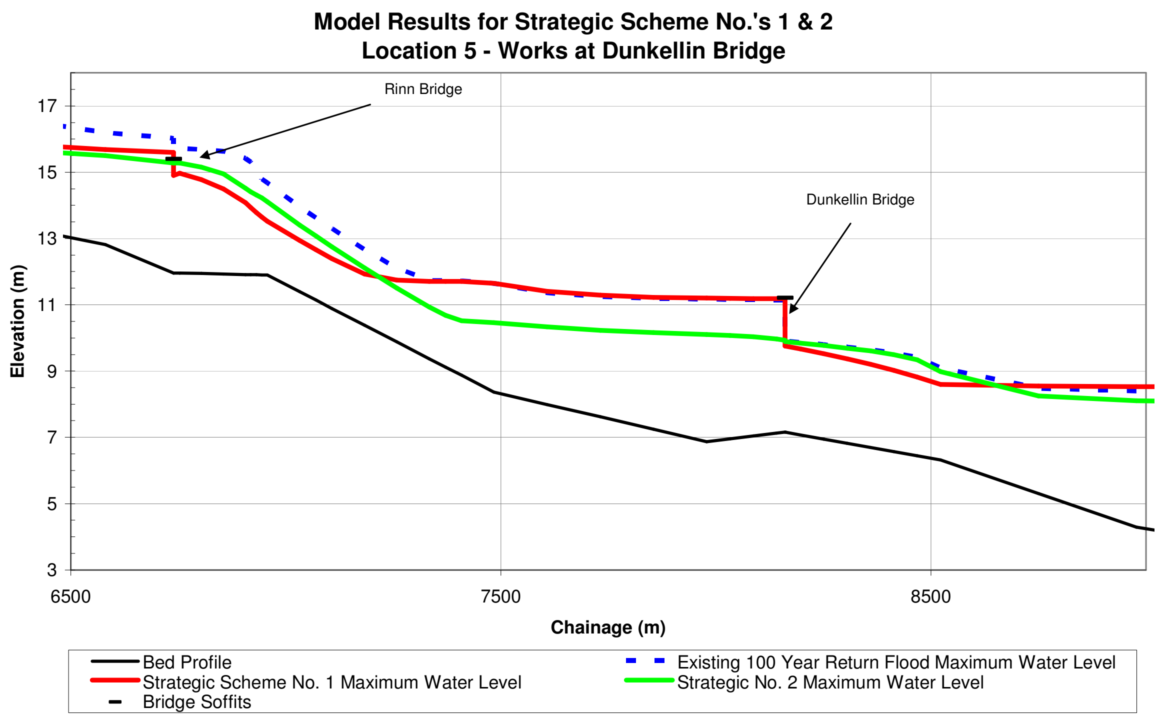

Figure 6.6 Predicted Model Results for Location No 5

From Figure 6.6, it can be seen that the two strategic schemes offer significantly different results just upstream of the Dunkellin Bridge. Unblocking of the flood eyes without any significant change in channel width or level at the bridge offers a minimal reduction in the predicted surface water profile. However, for Strategic Scheme No. 2, where the bridge is replaced with a larger span structure, the model predicts that the level of the 100 year return surface water profile (green line) would be reduced by up to 1.3m when compared with the existing base profile.

However, it is also evident that these works at the Dunkellin Bridge have a significant impact on the surface water profile downstream towards the townland of Killeely Beg. This increased conveyance through the Dunkellin Bridge has offset the benefits gained by increasing the channel width downstream between this location and Killeely Beg Bridge.

A further increase in channel width, beyond the 50% considered in Section 6.2.1.5, will be required to reduce the impact of the increased conveyance at Dunkellin.

Analysis of the impact of more extreme events such as in November 2009 are discussed in Section 6.5 and the potential flood alleviation benefits are detailed in Section 7 of this report.

6.2.1.6 Location No. 6, Channel Works from the Dunkellin Bridge to Rinn Bridge

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is proposed to examine deepening this particular stretch of the channel by 0.5m along its full length (circa 1,350m) from just upstream of the Dunkellin Bridge to downstream of Rinn Bridge, and make no changes to the channel width. However, these proposed works would require significant excavations in rock and may not be cost effective.
>
> Under **Strategic Scheme No. 2**, it is proposed to widen this particular stretch of the channel by 50% along its full length (circa 1,350m), from Dunkellin Bridge to Rinn Bridge, and make no changes to the channel depth or bed level. The existing soffit levels have been retained in the model with the exception of the removal of a localised section of *"in-channel rock removal"* approximately 180m downstream of Rinn Bridge.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.7.

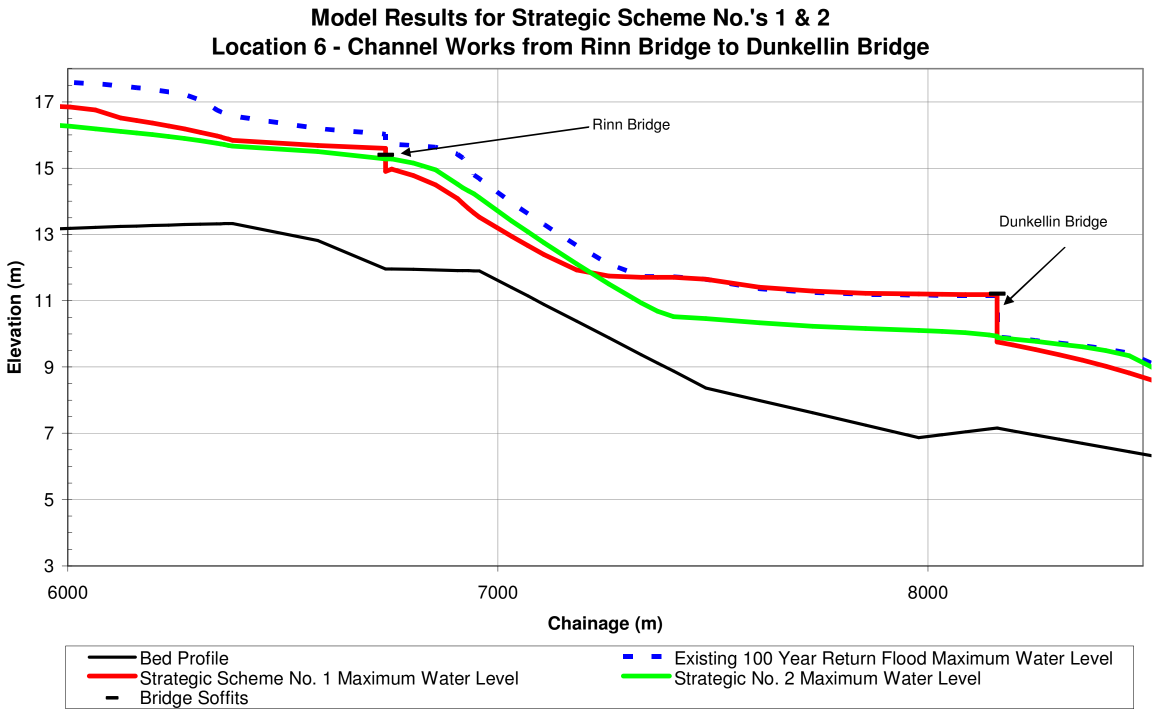

Figure 6.7 Predicted Model Results for Location No 6

It is predicted that channel widening and bridge replacement would offer the greatest reduction in level along the lower reaches of this stretch of river. However, channel deepening for the distance of 500m downstream of Rinn Bridge predicts a greater reduction in the level of the 100 year return surface water profile.

As part of the brief, the OPW also requested that consideration be given to removing a section of rock (150m) along the bed of the channel approximately 100m downstream of Rinn Bridge. The impact of this rock removal would be similar to the channel deepening considered under Strategic Scheme No. 1 (red line).

Any decrease in level of the surface water profile (100 year return) along this section of channel, will also have an impact on the flood levels normally expected within the Dunkellin Turlough. Therefore consideration will need to be given to the possible impacts upon the local ecological status of this water body, before works are completed.

The predicted water level for more extreme events, such as the November 2009 Flood Event, are modelled in later in Section 6.4 of this report.

Further analysis of the cost benefits from these potential flood alleviation measures are detailed later in Section 7 of this report.

6.2.1.7 Location No. 7, Works at Rinn Bridge

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is proposed to examine the impacts of providing a bypass channel adjacent to Rinn Bridge whilst maintaining the existing bridge bed level of 12.32mOD Malin Head.
>
> Under **Strategic Scheme No. 2**, it is proposed to provide a new (larger) bridge structure at Rinn Bridge with no central pier, whilst also maintaining the existing bridge bed level of 12.32mOD Malin Head.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.8.

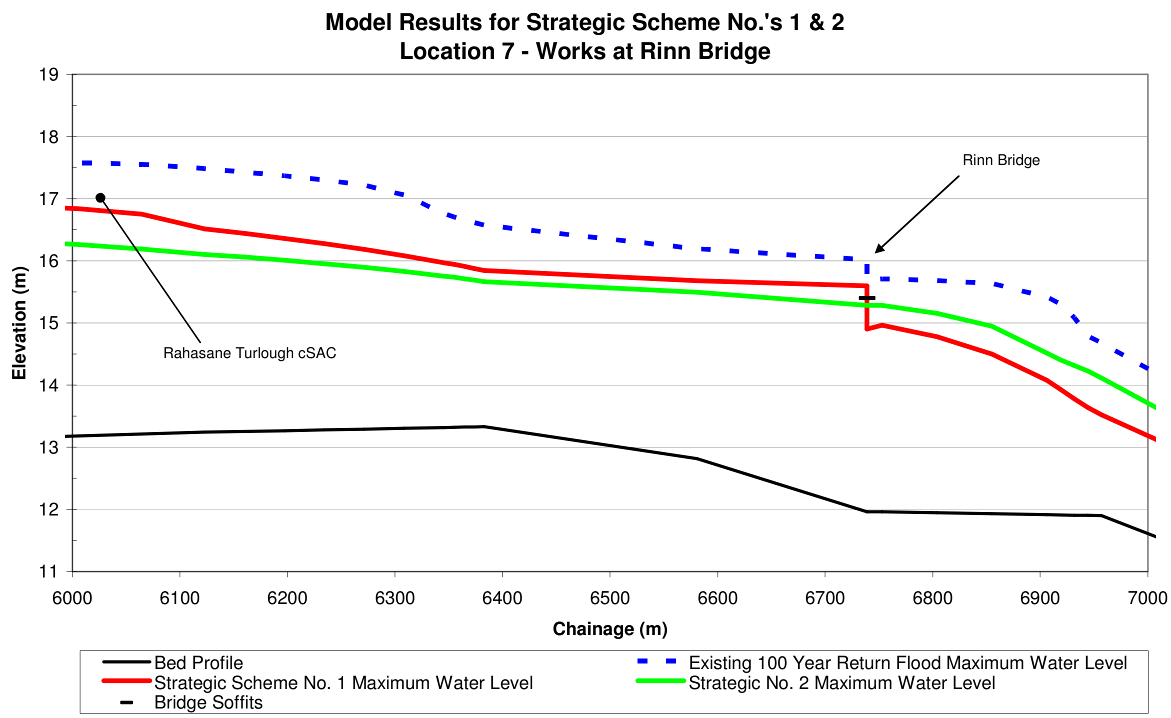

Figure 6.8 Predicted Model Results for Location No 7

From Figure 6.8, it can be seen that the two strategic schemes offer different results upstream of the Rinn Bridge. The bypass culvert at the bridge offers a reduction in the predicted 100 year return surface water profile of 0.3m. However, with Strategic Scheme No. 2, where the bridge is replaced with a larger span structure and the existing bridge bed level of 12.32mOD Malin Head is maintained, the model predicts that the level of the 100 year return surface water profile (green line) would be reduced by up to 0.8m when compared with the existing base profile.

6.2.1.8 Strategic Scheme 1 – Location No. 8, Channel Works from the Rinn Bridge to Rahasane Turlough

The following works were examined at this location :

> Under **Strategic Scheme No. 1**, it is proposed to examine deepening this particular stretch of the channel by 0.5m along its full length (circa 700m), improve its conveyance by providing channel maintenance works along the left and right banks and maintain the existing channel width.
>
> Under **Strategic Scheme No. 2**, it is proposed to widen this particular stretch of the channel by 50% along its full length (circa 700m), from Rinn Bridge to the Rahasane Turlough cSAC, improve its conveyance by providing channel maintenance works along the left and right banks and maintain the existing channel bed level.

It is not proposed to enter or complete any works within the Rahasane Turlough cSAC.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.9.

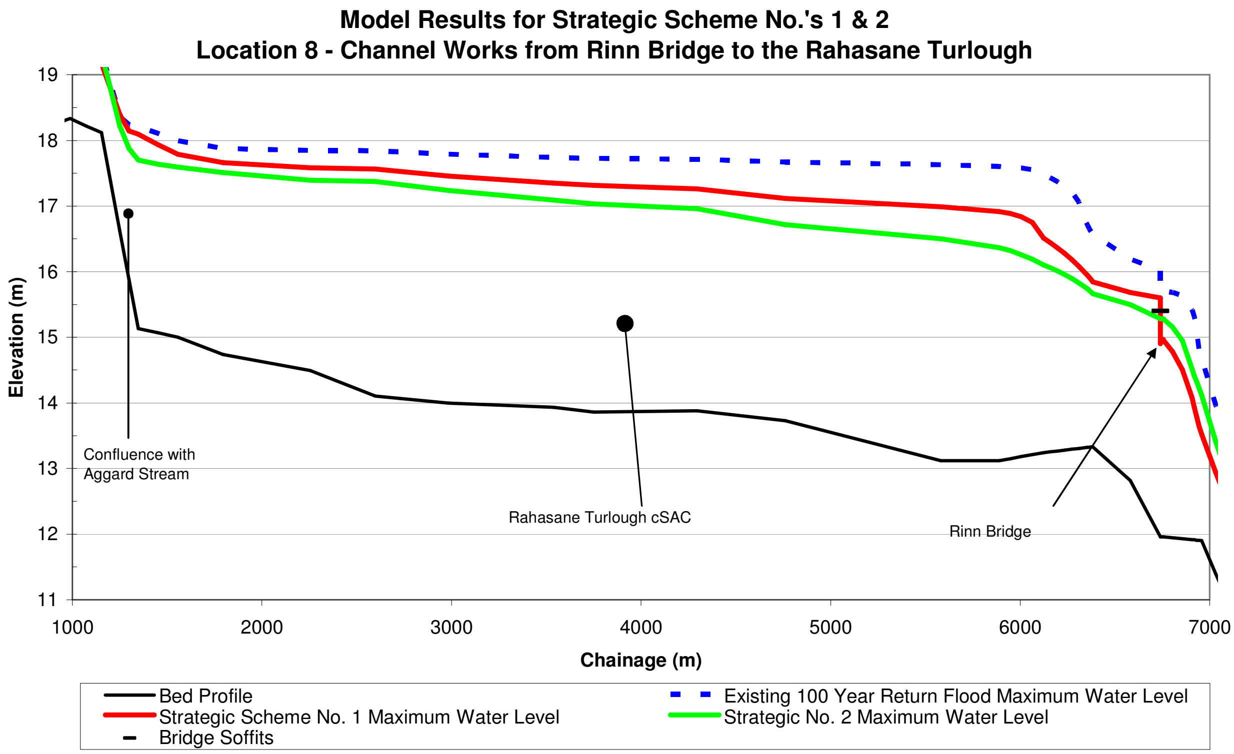

Figure 6.9 Predicted Model Results for Location No 8

From Figure 6.9, it can be seen that the resultant changes (green and red lines) in the predicted surface water profile based on the 100 Year Return Flood, are variable across the length of the Rahasane Turlough cSAC.

However, it is predicted that the change in level of the surface water profile, from the 100 Year Return Flood, within this particular stretch of channel (700m) ranges from 0.3 to 0.4m.

This decrease in level of the surface water profile may have a lesser impact on the flood levels normally expected within the Rahasane Turlough cSAC and there may be an impact on the ecological status of this water body. This impact may be insignificant at the higher flood levels. However, for the purposes of this report, it has been assumed that the proposed works could decrease the 100 year flood level to 16.5mOD without impacting on the riparian zones of the turlough. Each year, the Rahasane Turlough cSAC tends to flood to within 10 m of the Kilcolgan road on its northern banks and typical ground levels in this area are 16.5mOD (Malin Head). Further ecological studies will be required to examine the potential impact of the proposed flood alleviation measures on the Rahasane Turlough cSAC. These studies will also require an “appropriate assessment” under the Article 6 (3) of the Habitats Directive.

The predicted water level for extreme events such as the November 2009 Flood Event, is modelled in later in Section 6.4 of this report. Further consideration should be given to modelling the impact of smaller events, such as the annual average daily flow, for the purposes of an "appropriate assessment" under the Habitats Directive.

Further analysis of the potential flood alleviation benefits are detailed in Section 7 of this report.

6.2.1.9 Strategic Scheme 1 – Locations 9, 10 and 11, Works within Craughwell Village

The following works were examined within the environs of Craughwell Village.

Under **Strategic Scheme No. 1**, it is proposed to examine:

- widening of the channel downstream of the Railway Bridge whilst maintaining the existing bed level,
- the addition of a flood relief culvert/bypass channel at the Railway Bridge,
- the removal of the old N6 Bridge Crossing (multi-arched stone bridge), and
- completing the connection of the Craughwell bypass channel to the Main Craughwell River.

Under **Strategic Scheme No. 2** it is proposed to examine:

- regrading the channel downstream of the Railway Bridge (reduction of local "hump" in the river bed through regrading),
- deepening of the river bed under the Railway Bridge in combination with scour protection, such as a flume to ensure that the structure is not impacted upon,
- the removal of the old N6 Bridge Crossing (multi-arched stone bridge) and
- the provision of a new bridge at the Main N6 Bridge Crossing, and
- completing the connection of the Craughwell bypass channel to the Main Craughwell River.

The predicted model results for these proposed flood alleviation measures are illustrated in Figure 6.10.

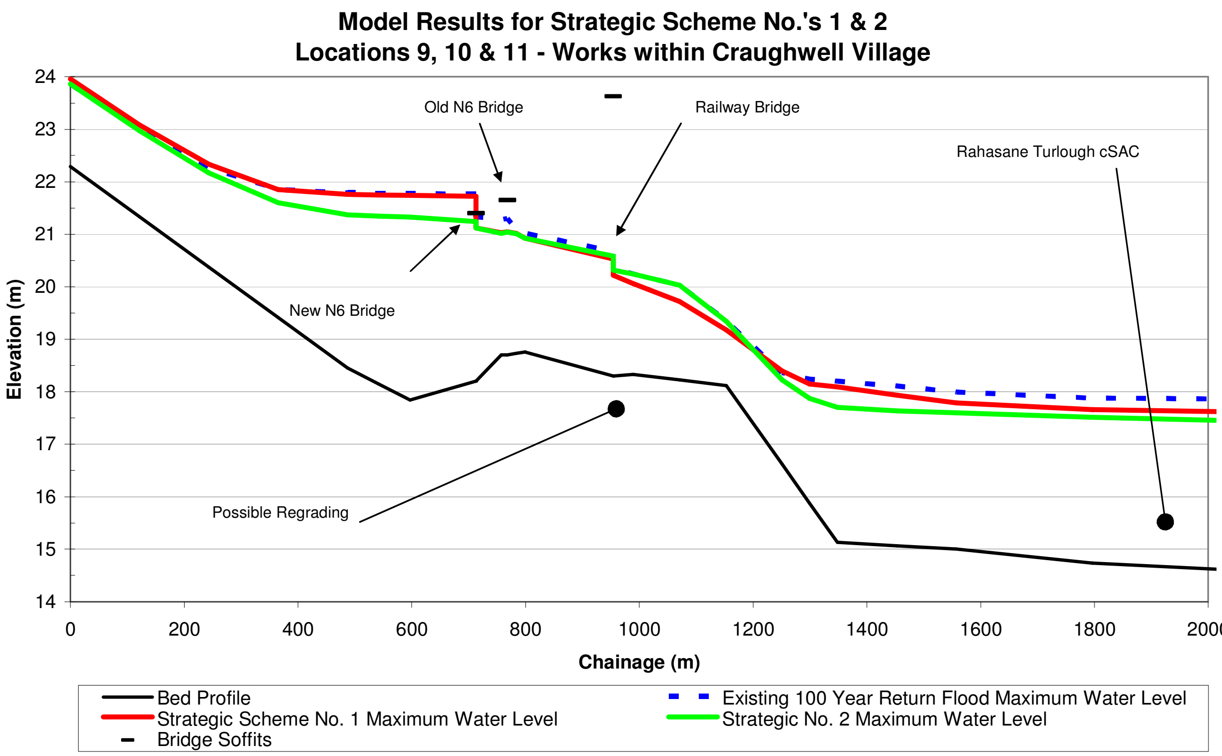

Figure 6.10 Predicted Model Results at Location No's 9, 10 and 11 in Craughwell Village

From Figure 6.10, it can be seen that Strategic Scheme No. 2 offers the greatest reduction in the resultant predicted surface water profile. The reduction in the surface water profile at the Old N6 Bridge location, as predicted in Strategic Scheme No.2, is 0.52m at the 100 Year Return Flood.

Strategic Scheme No. 1, offers minimal reductions in the level of the predicted surface water profile.

Based on the aerial photography taken along this stretch of river, downstream of Railway Bridge, in January 2005 (Photograph No. 16), it is predicted that this 0.52m decrease in water level would offer protection, to approximately five houses within Craughwell, from the 100 Year Return Flood.

The predicted water level for more extreme events such as the November 2009 Flood Event, is modelled in later in Section 6.4 of this report and further analysis of the potential flood alleviation cost benefits are detailed in Section 7 of this report.

6.3 SUMMARY OF MODELLING SCENARIOS

As discussed in Section 6.2, two strategic schemes were developed to assess the potential of possible flood alleviation measures along the Dunkellin River. The results of including these particular flood measures are summarised in Figure 6.11 and numerically in Table 6.2.

Table 6.2: Summary of Model Results for the 100 year Flood Design Flow

Description of Location	Baseline 100 Year Return Flood Water Level mOD Malin Head	Scheme No. 1 Predicted Water Level mOD Malin Head	Scheme No. 2 Predicted Water Level mOD Malin Head
Main N6 Road Bridge	21.77	21.72	21.24
Bypass bridge	21.71	21.66	21.23
Old N6 Road Bridge	21.30	21.04	21.04
Railway Bridge	20.68	20.53	20.58
Rinn Bridge	16.02	15.60	15.28
Dunkellin Bridge	11.15	11.18	9.93
Killeely Beg Bridge	8.34	8.5	8.00
Kilcolgan Bridge	3.53	3.74	3.48

Figure 6.11 illustrates the difference between the surface water profile from the 100 Year Flood (blue line) and the predicted surface water profiles for each Strategic Scheme, during a 100 year design flow.

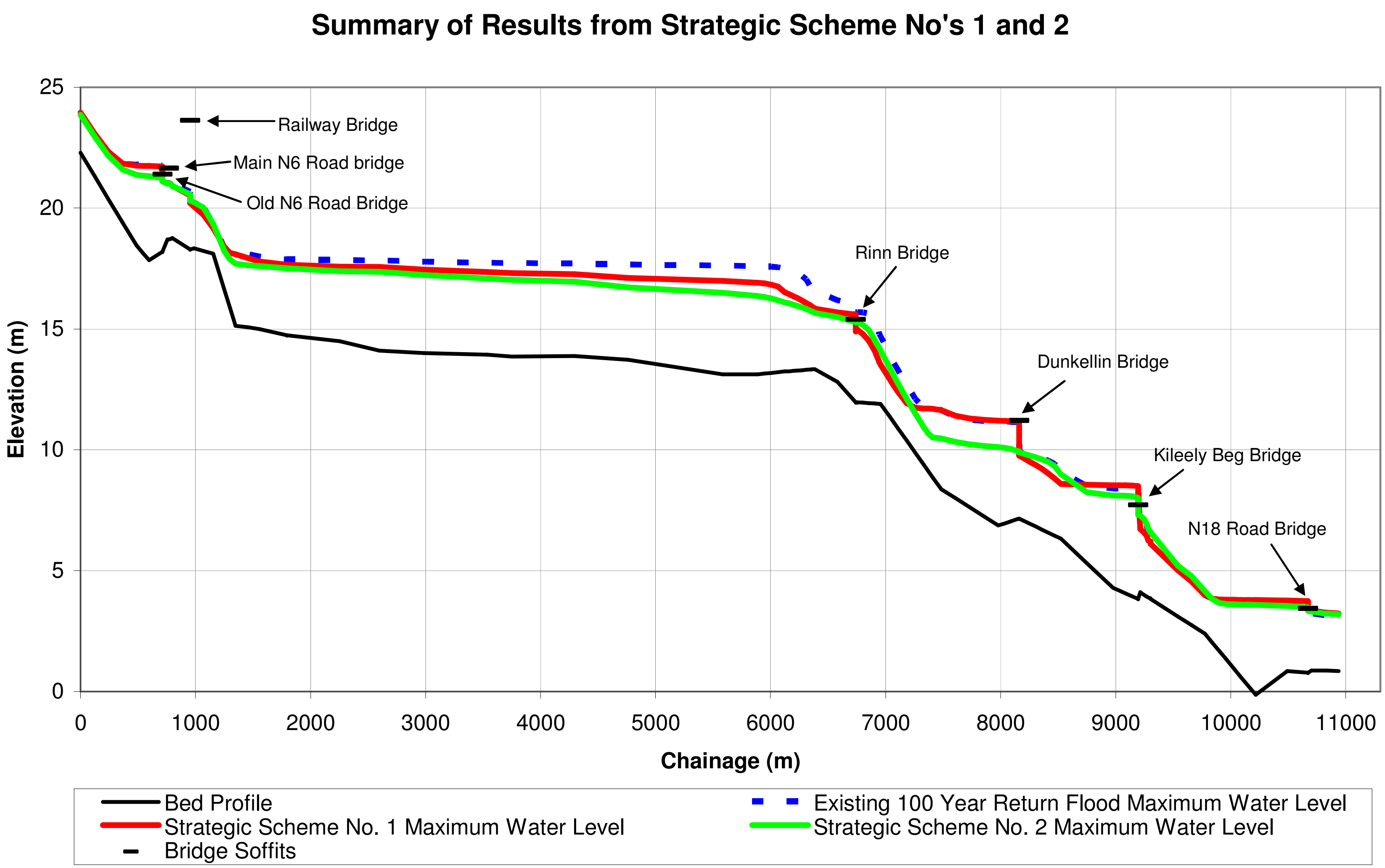

Figure 6.11 Predicted Surface Water Profile for Strategic Scheme No.'s 1 & 2

6.4 MODELLING WORK ALONG THE AGGARD STREAM AND LACKAN CHANNEL

Channel maintenance works and improvements, along the Aggard Stream, Monksfield River and Cregaclare Channel up to the townland of Lackan, and their impact on improving the conveyance of flood waters towards the Dunkellin River were modelled as part of this study.

All of the main culvert crossings and field crossings, along the Aggard Stream, were modelled as a new 1.5m diameter pipe (cross sectional area of $1.77m^2$) i.e., all culverts have been replaced with a new 1500mm diameter pipe. Details and photographs of the main existing culverts along the Aggard Stream are included in Appendix No. 4.

Figure 6.12 shows the model output hydrographs for the 100 Year Flood prior to implementing channel improvement works and after channel improvement works have been undertaken.

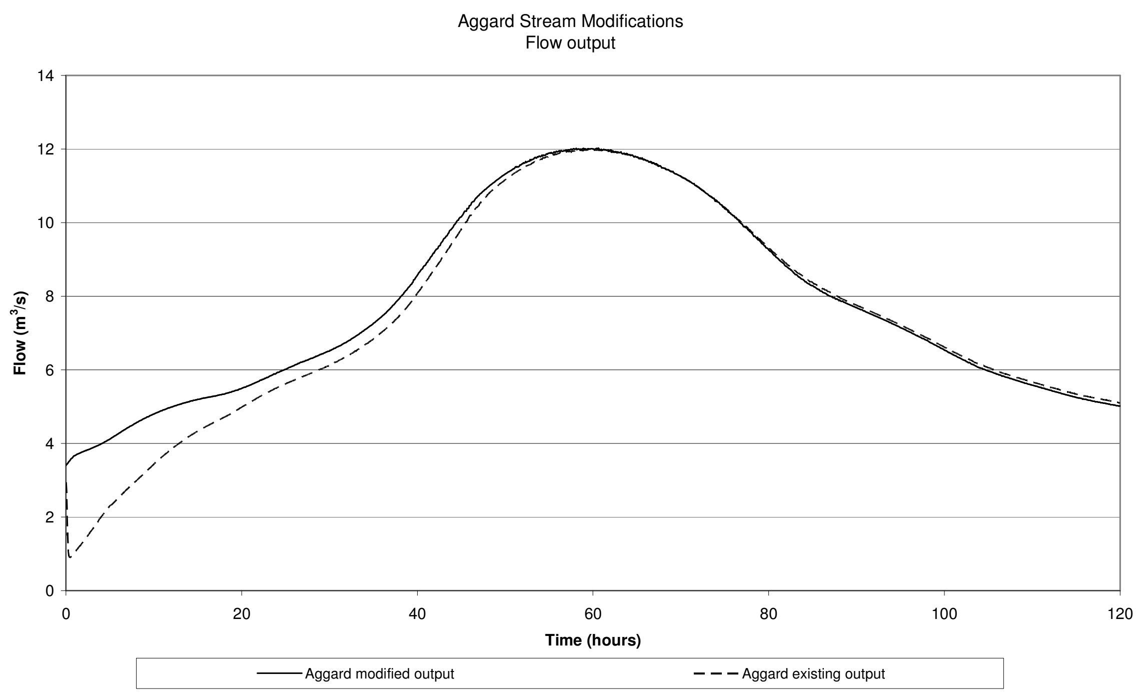

Figure 6.12 Predicted Surface Water Profile for the Lower Reaches of the Aggard Stream for the 100 Year Flood

From this Figure 6.12 it can be seen that there is negligible difference between the peak flows, before and after channel improvement works are implemented. The predicted increase is $0.05m^3$/sec or 4% of the $12m^3$/sec peak flow recorded in November 2009.

This predicted data output was used in the development of the Strategic Schemes as detailed in Section 6.2 and the Preferred Scheme detailed in the following Section 6.5.

6.5 STAGE 3- DEVELOPMENT OF THE RECOMMENDED FLOOD ALLEVIATION SCHEME

Following on from the development of the two strategic schemes, as detailed in Section 6.2, it is clear that, whilst a number of the possible flood alleviation measures do have a significant impact on the level of the surface water profile during the 100 year Flood Event, this impact needs to be analysed at lesser annual floods from an ecological viewpoint and an appraisal needs to be made of the economic and social benefit, against its cost.

Taking into consideration the ecological status of the Dunkellin River, more particularly the Rahasane Turlough cSAC, and the extent of the predicted reductions in the 100 Year Return flood level, a Preferred Scheme can be established.

However, in establishing the Preferred Scheme, consideration has also being given to the minimum level of measures required to provide beneficial flood alleviation in the upper reaches of the study area at Craughwell Village, whilst also minimising or eliminating the resultant potential aggravation of flooding downstream along the banks of the Rahasane Turlough cSAC and in the townlands of Rinn, Dunkellin, Killeely Beg and Kilcolgan. For example increased conveyance of flood flows ;

1. through the N6 bridge crossing and the Railway bridge will have the potential impact of increasing flood levels in the Rahasane Turlough cSAC and further downstream at Rinn, Dunkellin and Killeely Beg, if downstream flood measures are not implemented, and

2. along the Aggard Stream, through channel maintenance and improvements, these will have the potential impact of increasing flood levels in the Rahasane Turlough cSAC and further downstream at Rinn, Dunkellin and Killeely Beg, if downstream flood measures are not implemented.

This Preferred Scheme is summarised in Table 6.3 and discussed in the following paragraphs.

We would note at this point, that the Preferred Scheme has also been further enhanced by increasing the depth of the river channel by 0.5m, as detailed in Strategic Scheme No. 1, to 1.0m in this Preferred Scheme. This additional channel deepening commences at a point approximately 275m upstream of the Railway Bridge in Craughwell Village and finishes at a point approximately 275m downstream of the bridge.

Figure 6.13 shows the predicted surface water profile for the 100 Year Return Flood when modelled using the Preferred Scheme detailed in Table 6.3.

Table 6.3: Summary of the Preferred Scheme

Location No.	Description of Location	Preferred Scheme	Reason For this particular Selection
1	Works at Kilcolgan & N18 Bridges	No measures considered	The impact of high tides negate the benefits gained by replacing the N18 Bridge
2	Channel Works from the N18 Bridge to Killeely Beg Bridge	Widen channel by 50% for each cross section through the provision of two stage channel works.	Channel Widening offersthe largest predicted reduction. Removal of the Salmon Counter on the existing channel offers no significant reduction in flood levels.
3	Works at Killeely Beg Bridge	Full Bridge Replacement to match channel widening	Increased bridge opening offers the largest predicted reduction.
4	Channel Works from Killeely Beg Bridge to Dunkellin Bridge	Widen channel by 50%	Channel Widening is more effective than channel deepening.
5	Works at Dunkellin Bridge	Retain the existing main Stone Arch Bridge and provide a large overflow flood eye.	New flood eyes are more effective than utilising the existing flood eyes. Works on the upstream channel will also be required to improve conveyance.
6	Channel Works from Dunkellin Bridge to Rinn Bridge	Widen channel by 50% between bridges and localised in channel rock removal. The bed level remains the same.	Widening of the channel is more effective than deepening.
7	Works at Rinn Bridge	Bypass culvert adjacent to Rinn Bridge.	A bypass culvert is required at this location. The removal of the central pier offers no reduction in flood levels.
8	Channel Works from Rinn Bridge to the Rahasane Turlough *Works at Rahasane Turlough*	Widen the existing channel 50% and improve conveyance of the banks. *It is Not Proposed to Complete any Works within the Rahasane Turlough cSAC*	Widening the channel through the use of a two stage channel maintains the normal base flows within the existing channel. Deepening the channel may have a negative impact on base flows within the turlough
9	Channel Works from Aggard Stream to the Railway Bridge	Deepen the channel locally to reduce the "hump" in the river bed.	The combination of these works is predicted to be the most effective flood alleviation measure within Craughwell, based on assessments carried out for this study, as well as those carried out by OPW under previous studies.
10	Railway Bridge in Craughwell	Deepen river bed under bridge, by 1.0m and use scour protection such as a flume to ensure that the structure is not impacted upon.	
11	Channel & Bridge Works in Craughwell	Remove old N6 bridge (Multi Arch Bridge), Deepen the main channel by up to 1.0m and connect the bypass channel to the main channel.	

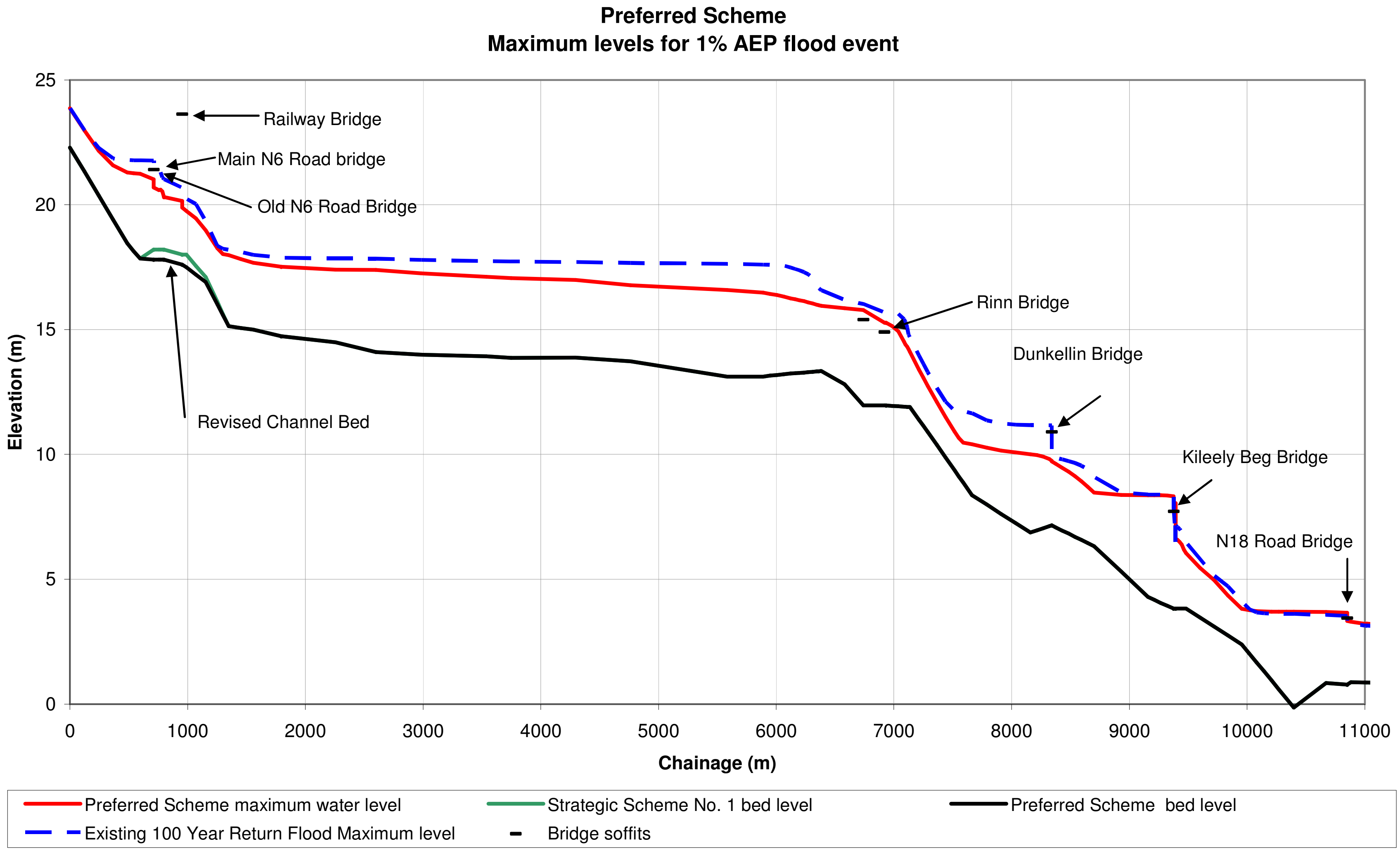

Figure 6.13 Predicted Surface Water Profile for the Dunkellin River for the 100 Year Flood when modelled under the Preferred Scheme

From Figure 6.13 it can be seen that the flood alleviation measures considered under the Preferred Scheme offer a reduction in the maximum level of the 100 Year Return Flood Event for the majority of the Dunkellin River.

It can also be seen that the proposed bypass channel and culvert (3.0 x 1.5m) at Killeely Beg does not offer any significant change in the predicted surface water profile. However, the hydraulic gradient upstream and downstream would indicate that further benefits could be achieved, if the Killeely Beg Bridge was replaced in full by a larger spanned bridge, which would be constructed so as to not impede on the benefits gained by increasing the channel width by 50%.

The predicted changes in water level for the 100 Year Return Flood at the main hydraulic structures along the Dunkellin River are as follows :

Table 6.3: Preferred Scheme - Predicted Change in the Surface Water Profile for the 100 year Flood Design Flow

Description of Location	Preferred Scheme Predicted Change in Water Level
Main N6 Road Bridge	- 750mm
Railway Bridge	- 520mm
Outlet From the Rahasane Turlough	- 1,200mm
Rinn Bridge	- 430mm
Dunkellin Bridge	- 1,240mm
Killeely Beg Bridge	- 50mm
Kilcolgan Bridge	+130mm

From Table 6.3, it can be seen that, localised flooding is predicted to occur at the N18 Bridge Crossing, when the 100 Year Return Flood coincides with a high tide at Kilcolgan. However, with the design of the new M18 Motorway now at an advanced stage, the benefits of replacing this particular bridge would be minimal as the road blockage would potentially only occur during high tides.

Following on from the development of the Preferred Scheme, and its testing under the design flows from the 100 Year Return Flood, it is clear that whilst a number of the possible flood alleviation measures do have an impact on the level of the surface water profile during this particular event, this impact needs to be analysed under a more extreme flood event. As part of this study the November 2009 event, which is detailed earlier in Table 4.4, has been modelled under the Preferred Scheme together with the additional changes in bed levels at the Railway Bridge.

Figure 6.14 shows the predicted difference between the surface water profile for the Preferred Scheme when modelled using the flows recorded for the November 2009 Flood event and the 100 Year Return Flood.

Predicted Surface Water Profile for the Preferred Scheme when modelled with November 2009 flow

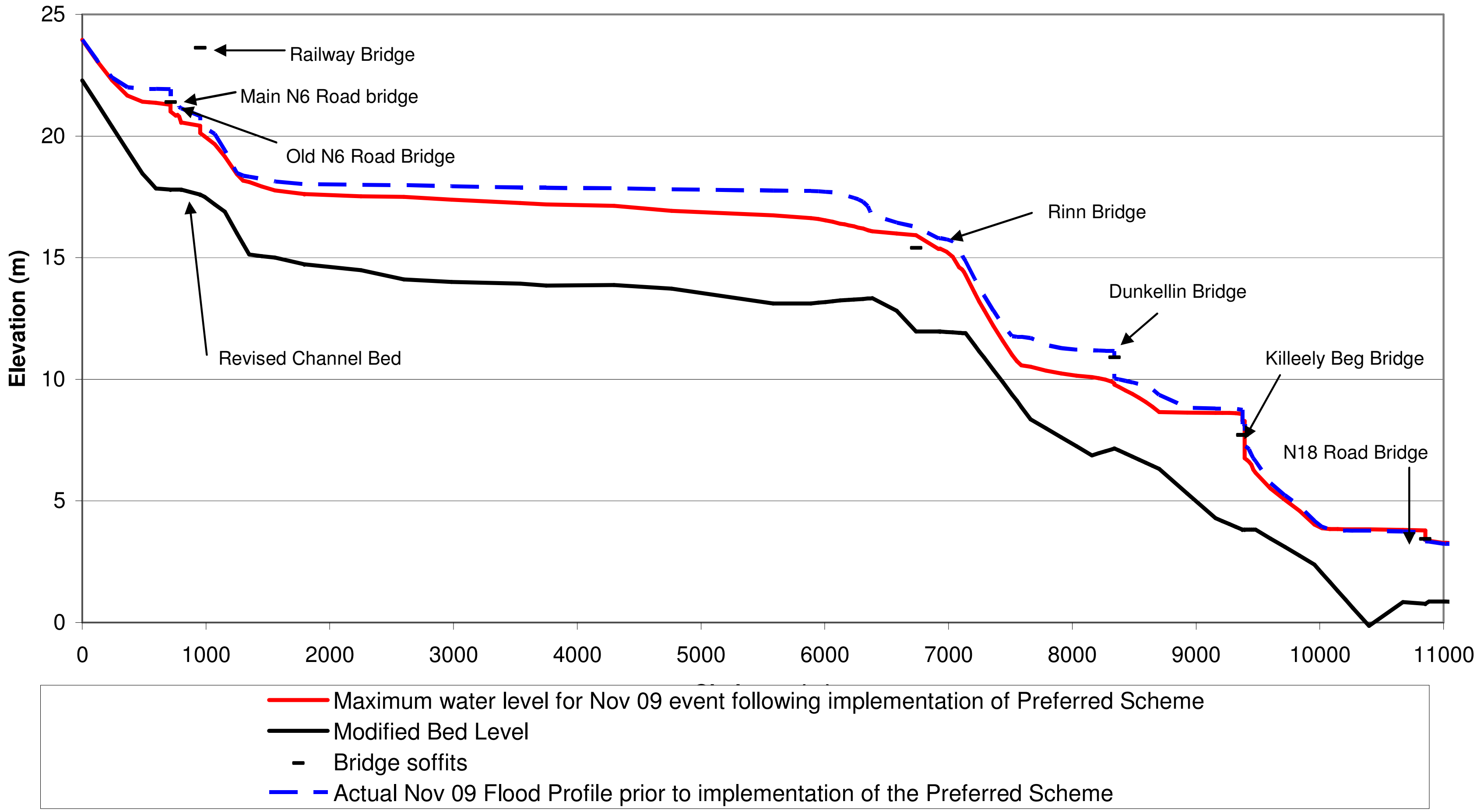

Figure 6.14 Predicted Surface Water Profile for the Dunkellin River for the November 2009 Flood when modelled under the Preferred Scheme

From Figure 6.14 it can be seen that the flood alleviation measures considered under the Preferred Scheme offer a predicted reduction in the maximum level of an extreme flood event, similar in magnitude to that recorded in November 2009, for the majority of the Dunkellin River. Again, it can also be seen from Figure 6.14, that the proposed bypass channel and culvert at Killeely Beg offers little benefit. However, if the Killeely Beg Bridge was replaced in full by a larger spanned bridge, together with the 50% increase in channel width, the predicted hydraulic gradient upstream of the bridge could be largely continued through to the downstream channel.

The predicted difference in water level for extreme flows, when compared with the 100 Year Return Flood (design flow), at the main hydraulic structures along the Dunkellin River are as follows :

Table 6.4: Preferred Scheme - Predicted Difference in the Surface Water Profiles for the November 2009 Event Pre & Post Works

Description of Location	Predicted Level of Surface Water Profile for Nov 2009 Flood Event Pre Works (mOD Malin)	Predicted Level of Surface Water Profile for Nov 2009 Flood Event Post Works (mOD Malin)	Difference in Water Level (mm)
Main N6 Road Bridge	21.93	21.28	- 650mm
Railway Bridge	20.82	20.42	- 400mm
Central portions of the Rahasane Turlough cSAC	17.87	16.92	-950mm
Outlet From the Rahasane Turlough	17.68	16.4	- 1280mm
u/s of Rinn Bridge	16.26	15.37	-890mm
u/s of Dunkellin Bridge	11.17	9.99	- 1,180mm
u/s of Killeely Beg Bridge*	8.79	8.57	- 320mm*
u/s of Kilcolgan Bridge	3.74	3.81	+70mm

* Note : Results for Bypass Channel only - Full Bridge replacement will improve on predicted water levels

Again, from the predicted changes shown in Table 6.3, it can be seen that it is predicted that localised flooding will occur on the N18, when the 100 Year Return Flood coincides with a high tide at Kilcolgan.

6.6 ALTERNATIVE FLOOD MEASURES CONSIDERED

In addition to the works proposed under the Preferred Scheme, as discussed in Section 6.5, an examination of the impact of retaining the old N6 bridge Crossing (multi-arched bridge), whilst implementing the proposed channel deepening within Craughwell, has also been examined.

In this particular modelling scenario, the old bridge was retained and all of the six existing arches were deepened to reflect the proposed downstream channel deepening works, i.e., the base of the bridge was lowered by 0.5m. Figure 6.15 shows the predicted model results for the November 2009 flood event when the bridge is retained (green line) and when the bridge is removed (red line). The actual November 2009 flood is also shown in blue.

It can be seen that retention of this multi arched bridge does not offer the same degree of protection from the November 2009 year flood when compared with its complete replacement. The predicted difference in water level is approximately 400mm i.e., the difference between the red and green lines and the water level is also predicted to overtop the Main N6 Bridge crossing.

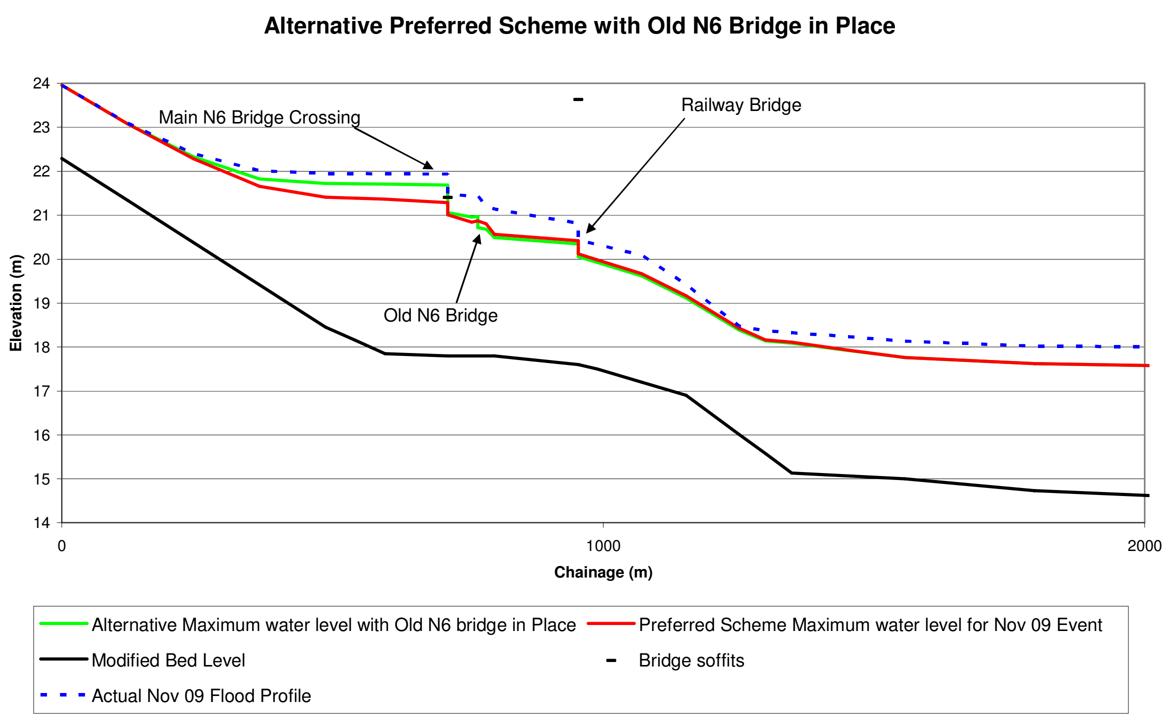

Figure 6.15 Predicted Surface Water Profile at the Old N6 Bridge Crossing (before and after its removal)

7 ESTIMATED CAPITAL COSTS AND ASSESSMENT OF SCHEME BENEFITS

7.1 ESTIMATED CAPITAL COST OF THE PREFERRED SCHEME

In arterial drainage works the estimation of costs can be broken down into two distinct methods:

a. forecasting the method of execution and computing expenditure on consumption of materials, operatives time (labour) and equipment needed (plant), or

b. by breaking down the work into individual components and applying known costs from recent drainage works to estimate the expenditure.

The overall cost estimates, contained with this report, have been prepared in association with OPW staff by utilising available works studies and recent drainage works costs.

The estimated capital cost can be summarised under five main headings:

i) channel maintenance and improvement works,
ii) channel excavations where it is has been recommended to revise bed profiles or increase the width,
iii) bridge works where it is proposed to replace existing bridges,
iv) the provision of flood eyes and bypass channels where required, and
v) the addition of overheads and potential compensation and remedial costs due to the removal/storage of spoil.

The estimated Capital Cost of the Preferred Scheme is €3,843,707 including VAT @13.5% and is summarised in Table 7.1.

Table 7.1: Estimated Capital Cost

Item	Description of Location	Preferred Scheme	Length of Works (m)	Rate	Estimated Capital Cost
1	Works at Kilcolgan & N18 Bridges	No measures considered	N/A	N/A	N/A
2	Channel Works from the N18 Bridge to Killeely Beg Bridge	Widen channel by an equivalent 50% across a two stage channel.	1400	30% of works costed @ €364.15 Per m run in rock 70% of Works costed at €167.85 per m run in overburden	€317,436
3	Works at Killeely Beg Bridge	Replace Bridge in Full with New Bridge to match new channel width	Increased bridge opening	N/A	€300,000
4	Channel Works from Killeely Beg Bridge to Dunkellin Bridge	Widen channel by 50%	1000	30% of works costed @ €364.15 Per m run in rock 70% of Works costed at €167.85 per m run in overburden	€226,740
5	Works at Dunkellin Bridge	Retain the existing main stone arch and replace flood eyes in full with a new bridge crossing.	New Large Flood Eyes	N/A	€400,000

Table 7.1 continued : Estimated Capital Cost

Item	Description of Location	Preferred Scheme	Length of Works (m)	Rate	Estimated Capital Cost
6	Channel Works from Dunkellin Bridge to Rinn Bridge	Widen channel by 50% between bridges and remove approximately 180m of rock within the existing channel.	1350	All of these works are measured in rock cut @ €364.15 Per m run	€491,602
7	Works at Rinn Bridge	Bypass culvert adjacent to Rinn Bridge.	Bypass Culvert	N/A	€200,000
8	Channel Works from Rinn Bridge to the Rahasane Turlough	Widen the existing channel by 50% and improve conveyance of the banks.	700	50% of works costed @ €364.15 Per m run in rock 50% of Works costed at €167.85 per m run in overburden	€186,200
9	Channel Works from Aggard Stream to the Railway Bridge	Deepen by up to 1.0m to take out the hump in the river bed.	575	20% of works costed @ €364.15 Per m run in rock 80% of Works costed at €167.85 per m run in overburden	€119,088

Item	Description of Location	Preferred Scheme	Length of Works (m)	Rate	Estimated Capital Cost
10	Railway Bridge in Craughwell	Deepen river bed under bridge, using scour protection such as a flume to ensure that the structure is not impacted upon.	Channel Deepening & Underpinning Required		€300,000
11	Channel & Bridge Works in Craughwell	Remove old N6 bridge (Multi Arch Bridge) & Deepen channel by up to 0.5m including minor bridge works	N/A	Varies	€50,000
	Provisional Sum	Provisional Sum for New Footbridge to Replace Old N6 Bridge	N/A		€150,000
12	**Sub- Total**				**€2,741,060**
13	Aggard Stream	Channel Maintenance Works Along the Aggard Stream	9500	€6.71 Per m run	€63,745
14	Aggard Stream	Replacement of 14 No. Culverts	14	€10,000.00	€140,000.00
15	**Sub- Total**				**€2,944,805**
16	Add Preliminaries, General Items and Compensation	Assume a 15% increase for this element		15%	€441,721
17	**Sub-Total**				**€3,386,526**
18	Add VAT			13.50%	€457,181
19	**Total Estimated Capital Cost**				**€3,843,707**

7.2 ASSESSMENT OF SCHEME BENEFITS

The potential benefits of the proposed works can be summarised under the following headings :

- reduction in the risk of damage to residential and commercial property along the reaches of the channel, together with the costs of emergency accommodation for affected persons,
- reduction in risk of economic loss to commercial properties particularly in Craughwell Village and in the townlands of Shanbally (Rahasane Turlough) and Killeely Beg.
- reduction in the extent of agricultural lands damaged and improvements to lands normally flooded during extreme weather events,
- reduction in the overall social disruption in the Craughwell environs,
- reduction in the risk of disruption and delays to traffic in the region.
- reduction in the extent of emergency measures required to deal with particular design floods.

The Office of Public Works requires any applicant for funding to demonstrate the economic viability of the project by undertaking a cost - benefit analysis.

This assessment ahs been carried out, using the document entitled *"The Benefits of Flood and Coastal Defence: Techniques*" and data for 2005, as published by Middlesex University (known as Multi Coloured Manual (MCM)) and the approach developed for the UK by the Flood Hazard Research Centre but adapted for the Irish situation.

This section of the report summarises the cost-benefit analysis undertaken for the Dunkellin flood alleviation scheme and outlines the strategy level appraisal that has been carried out in accordance with the assessment techniques as set out in the Flood Hazard Research Centre and in line with the requirements of the OPW.

7.2.1 Flood Damage to Residential Properties

A strategy level project appraisal, as set out under section 4.5.2 of the Multi-coloured Manual, makes use of the number of residential properties in a benefit area. Approximate flood alleviation benefits are based on assumptions about the depth of flooding for different return periods. The Multi-coloured Manual gives a weighted Annual Average Damage (AAD) figure for the average property.

At present, the Dunkellin River does not have a flood warning system, and no flood defences have been installed. As such, the Multi-coloured Manual recommends the use of an Annual Average Damage figure of £6,027 per property as detailed in Table 4.17 of the manual.

Prices given in the Multi-coloured Manual 2005 are at mid-2005 prices, and in British Pound Sterling (GBP). These prices have been converted to Euro and Irish prices using the most recent Purchasing Price Parity figures available. Purchasing Price Parity figures are the rates of currency conversion that eliminate the differences in price levels between countries, and are determined by the Organisation for Economic Co-operation and Development (OECD).

Per capita volume indices based on Purchasing Price Parity converted data reflect only differences in the volume of goods and services produced. Comparative price levels are defined as the ratios of Purchasing Price Parity figures to exchange rates. They provide measures of the differences in price levels between countries. The Purchasing Price Parity figures are given in national currency units per US dollar. The price levels and volume indices derived using these Purchasing Price Parity figures have been rebased on the OECD average.

The OECD gives a Purchasing Price Parity figure of 1.010 for Ireland in 2005, where the UK has a figure of 0.636. This results in a conversion factor of 1.588 to establish the Annual Average Damages in Euro for the Irish situation in 2005 of €9,570.88 per property.

However, the base date for this study is April 2010. The mid-2005 prices of the Multicoloured Manual have been converted to April 2010 prices using the Irish Consumer Price Index (CPI). The CPI figures have been obtained from the Central Statistics Office website. The Central Statistics Office have determined the CPI for 2005 at 111.5 and for April 2010 (latest available) a CPI of 118.9 is given. This results in a conversion factor of 1.066 to bring the AAD to present day value.

The Annual Average Damages used in this study, for April 2010, is therefore estimated to be €10,202.56 per property.

The amount of properties benefitting from the scheme is twenty (20), resulting in an overall AAD of €204,051.20.

The design life of the flood alleviation scheme is estimated to be 50 years. The Net Present Value (PV) of potential flood damage within the flood management unit has been calculated over that 50 year period in accordance with "The Green Book" published by HM Treasury. The *"Green Book"* states as follows :

"The main rationale for declining long-term discount rates results from uncertainty about the future. This uncertainty can be shown to cause declining discount rates over time."

The following discount rates have been used in accordance with the discount rate as set by the OPW and the declining long-term discount rates as per the Table 6.1 from "The Green Book - Appraisal and Evaluation in Central Government by HM Treasury".

- 4.0% for the period 0-30 years, and
- 3.5% for the period 31-75 years.

The net present value of the damages can be calculated by discounting the Average Annual Damage at the discount rate over the 50 year design life period. The present value factor to apply to the annual average damage is 23.42, based on the discount rates given above, and assuming no change in the AAD value in each year, i.e. when no allowance for climate change is made. The Net Present Value of Damage for the Dunkellin River Study area can be estimated to be €4,778,879.

7.2.2 Road Disruption

A further strategy level appraisal, as set out under Section 6 of the Multi-coloured Manual, makes use of the estimated number of vehicles which were diverted around Craughwell during the November 2009 event. The Main N6 Road Crossing was closed for a total four days and traffic was diverted to the new M6 Motorway, which was opened temporarily for these four days. This road resulting in diversions of >10km.

The Multicoloured Manual (FHRC,2005) notes that the traffic diversion costs incurred in a flood can be calculated by using the following equation.

Number of Vehicles * Additional Cost per Vehicle * Number of Hours that the flood Lasts **Eqn. 8**

For the purposes of this study, the number of vehicles diverted in November has been estimated to be a total of 10,000 per day in both directions (NRA Website – Traffic Counter located along the old N6 at Kilreekil, Co. Galway).

The additional cost per vehicle has been estimated to £0.14 GPB from Table 6.3 of the Multicoloured Manual. This can be estimated to be approximately €0.237 per vehicle, by applying the same Purchasing Price Parity figures and Irish Consumer Price Index factors detailed in Section 7.2.1.

Therefore the additional cost of the November 2009 Flood, can be calculated to be €226,560.00 for the four days that the road was closed.

7.2.3 Other Cost Benefits

The Multicoloured Manual (FHRC, 2005) describes a series of other flood damage costs which could also be used to assess the benefits of the proposed flood alleviation measured considered under this particular study.

Other such damage costs can include :

1. Flood Damage to Non-Residential Properties,
2. Emergency Costs,
3. Recreational Losses including landscape, wildlife and natural amenities ,
4. Agricultural losses

However, due to the overall strategic level view undertaken in this particular study, and high level of input data required, these additional analyses have not been undertaken at this point.

However, from the following Section 7.3, it can be seen that by taking the residential and traffic cost into account, the current benefit to cost ratio would only be improved upon its current positive conclusions.

7.3 COST BENEFIT RATIO

Referring to Table 7.1 and the calculations contained in Sections 7.2.1 and 7.2.2, the Benefit to Cost Ratio for the Preferred Flood Alleviation Scheme can be calculated as follows :

Estimated Benefit resulting from Implementation of the Preferred Scheme	
Present Value Cost of Annual Average Residential Damages	€4,778,879
Cost of Traffic Diversions	€226,560
	€5,005,439
Estimated Capital Cost of the Preferred Scheme	€3,843,707
Benefit/Cost Ratio	**1.30**

8 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY & CONCLUSIONS

A hydraulic model of the Dunkellin River and the Aggard Stream has been developed as part of this Study, to test a series of proposed flood alleviation measures against the expected benefits of including these measures in an overall package of works.

The hydraulic model, which was calibrated against recorded flood events across four automatic gauge recorders within the Dunkellin Catchment, has been used initially, to develop two Strategic Level Schemes and predict the changes in the surface water profile as a result of the proposed flood alleviation measures.

Taking into consideration the ecological status of the Dunkellin River, more particularly the Rahasane Turlough cSAC, and the extent of the predicted reductions in the 100 Year Return flood level, a Preferred Scheme has been established.

The Preferred Scheme, which uses elements of the two Strategic Schemes, examines the impact of works associated with :

- widening of particular lengths of the channel,
- the use of a bypass culvert at Killeely Beg and Rinn Bridges,
- the replacement Dunkellin Bridge,
- deepening of the bed level at the Railway Bridge and N6 bridges,
- the removal of the old N6 bridge crossing in Craughwell Village,
- channel maintenance and improvement works including culvert replacement, along the Aggard Stream, Monksfield River and Cregaclare Channel up to the townland of Lackan, and
- Completing the connecting of the bypass channel to the main channel just upstream of Craughwell.

The model of the Preferred Scheme, predicts that varying degrees of flood protection, from the 100 Year Return Event, can be achieved at five main locations along the Dunkellin River from Craughwell to Kilcolgan.

Within Craughwell Village it is predicted that the removal of the old N6 Bridge Crossing coupled with deepening of the channel will offer a reduction of up to 490mm in flood levels at the N6 Bridge Crossing, when compared with the 100 Year Return Design Flood. Further deepening and under-pinning of the Railway Bridge will offer a predicted reduction of 520mm in this location.

Along the northern shores of the Rahasane Turlough cSAC, it is predicted that a reduction of 750mm in flood levels can be achieved, when compared with the 100 Year Return Design Flood.

Within the townland of Rinn, it is predicted that the provision of a bypass channel and culvert together with widening of the channel upstream and downstream of the structure will offer a reduction of 430mm in flood levels at the bridge, when compared with the 100 Year Return Design Flood.

The complete replacement of the Dunkellin Bridge, is also predicted to offer a reduction of 1,200mm in flood levels, when compared with the 100 Year Return Design Flood.

Within the townland of Killeely Beg, it is predicted that the provision of a bypass channel and culvert together with widening of the channel upstream and downstream of the structure will offer little by way a change in flood levels, when compared with the 100 Year Return Design Flood. However, following further consideration of the predicted hydraulic profile, the complete replacement of the Killeely Beg Bridge beyond the proposed channel width, has the potential to offer a reduction of up to 1,100mm upstream of the bridge.

It is also concluded that other works such as :

- the removal of the salmon counter in Killeely Beg,
- the re-opening of existing flood eyes at Dunkellin Bridge, and
- the removal of the central pier at Rinn Bridge,

have minimal impact on the predicted surface water profile for the Dunkellin River as a result of the 100 Year Flood Event.

It is also concluded that channel maintenance and improvement works including the replacement of culverts along the Aggard Stream to Lackan Townland has a negligible impact on predicted flood levels along the Dunkellin River.

The Present Value Cost of annual average flood damages, resulting from the events similar to that which occurred in November 2009 event, has been estimated to €4,778,879 in accordance with the Multicoloured Manual (FHRC, 2205).

The Capital Cost of the Preferred Scheme has been estimated to be € 3,843,715 including VAT @13.5% and by comparing the Present Value Damage with this cost, it can be concluded that it is financially feasible to complete the proposed works detailed in the Preferred Scheme and reduce the flooding impact of the 100 Year Return Flood Event and other more extreme events such as that which occurred in November 2009.

8.2 RECOMMENDATIONS

To address flooding within the study area, a 100 Year Return Flood has been used, as a design criteria, to predict the outcome of providing a number of flood alleviation measures at five main locations along the Dunkellin River and providing channel maintenance and improvement works along the Aggard Stream. The study concludes that it is financially feasible to complete the proposed flood alleviation measures, as detailed in the Preferred Scheme, and therefore reduce the flooding impact resulting from the 100 Year Return Flood Event.

It is therefore recommended that the following is carried out :

- Early consultation, particularly with regard to potential ecological impacts, should be entered into with the relevant Stakeholders, including :

  i) Galway County Council Technical Staff, and
  ii) Galway County Council Elected Members
  iii) the Development Applications Unit of the Department of the Environment, particularly the National Parks & Wildlife Service,
  iv) the Irish Farmers Association,
  v) Iarnrod Eireann,
  vi) Western Fisheries Board,
  vii) Western River Basin District Project Office,
  viii) Bord Iascaigh Mhara,
  ix) The Clarinbridge Oyster Co-Operative Society, and
  x) The National Roads Authority.

- A thorough land registry search should be carried out to establish the legal owners of the lands and to enter into discussions with landowners and relevant stakeholders regarding the implementation of the Preferred Scheme.

- Given the potential impacts on the Rahasane Turlough cSAC and the Galway Bay Complex, an "Appropriate Assessment" should be carried out in accordance with Article 6(3) of the Habitats Directive. This assessment may take the form of an Environmental Impact Statement, where under the Schedule 5, Part 2, Item 10 (f) of the Planning and Development Regulations 2001 (SI 600 of 2001), it is stated that an EIA is required for :

  "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."

Appendices

Appendix No. 1 Drawings

Appendix No. 2 Graphical Representation of Hydrographs

Appendix No. 3 Hydrometric Data

Appendix No. 4 Main Culverts along the Aggard Stream and Monksfield River

Appendix No. 1

Drawings

1. Scheme Overview and Location Map
2. Flood Plain Map from the November 2009 Event
3. Longitudinal Sections of Dunkellin River
4. Sketches of the Proposed & Existing Bridges along Dunkellin River

Appendix No. 2

Graphical Representation of Hydrographs

Appendix No. 3

Hydrometric Data

Appendix No. 4

Main Culverts along the Aggard Stream and Monksfield River

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