



ESB Energy International
Production Engineering
Generation Operations

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Executive Summary

ESB operates hydro-electric power plants on five rivers in Ireland, i.e. Rivers Liffey, Lee, Shannon, Erne and Clady, and a pumped storage scheme at Turlough Hill. Dams and embankments form part of the infrastructure associated with these schemes. A preliminary flood risk assessment for ESB's dams and embankments has been undertaken to address the requirements of EU Directive 2007/60/EC on the Assessment and Management of Flood Risks and the European Communities (Assessment and Management of Flood Risks) Regulations (S.I. No. 122 of 2010). This preliminary flood risk assessment was undertaken to assess the role of the dams and embankments during past floods and also during potential future floods with the following flooding scenarios being investigated:

- River Floods Downstream of Dams
- Floods around Reservoirs
- Breaches of Dams or Embankments
- Overtopping of Dams or Embankments
- Operational Malfunctions

For river floods downstream of dams, the preliminary flood risk assessment has indicated that the construction of dams and embankments on the Rivers Liffey, Lee, Shannon, Erne and Clady has not lead to increased flooding downstream of the dams. In fact, the operation of the dams (check rest of report) has beneficial effects with regard to flooding of the areas downstream. Similarly for potential future river floods downstream of dams, the water management procedures that are implemented by ESB are such that even for very extreme design floods, the operation of the dams will have some beneficial effects for downstream flooding.

To cater for increased upstream water levels, ESB acquired lands around reservoirs and lakes upstream of its dams and embankments. There has not been a history of significant flooding above the ESB's land acquisition levels upstream of the dams and embankments. However, during extreme floods, such as the design 10,000-year flood, there is potential for some future flooding above ESB's land acquisition levels.

ESB has an excellent record regarding dam safety and there has never been a breach of any of its dams or embankments. ESB implements

comprehensive dam safety procedures and potential future breaches are considered extremely unlikely.

The water management procedures, in place for ESB's major dams and embankments, require that the extreme design 10,000-year flood can be passed without overtopping the structures. Overtopping of one of ESB's major dams or embankments has never occurred and potential future overtopping is considered extremely unlikely.

Embankments constructed on the River Shannon near Portumna differ from other ESB dams and embankments, in that they were constructed along the bank of the river to prevent low lying lands from flooding during the summer. Overtopping of these embankments has occurred during the largest winter floods. Low lying land and some roads, but no properties, were flooded as a result of this overtopping.

ESB's current dam safety procedures have been in place since 1988. Since then, there has been no flooding as a result of operational malfunctions of water control equipment. These procedures will also protect against potential future operational malfunctions of water control equipment.

ESB has been working with the Office of Public Works and Local Authorities in relation to Catchment Flood Risk Assessment and Management Studies and the implementation of Catchment Flood Risk Management Plans. One of the issues being investigated during these studies is how ESB infrastructure on the rivers might be used to manage or reduce the flood risk from river floods. ESB will continue to work with these bodies during future cycles of this process for the Rivers Liffey, Lee, Shannon, Erne and Clady.

The integrity of the dams and reservoirs and safe water management on the rivers are serious priorities for ESB. The implementation of comprehensive procedures will continue to ensure the safety of the dams and embankments at all times. These procedures include the independent evaluation of ESB's dam safety activities by the External Dam Safety Committee of international experts. Contacts will be maintained with international experts, through the External Dam Safety Committee, and with international dams organisations through the International Commission on Large Dams. Where identified, advances in the state-of-the-art with regard to dam safety will be implemented to ensure that procedures continue to be improved.

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1 Introduction to Preliminary Flood Risk Assessment

1.1 Introduction

The ESB is the owner of 16 major dams and 14 other dams on 5 river systems and a pumped storage plant in Ireland. The dams were constructed between 1929 and 1973 to the highest standards of the day. However, there have been significant developments in dam safety and reservoir engineering since the dams were constructed. Therefore, in the mid 1980s, ESB commissioned flood control and dam safety studies to check the dams for compliance with modern standards and practices. These studies identified areas where improvements or upgrading works were required in order to bring the ESB's dams into compliance with modern standards and practices.

These improvements and upgrading works have been undertaken and ESB is confident that its dam safety standards comply with current international practice. This is confirmed by independent evaluation by an External Dam Safety Committee of international experts, which carries out regular inspections of the dams and embankments.

The purpose of this document is to address the preliminary flood risk assessment requirements of the following in relation to ESB's dams and embankments:

- EU Directive 2007/60/EC on the Assessment and Management of Flood Risks
- S.I. No. 122 of 2010 – European Communities (Assessment and Management of Flood Risks) Regulations

These legislative documents require that previous floods that have occurred are described and that potential sources of future floods are assessed. Therefore, this preliminary flood risk assessment for ESB's dams and embankments will be undertaken under the following broad headings:

- Past Floods
- Potential Future Floods

1.2 ESB Dams and Embankments

The following ESB dams and embankments are covered by this report:

River Liffey:

Pollaphuca Dam – concrete gravity dam

Dry Gap Embankment – earthfill embankment

Golden Falls Dam – concrete gravity dam

Leixlip Dam – concrete gravity dam



Figure 1.1 Pollaphuca Dam and Reservoir

River Lee:

Carrigadrohid Dam – concrete gravity dam

Inniscarra Dam – concrete buttress dam

River Shannon:

Ballintra Sluices – concrete gravity dam

Lough Allen Embankment – earthfill embankment

Portumna No. IV Embankment – earthfill embankment

Portumna No. V Embankment – earthfill embankment

Portumna No. VI (a) Embankment – earthfill embankment
Portumna No. VI (b) Embankment – earthfill embankment
Kilmastulla Embankment – earthfill embankment
Fort Henry Embankment – earthfill embankment
Ardclooney Embankment – earthfill embankment
Parteen Weir and Canal Intake Structure – concrete gravity dam
Ardnacrusha Headrace Left Bank – earthfill embankment
Ardnacrusha Right Bank – earthfill embankment
Ardnacrusha Dam – concrete gravity dam



Figure 1.2 Ardnacrusha Dam

River Erne:

Cliff Dam – concrete gravity dam
Erne Embankment No. 1 – earthfill embankment
Erne Embankment No. 2 – earthfill embankment
Erne Embankment No. 3 – earthfill embankment
Cathaleen's Fall Dam – concrete gravity dam

River Clady:

Cung Dam – earthfill embankment

Gweedore Weirs – concrete gravity dam

Clady Headrace Left Bank – earthfill embankment

Clady Headrace Right Bank – earthfill embankment

Dore Intake – concrete gravity dam

Turlough Hill Pumped Storage Plant:

Upper Reservoir Embankment – rockfill embankment



Figure 1.3 *Turlough Hill Upper Reservoir*

The locations of ESB's major dams are indicated on the map in Figure 1.4. More detailed maps indicating the locations of dams and the extent of embankments are provided in Appendix A.

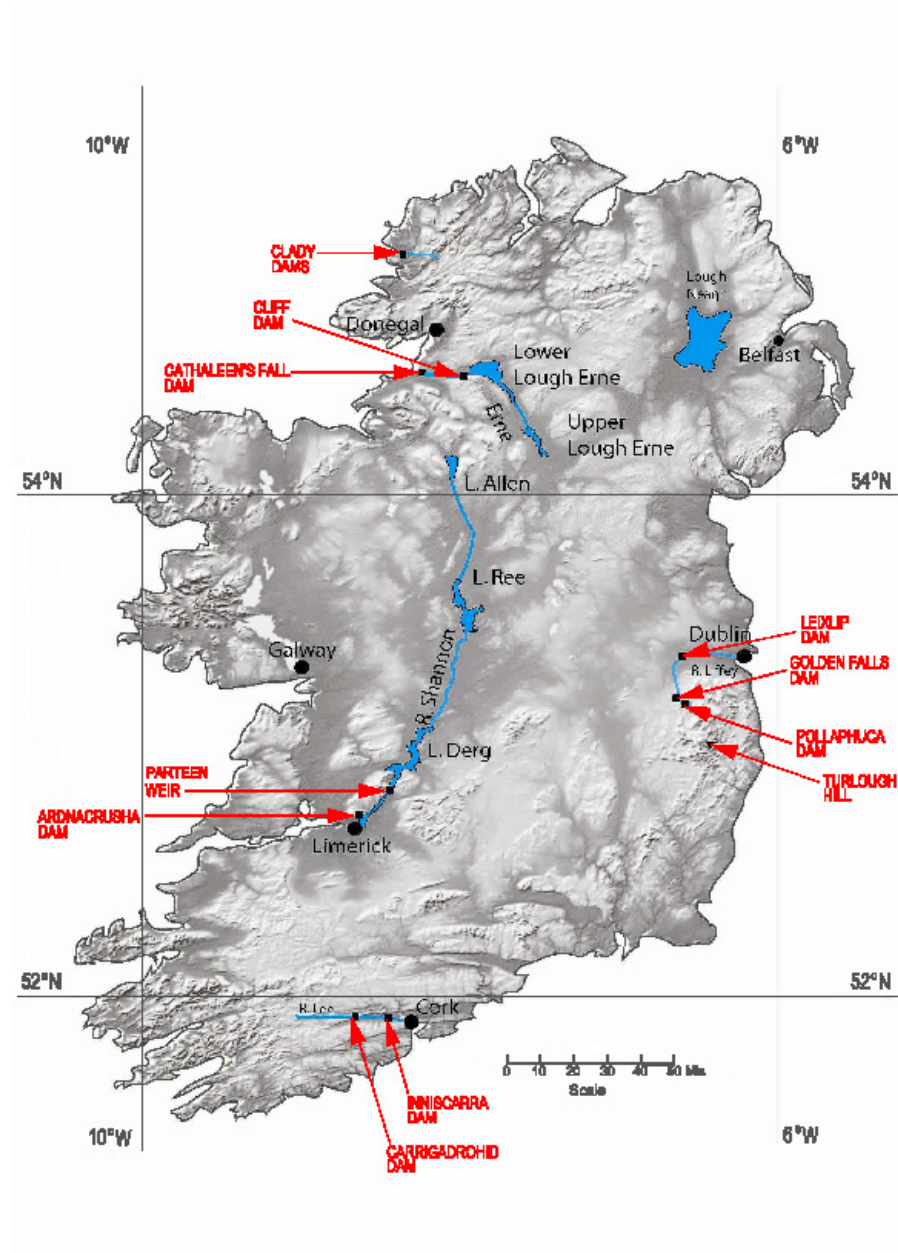


Figure 1.4 Locations of Major Dams

1.3 Dam Safety Standards

1.3.1 Introduction

Dam and embankment safety is ESB's key priority in relation to the operation of its hydro-electric schemes on the Rivers Liffey, Lee, Shannon, Erne and Clady. Dam safety activities in ESB are governed by the "ESB Dam Safety Organisational Structure", since it was approved by the ESB Board of Directors in 1988. The latest revision of this was approved by the ESB Board of Directors in September 2009. This document defines the roles and responsibilities of dam safety personnel in ESB.

The ESB Chief Civil Engineer, who is designated as the Responsible Engineer for Dam Safety, ensures that rigorous surveillance procedures and ongoing compliance checks, required by the "ESB Dam Safety Organisational Structure", are carried out.

ESB dam safety performance is also independently evaluated by an External Dam Safety Committee (EDSC), which carries out scheduled inspections and reviews. The EDSC recommends additional dam safety improvements where deemed necessary and certifies their approval to the Board of ESB. The EDSC consists of internationally recognised dam experts, whose chairman is appointed by the ESB Board of Directors. The chairman selects other specialist experts to assist him in assessing the safety of ESB's dams.

The purpose of this section is to summarise the design criteria and safety standards adopted by ESB to ensure against dam and embankment failures. It covers the key areas of hydrology, geotechnical and structural integrity, water control equipment and operational management. It is intended to inform the preliminary flood risk assessment process, in relation to the safety of ESB's dams and embankments.

1.3.2 Hydrology

ESB has categorised its dams in a similar manner to the Institution of Civil Engineers (UK) guide; "Floods and Reservoir Safety". Dams are categorised based on the consequences of a breach. ESB's 16 major dams and embankments on the Rivers Liffey, Lee, Shannon and Erne are "Category A" dams, where a breach "could endanger lives in a community". The following are the design flood standards used by ESB for its Category A dams:

- Ability to pass the 10,000 year flood without overtopping the dam crest when all spillway gates are in operation
- and
- Ability to pass the 1,000 year flood with one spillway gate unavailable and with a freeboard allowance for wave run-up

In addition to its 16 major dams, ESB has four other significant dams, i.e. Cunga Dam, Gweedore Weirs, Dore Intake Structure (all River Clady) and Bellantra Sluices (Lough Allen). These are not “Category A” dams, as it is considered that there would be negligible risk to human life in the case of a dam breach. The following design flood standard is used for these dams:

- Ability to pass the 1,000 year flood with one spillway gate unavailable and with a freeboard allowance for wave run-up

The above standards and their associated design flood levels are also applied to any embankments, including headrace canals, associated with each dam.

Where necessary to safely pass the design floods, reservoir or spillway capacities were increased. In addition, downstream channel protection and improvement works were carried out as required to ensure the safe passage of extreme floods.

Water Control Regulations have been produced for the Rivers Liffey, Lee, Shannon and Erne, to ensure the safe operation of the dams, particularly during floods. During floods the top priority is the proper management of the flood to avoid any risk to dam safety.

In keeping with widespread international practice, downstream inundation studies have been undertaken for the above dams. These studies address the downstream effects of the design flood events as well as dam breaches. These studies have been presented to relevant Local Authorities on the Rivers Liffey, Lee, Shannon and Erne.

1.3.3 Dam Structures

1.3.3.1 Geotechnical Criteria

Extensive site investigations, employing eminent geologists and utilising the most up to date techniques at the time were carried out during the

original design and construction of ESB's dams. As part of the flood control and dam safety reviews started in the mid 1980's, further site investigations were carried out to enhance these original investigations and comprehensive geological mapping was undertaken for each "Category A" dam. Interpretation of the combined geological investigations and mapping by prominent external contemporary geologists has resulted in revised assessments of foundation rock parameters from those that were used in the original designs. These, together with re-evaluated embankment fill parameters, have been employed in stability reassessments.

1.3.3.2 Seismic Criteria

In accordance with accepted practice at the time in Ireland and the U. K., seismic loading was not considered in the original design of ESB Dams. However, as modern earthquake engineering design methods were developing in the 1970's and 1980's and as some minor earthquake events were experienced in Ireland, ESB, as part of their overall review of dam safety, initiated studies into the effects of earthquake loading on its dams. Superimposed static lateral loads equivalent to the dynamic seismic loads resulting from the 10,000 year earthquake were employed in the studies.

1.3.3.3 Concrete Dams

Following a review of international practice, the following load combinations were generally considered in re-evaluating factors of safety for sliding and overturning for ESB's "Category A" concrete dams:

Load Case	Water Level	Uplift	Other Loads	Factor of Safety
Unusual Load Case 1	MNOL	100%	-	1.3
Unusual Load Case 2	CWL	50%	-	1.5
Extreme Load Case 1	MNOL	100%	10,000 Year Earthquake	1.1
Extreme Load Case 2	CWL	100%	-	1.1

MNOL = Maximum Normal Operating Level

CWL = Crest Water Level

The crest water level is used as the 10,000 year flood level for design purposes, as this is the maximum level allowed by the hydrology standards above.

The principal exception to the above table is Leixlip Dam, where particular foundation conditions exist and a more detailed stability assessment was required.

Dam stability assessments indicated that some dam blocks did not fully comply with the more stringent modern requirements set out above, generally with regard to the sliding mode for Extreme Load Cases. In these cases dam stability improvement works were undertaken to ensure that all of ESB's "Category A" dams satisfy the above requirements. These works mainly comprised installation of rock anchors and infilling voids with concrete. More general improvement measures were also undertaken regardless of the results of the stability assessments. These comprised rock grouting, joint sealing and relief drainage.

1.3.3.4 Embankments

In addition to the construction of concrete dams for the ESB hydro-electric schemes, extensive embankments were constructed to form headraces or secondary reservoir containment structures. These embankments were designed and constructed in accordance with the best practices at the time.

In 1979, following a "non critical" slip on one of the Shannon Reservoir embankments, ESB commissioned Swedish consultants SWECO to carry out a major review of the Category A Shannon Embankments, i.e. Ardnacrusha Headrace, Fort Henry and Ardcloney Embankments. This very comprehensive review, investigated the performance and stability of these embankments, with stability checks being carried out on representative sections of embankments. For the purposes of this review and also for subsequent stability studies, two conditions have been considered:

- Likely Conditions – Analyses use the "best estimate" soil parameters and the likely pore water pressures, as measured by piezometers, with the requirement for a minimum factor of safety of 1.3
- and
- Conservative Conditions – Analyses use the "worst credible" soil parameters and conservative pore water pressures, taken as 1m above measured values, with the requirement for a minimum factor of safety of 1.0

The earthfill embankments on Assaroe Lake (Cathaleen's Fall Reservoir) on the River Erne were originally designed to have a minimum factor of safety of 1.5.

The rockfill embankment forming the Upper Reservoir at Turlough Hill Pumped Storage Scheme was originally designed to have a minimum factor of safety of 1.2.

Evaluations of all ESB “Category A” embankments have indicated that their stability is ensured under the relevant seismic conditions.

Extensive surveillance, maintenance and improvement works are carried out on the embankments on an ongoing basis, e.g. daily inspections of earthfill embankments, drainage improvements, berm construction, grouting, lining repairs, etc. Of particular interest in relation to the Shannon Embankments, was the undertaking of extensive improvement works to address the recommendations of the SWECO Report.

1.3.4 Water Control Equipment

The water control equipment originally installed at ESB's dams was to the best standards available at the time of construction and had proved very reliable over the years. In the late 1980s, the ESB dam safety review identified water control equipment as requiring critical examination in the context of modern technology and control systems. With this in mind and to address the relevant recommendations of the External Dam Safety Committee, a Working Party on Water Control Equipment was established to ensure that the design philosophy, detailed design of mechanical and electrical components and control and instrumentation systems, physical condition of plant, operating procedures and staffing comply with best current international standards, codes and practice and thereby provide the highest possible degree of reliability in operation of the water control equipment.

A programme of total refurbishment of water control equipment was undertaken during the 1990s to address the recommendations of the Working Party.

Computerised programmes are in place that ensure regular testing and maintenance of all water control equipment is carried out.

1.3.5 Operations and Surveillance

1.3.5.1 Operations

To ensure dam safety, generation of electricity at the hydropower plants must be carried out within the framework of the requirements of ESB's internal Water Control Regulations. These regulations cover all aspects of water control, including maintenance of seasonal upstream and downstream water levels and navigational requirements and taking account also of catchment hydrological factors, and the dams capacity to discharge floods.

The ESB Chief Civil Engineer as "Responsible Engineer" carries overall responsibility for dam safety and issues regulations and guidelines as required. He/she has the authority and the responsibility to make final decisions relating to dam safety. This ensures a quick response to all deviations of normal dam performance, especially in cases of emergency and avoids gaps between conflicting responsibilities.

All of ESB's dams are operated under the direction of the Hydro Stations Manager. For each river system, the Hydro Stations Manager is assisted by a Plant Manager and a Supervising Engineer. The Supervising Engineer also reports to the Chief Civil Engineer on matters relating to dam safety and ensures that the regulations and guidelines are properly interpreted and applied. The Supervising Engineer personally carries out surveillance on the dams, manages a comprehensive monitoring system, and certifies the safety of the dams in his area each month.

Consultancy services relating to dam safety are provided by ESB International.

1.3.5.2 Surveillance

Surveillance is an essential activity in the operation of ESB's Dams and the Supervising Engineer on each river system is responsible for surveillance activities. To assist the Supervising Engineer, comprehensive Structural Safety Surveillance Manuals have been prepared for all of the major dams. These contain a full description of the performance and technical aspects of each dam. The surveillance activities include dam monitoring and inspections.

Dam monitoring instrumentation for measuring movement, uplift pressures, seepage, temperatures, etc. has been installed on ESB's dams to detect any unfavourable trends in performance. To date, in excess of 1,500

monitoring points have been installed and new instrumentation is added as requirements are identified. The measured data is recorded on a networked computerised database called "DAM MONITOR". Following stability studies alert values have been assigned to selected readings which, if exceeded, raise an indicator. This allows such readings to be double checked and if necessary remedial measures to be put in place.

Regular inspection of the dams, embankments and water control equipment is an integral part of the surveillance activity. Regular inspections are carried out by the Supervising Engineer and his staff. These range from daily and weekly patrolling of critical areas to monthly inspections and certification by the Supervising Engineer. ESB International carries out annual inspections on the dams for ESB. Five-yearly inspections are carried out by the Chief Civil Engineer. The independent External Dams Safety Committee, drawn from specialised experts of international repute, carries out annual and five-yearly reviews, and ten-yearly inspections of the dams. This Committee reports to the Chief Executive of ESB and the Committee's reports are formally presented for noting by the ESB Board of Directors.

1.3.6 Dam Safety Standards - Conclusion

Although there is no dam safety legislation in Ireland, the dam safety practices employed by ESB compare favourably with best practice internationally. ESB operates a comprehensive dam safety management programme, which includes both internal and independent external inspections and reviews of dam safety activities. This programme is intended to ensure the safety of ESB's dams and embankments during both normal operational conditions and during extreme events.

As indicated above, studies have been carried out to assess the safety of the dams and embankments during extreme events, i.e. 10,000-year floods and earthquakes. Where necessary improvement works were carried out to ensure that the structures are capable of withstanding these events. Therefore, the probability of a dam failure causing flooding is assessed as being less than 0.01% in any one year.

In addition, based on the philosophy that a major failure does not take place without warning, the dams are continuously observed. Therefore, ESB implement comprehensive monitoring and surveillance procedures, which ensure that dams and embankments are observed and measurements taken at appropriate frequencies to monitor the behaviour of the structures. This ensures that, if necessary, any deviations from expected behaviour can be assessed and remedied in a timely manner.

1.4 Potential Causes of Flooding at ESB's Dams and Embankments

EU Directive 2007/60/EC on the Assessment and Management of Flood Risks requires that preliminary flood risk assessments assess potential causes of flooding.

The most significant potential causes of flooding at ESB's dams and embankments are significant rainfall events. While the dams are operated so that discharges to the river downstream do not exceed the inflows to the catchment, these events can lead to controlled increased discharges into the rivers. Upstream of the dams, these can lead to increased water levels in reservoirs. Such events will be discussed in more detail in the following sections of this document.

Other potential causes of flooding at ESB's dams and embankments relate to uncontrolled discharges from the dams and embankments. ESB dams and embankments have an excellent dam safety record, due to the dam safety procedures that it implements. Therefore, uncontrolled discharges from the dams and embankments are deemed to be extremely unlikely. However, the following are the main potential causes of flooding resulting from uncontrolled discharges at ESB's dams and embankments that have been identified:

- Dam or embankment breaches
- Overtopping of dams or embankments
- Operational malfunctions

Such potential events will also be assessed in the following sections of this document.

2 Past Floods

2.1 Introduction

Both the EU Floods Directive and the European Communities (Assessment and Management of Flood Risks) Regulations require an assessment of floods that have occurred in the past. This section will examine the role of ESB's dams and embankments on floods that have occurred.

Floods on the rivers, on which ESB's dams and embankments are constructed, have generally occurred as a result of heavy rainfall on the catchments upstream of the structures. However, there are other potential causes of flooding relating to dams and embankments, such as breaches of dams or embankments, overtopping of dams or embankments and operational malfunctions. Each of these issues will be assessed in this section, with particular reference to significant past floods and incidents.

2.2 River Floods Downstream of Dams

Following periods of heavy rainfall, floods can occur on the rivers, on which ESB's dams and embankments are constructed. ESB has produced Regulations and Guidelines for the Control of the Rivers Liffey, Lee, Shannon and Erne, which provide water management procedures for operation of the dams during both routine and flood periods. These procedures ensure that the design 10,000-year floods for Category A dams can be passed without overtopping the dams.

Overtopping of the dams during floods could lead to damage of the structure and its foundations, potentially leading to a failure of part of the dam. Therefore, during flood periods, the Regulations must be applied. In general, a flood period commences when conditions and all available information are such that spilling may be necessary and continues until normal conditions prevail. During a flood period the top priority is the proper management of the flood to avoid any risk to dam safety. All other factors such as efficiency of generation, system requirements, environmental, social, legal and economic considerations are secondary.

The Regulations stipulate that, during a flood, the peak discharge from the catchment shall not be allowed to exceed the peak inflow to the catchment during the rising flood. Generally the Regulations require incremental increases in discharges as river flows or upstream water levels increase during a flood. This provides for the beneficial use of the reservoir storage during a flood, with discharges being less than the inflows. However, these beneficial effects decrease as floods become larger.

Following past significant flood events, ESB International has been commissioned to undertake studies of the floods and how they were managed. These studies broadly involve an analysis of the extent of the rainfall, an examination of the flooding that occurred and how the flood was managed at the dams.

The following is a list of the significant floods for which studies have been carried out by ESB International:

- Liffey Flood June 1993
- Liffey Flood November 2000
- Liffey Flood November 2009
- Lee Flood August 1986
- Lee Flood February 1997
- Lee Flood November 2000
- Lee Flood December 2006
- Lee Flood November 2009
- Shannon Flood Winter 1994-1995
- Shannon Flood Winter 1999-2000
- Shannon Flood Winter 2006-2007
- Shannon Flood November/December 2009
- Erne Flood December 1991
- Erne Flood Winter 1999-2000
- Erne Flood November 2009
- Clady Flood August 1998

Copies of many of the reports on these floods are available on www.floodmaps.ie. Requests for further information can be made to ESB.

2.2.1 River Liffey Floods

The Upper Liffey Catchment, upstream of Pollaphuca and Golden Falls Dams, comprises steep mountainous terrain. These upper reaches of the Liffey Catchment consist generally of blanket bog overlying granite, which gives rise to its flashy response to significant rainfall events. However, Pollaphuca Reservoir is very large in relation to its inflows. During significant floods, the flood storage capacity of the reservoir is used to

restrict discharges to the catchment downstream of Golden Falls Dam. The use of this storage capacity during floods provides major benefits to the areas downstream by significantly reducing flows in the River Liffey between Golden Falls and Leixlip Dams, and also downstream of Leixlip Dam and in Dublin City.

The Middle Liffey Catchment, between Golden Falls, and Leixlip Dam, is relatively flat. In contrast to the Upper Catchment it displays a slow response to rain storms. The flood storage capacity of Leixlip Reservoir is very small and provides only marginal benefits during significant floods. Flows in the River Liffey are augmented by the River Ryewater, which joins the main channel just downstream of Leixlip Dam.

2.2.1.1 Liffey Flood – June 1993

June 1993 rainfall totals recorded over parts of the Dublin-Kildare area exceeded three times the normal June rainfall – this was largely due to severe rainfall on 11th June. This rainfall event resulted in 24 hour totals in excess of 100mm of rain in parts of the Dublin-Kildare area.

The peak hourly inflow to Pollaphuca of 225m³/s was not exceptionally high. However, inflows exceeded 100m³/s for a continuous 24 hour period commencing on 11th June at 8.00 a.m. Indeed, inflows exceeded 200m³/s for a continuous period of 9 hours. The maximum average daily discharge at Pollaphuca of 53.4m³/s occurred on 19th June 1993, when the flood had abated downstream. All the discharge from Pollaphuca was through the sets and no spilling took place.

The inflow to Golden Falls reservoir resulted almost totally from the station discharge at Pollaphuca. The highest recorded post scheme average daily discharge at Golden Falls at that time also occurred during this flood and amounted to 52.80m³/s on 19th June 1993, made up of 31.4ml/s through the station and 21.4m³/s spilling.

The inflow to Leixlip is comprised of two parts - the natural inflow from the Middle Catchment between Golden Falls and Leixlip and the discharge from Golden Falls. The peak inflow to Leixlip was estimated to have been 126m³/s. It was estimated that the natural inflow from the Middle Catchment was in excess of 115m³/s and this was augmented by 11m³/s as a result of running the Station at Golden Falls. Since the storage at Leixlip is small, the flood was passed straight through by means of running the power station and spilling through the spillway gates. Spilling started at 16.00 on June 11th and continued un-interrupted until midnight on June 20th. The maximum spilling occurred on June 12th at 21.00 and amounted

to $93\text{m}^3/\text{s}$. This was in addition to the $33\text{m}^3/\text{s}$ passing through the power station. Overall peak discharge was $126\text{m}^3/\text{s}$ at 21.00 on June 12th.

Overland flooding occurred adjacent to the Liffey River in the Middle Catchment, between Golden Falls and Leixlip. This flooding was most severe in the reach between Straffan and Celbridge – an area noted for flooding when the Liffey flow is in excess of approximately $40\text{m}^3/\text{s}$.

The River Liffey Flood of 1993 report concluded that “Pollaphuca Reservoir acts as a flood relief reservoir for the downstream Liffey Valley. If the dam at Pollaphuca did not exist the flooding throughout the Liffey valley would have been substantially worse, the peak discharge at Leixlip would have approached $300\text{m}^3/\text{s}$ as opposed to the $125\text{m}^3/\text{s}$ experienced.”

2.2.1.2 River Liffey Flood – November 2000

Heavy rainfall during November 2000 and particularly during the first half of the month resulted in flood conditions on the Liffey catchment. Most of this rainfall fell over 5th and 6th November. The rainfall on these two days was greater than the normal monthly average for November. Rainfall during November was in excess of 200% of the normal rainfall in the east and southeast of the country. This rainfall caused extensive flooding over the east of the country and most notably in the Liffey Catchment.

The peak hourly inflow to Pollaphuca was $430\text{m}^3/\text{s}$ on 5th November 2000 at 21.00. Inflows exceeded $200\text{m}^3/\text{s}$ for a continuous period of 22 hours and exceeded $100\text{m}^3/\text{s}$ for a continuous period of 45 hours. The hourly peak discharge from Pollaphuca was $74.8\text{m}^3/\text{s}$. However, this peak discharge occurred on 9 November after peak inflows to the Middle Catchment had abated.

The inflow to Golden Falls reservoir resulted almost entirely from the station discharge at Pollaphuca. Spilling at Golden Falls commenced at 11.00 on 8th November. The highest recorded average daily discharge that occurred during this flood was $51.2\text{m}^3/\text{s}$ on 10th November 2000, made up of $30.5\text{m}^3/\text{s}$ through the station and $20.7\text{m}^3/\text{s}$ spilling. Spilling ceased at Golden Falls on 17th November 2000.

The inflow to Leixlip Reservoir is comprised of two parts - the natural inflow from the Middle Catchment and the discharge from Golden Falls. The peak inflow to Leixlip was estimated to have been $98\text{m}^3/\text{s}$, comprising an estimated natural inflow from the Middle Catchment of approximately $83\text{m}^3/\text{s}$ and $15\text{m}^3/\text{s}$ as a result of running the station at Golden Falls. The

flood storage capacity at Leixlip is very small, therefore, the flood is passed straight through by running the power station and spilling through the spillway gates. Spilling started at 02.00 on 6th November and continued uninterrupted until 09.00 on 21st November. The peak discharge from Leixlip was 106.2m³/s on 6th November.

The River Liffey November 2000 Flood Report concluded that “Pollaphuca Reservoir acts as a flood relief reservoir for the downstream Liffey Valley. If the dam at Pollaphuca did not exist the flooding throughout the Liffey Valley would have been considerably greater. The peak discharge at Leixlip would have approached 350m³/s as opposed to the 106.2m³/s observed. The impact of such a flood on the Liffey Middle Catchment and downstream of Leixlip would have been extreme with flood levels up to 1 m higher than those recorded during the most severe flood in the previous 50 years - December 1954.”

2.2.1.3 River Liffey Flood – November 2009

Persistent heavy rain, starting in mid-October 2009 and continuing throughout November 2009, led to unprecedented levels of flooding in Ireland. While the east of the country avoided the worst of this flooding low pressure was centred to the east of Ireland during the last few days of the month. This resulted in a spell of heavy rain in eastern areas with widespread flooding on the 29th November. More than twice the average November amounts was recorded at all stations within the Liffey Catchment, with 250% of normal in many parts. The heavy rain of the 28th and 29th November, falling on an already saturated catchment, caused extensive flooding over parts of the Middle and Lower Liffey Catchment.

The peak hourly inflow to Pollaphuca was 299m³/s on 29th November 2009. The peak hourly discharge from Pollaphuca, although not continuous, was 56m³/s and occurred on occurred in December, long after peak inflows to the Middle Catchment had abated.

The inflow to Golden Falls reservoir resulted almost entirely from the station discharge at Pollaphuca. The highest recorded average daily discharge that occurred during this flood was 51.8m³/s on the 8th December 2009. This was made up of 32.3m³/s through the station and 19.5m³/s through the spillway gates.

The inflow to Leixlip Reservoir is comprised of two parts – the natural inflow from the Middle Catchment and the discharge from Golden Falls. Inflows to Leixlip exceeded 100m³/s continuously from 17:00 on the 29th November until 06:00 on the 30th November. Most of this inflow was the

natural inflow from the Middle Catchment, as the throughput from Golden Falls was reduced to compensation flow only ($1.5\text{m}^3/\text{s}$) from 29th November. The storage at Leixlip is very small and therefore floods are passed straight through by running the power station and spilling through the spillway gates. The maximum hourly spilling occurred around midnight on 29th November and amounted to $86\text{m}^3/\text{s}$. The peak discharge from Leixlip during this flood was $118\text{m}^3/\text{s}$, which includes spilling and discharge through the station, occurred at around midnight on 29th November.

Pollaphuca Reservoir acts as a flood relief reservoir for the downstream Liffey Valley. If the dam at Pollaphuca did not exist the flooding throughout the Liffey valley would have been considerably greater. The peak discharge at Leixlip would have approached $300\text{m}^3/\text{s}$, as opposed to the $118\text{m}^3/\text{s}$ observed. The impact of such a flood on the Liffey Middle Catchment and downstream of Leixlip would have been extreme with flood levels up to 1m higher than those recorded during the most severe flood in the last 60 years – December 1954.

2.2.1.4 River Liffey Floods – Summary

The above summaries indicate the beneficial effect of the operation of the dams and reservoirs on the River Liffey in attenuating flooding downstream of the dams. As noted above, Pollaphuca Reservoir acts as a flood relief reservoir, by holding inflows from the Upper Catchment until the flood on the Middle Catchment has abated. Of particular interest in this regard is a comparison between the estimated discharges that occurred during recent floods and the estimated discharges that would have occurred if the dams and reservoirs had not been constructed. These figures are presented for the 2000 and 2009 floods in Tables 2.1 and 2.2 below. It should be noted in these tables that the figures downstream of Leixlip include the flows from the River Ryewater.

Location	Estimated Peak Flow (m^3/s)	
	With Dams	Without Dams
Ballymore Eustace	55	425
Upstream of Leixlip	100	350
Downstream of Leixlip	170	400

Table 2.1 River Liffey Flood – November 2000
Effect of Operation of Dams and Reservoirs on Peak Flows

Location	Estimated Peak Flow (m ³ /s)	
	With Dams	Without Dams
Ballymore Eustace	52	250
Upstream of Leixlip	112	300
Downstream of Leixlip	150	340

Table 2.2 River Liffey Flood – November 2009
Effect of Operation of Dams and Reservoirs on Peak Flows

While these comparisons show the beneficial effects of the operation of the dams and reservoirs, they also show the potential for significant flooding can still occur downstream in the Middle and Lower Liffey Catchments as a result of significant rainfall events.

2.2.2 River Lee Floods

The catchment of the River Lee upstream of Carrigadrohid and Inniscarra Dams is quite steep and flashy. Therefore, floods can rise quickly following heavy rainfall. In addition, the flood storage capacities of the reservoirs are relatively small, particularly when compared to the total volume of large floods. The flood storage capacities of the reservoirs do provide a beneficial effect on discharges downstream of Inniscarra when compared to the inflows to the catchment, which is confirmed by the summaries of previous significant floods below. However, the benefits decrease as the magnitude of the flood increases.

2.2.2.1 Lee Flood – August 1986

On 6th August 1986, a severe rainstorm which lasted for a total of 22 hours affected the south western part of the country. The mean areal rainfall on the upper catchment to Carrigadrohid Dam was estimated to have been 92mm, resulting in the highest inflow to Carrigadrohid Reservoir on record at that time. The rainstorm on the intermediate catchment was not as severe, the resultant peak inflow from the intermediate catchment being approximately 50m³/s, which had been exceeded on a number of occasions previously. The total inflow to Inniscarra Reservoir was the highest recorded up to that time since the construction of the scheme.

The maximum inflow to Carrigadrohid during the flood rose to 653m³/s while the maximum discharge from Carrigadrohid peaked at 450m³/s. The maximum inflow to the Inniscarra Reservoir (including discharge from Carrigadrohid) during the flood was 504m³/s. The maximum discharge from Inniscarra reached a maximum value of 331m³/s.

2.2.2.2 Lee Flood – February 1997

The Month of January 1997 was exceptionally dry; the total rainfall at Cork Airport for January 1997 being 49% of the 1951-80 January average. However between 15th and 19th February 1997, heavy rain fell over the Upper Lee Catchment. Overall total rainfall at Cork Airport for February 1997 was 156% of the 1951-80 February average. Subsequently, flooding of roads and farmland occurred in a number of areas downstream of Inniscarra.

The maximum hourly inflow to Carrigadrohid during the flood rose to 304m³/s on 19th February 1997 while the maximum hourly discharge from Carrigadrohid peaked at 254m³/s on 20th February 1997. The maximum hourly inflow to Inniscarra (including discharge from Carrigadrohid) during the flood, 257m³/s occurred on 19th February 1997. The maximum hourly discharge from Inniscarra reached its maximum value of 230m³/s on 19th February 1997. The maximum catchment inflow to Inniscarra during this flood was estimated at 320m³/s and occurred on 19th February 1997.

2.2.2.3 Lee Flood – November 2000

Heavy rainfall towards the end of November and in early December 2000 resulted in flood conditions on the River Lee Catchment. In general, rainfall across the Lee Catchment for November was in excess of 200% of the normal monthly average for November. The rainfall period was characterised by a series of storm events that individually would not cause significant flooding, but when they occurred in series over consecutive days, resulted in significant and prolonged inflows to the Lee Catchment.

The peak hourly inflow to Carrigadrohid was 460m³/s, which was the second highest inflow on record at that time. The peak discharge at Carrigadrohid during the flood period was 354m³/s. The peak hourly inflow to Inniscarra was 380m³/s and the peak discharge was 274m³/s. The maximum catchment inflow to Inniscarra during this flood was estimated as 486m³/s.

2.2.2.4 Lee Flood – December 2006

Heavy rainfall towards the end of November and during December 2006 resulted in flood conditions on the River Lee Catchment. In general, rainfall totals across the Lee Catchment for November and December were in excess of 140% and 130% respectively of the normal monthly averages. The rainfall period was characterised by a series of storm events that individually would not cause significant flooding, but when they

occurred in series over consecutive days, resulted in significant and prolonged inflows to the Lee Catchment.

The peak hourly inflow to Carrigadrohid was $480\text{m}^3/\text{s}$ and the peak discharge at Carrigadrohid during the flood period was $342\text{m}^3/\text{s}$. The peak hourly inflow to Inniscarra was $415\text{m}^3/\text{s}$ and the peak discharge at Inniscarra during the flood period was $323\text{m}^3/\text{s}$. The maximum catchment inflow reached $475\text{m}^3/\text{s}$ on 3rd December 2006.



Figure 2.1 Flood Discharge at Carrigadrohid Dam (December 2006)

2.2.2.5 Lee Flood – November 2009

Persistent and often heavy rainfall occurred on the Lee Catchment from the 19th October 2009 to the end of November 2009. In general, rainfall totals across the Lee Catchment for October and November were in excess of 130% and 280% of the normal monthly averages for October and November respectively. Very heavy rainfall, which occurred on the 18th and 19th November, fell on already saturated ground. Consequently severe flooding of extensive areas into Cork City occurred.

The peak hourly inflow to Carrigadrohid was $689\text{m}^3/\text{s}$ and the peak total discharge at Carrigadrohid during the flood period was $520\text{m}^3/\text{s}$, both occurring on 19th November. The peak hourly inflow to Inniscarra (including discharge from Carrigadrohid) was $659\text{m}^3/\text{s}$ and occurred on 19th November. The peak discharge at Inniscarra during the flood period

was 547m³/s and occurred on 20th November. The maximum catchment inflow reached 806m³/s on 19th November 2009.

2.2.2.6 River Lee Floods – Summary

The above summaries indicate the beneficial effect of the operation of the dams and reservoirs on the River Lee in attenuating flooding downstream of the dams. Of particular interest in this regard is a comparison between the maximum discharge from Inniscarra Dam and the estimated peak total inflow into the catchment upstream of Inniscarra, which is summarised in Table 2.3 below for a number of significant past floods.

	Aug 1986	Feb 1997	Nov 2000	Dec 2006	Nov 2009
Peak Inflow	676 m ³ /s	320 m ³ /s	486 m ³ /s	475 m ³ /s	806 m ³ /s
Discharge	331 m ³ /s	230 m ³ /s	274 m ³ /s	323 m ³ /s	547 m ³ /s

Table 2.3 Inniscarra Dam – Comparison of Peak Total Catchment Inflow and Maximum Discharge for Significant Past Floods

While this comparison displays the beneficial effects of the operation of the dams and reservoirs, it also shows that significant flooding can still occur downstream of Inniscarra during significant rainfall events.

2.2.3 River Shannon Floods

The River Shannon drains through three major lakes, Lough Allen, Lough Ree and Lough Derg, and also widens out into a number of smaller lakes between Lough Allen and Lough Ree. The fall between the outlets from Lough Allen and Lough Derg, a distance of 190km, is only about 13m. Much of the river is consequently quite slow moving with any floodwaters remaining on the flood plains for long periods. The presence of the lakes and the restrictive capacity of the river channel have a marked effect in attenuating run-off resulting in a lag of many days between causal rainfall and resultant run-off.

The Upper Shannon Catchment, around Lough Allen upstream of Ballintra Sluices, is very steep and has a rapid response to rainfall. During floods, the discharge from Lough Allen is controlled by fixed gate openings at Ballintra Sluices, which allow the flood storage capacity in the lake to be used.

The Middle Catchment to the outlet from Lough Ree is quite flat, with the main river channel broadening out into a number of small lakes along this stretch. The lag between Lough Allen and Lough Ree is estimated to be

five days. The water level in and discharges from Lough Ree are controlled by a navigational weir at Athlone. The sluices on this weir are normally closed during flood periods to reduce flooding of large tracts of agricultural lands downstream. During significant floods on the River Shannon, the discharge at Athlone Weir is affected by backwater from the confluence of the River Suck and the main channel just downstream of Shannonbridge.

Most of the Lower Shannon Catchment, between Lough Ree and Parteen Weir, including the catchment of the River Suck, is relatively low lying with the channels having large flood plains. The inflow to Lough Derg, along the main channel, is not very flashy. The channel lag between Athlone and Lough Derg is approximately two days. However, the immediate catchment area around Lough Derg is quite steep and its resultant inflow can be very flashy and cause a sudden rise in the level of Lough Derg. The outlet from Lough Derg feeds into a channel about 3.5km long and then into an artificial reservoir about 4.5km long. The level of this reservoir is controlled at Parteen Weir, at which the flow diverges into the Headrace to Ardnacrusha Power Station.

Downstream of Parteen Weir the Shannon River flows a distance of approximately 20km to Limerick City. Tributaries which enter the Shannon in this reach include the Black, Kilmastulla, Mulkear, Groody and Blackwater Rivers. Flow which is diverted at Parteen Weir through Ardnacrusha Power Station re-enters the Shannon just upstream of Limerick City. During significant floods, the diversion of water into the Headrace provides substantial benefit to the areas downstream of Parteen Weir.

2.2.3.1 Shannon Flood – Winter 1994/1995

Rainfall amounts in the Shannon Catchment were significantly above average for each of the months December 1994, January 1995, February 1995 and March 1995. The rainfall totals were highest in the Lower Shannon Catchment, particularly between Portumna and Ardnacrusha. Total rainfall at Parteen during February was 282% of the average 1951-1980 value. The highest monthly rainfall total, 267.7mm at Killaloe, occurred in December 1994, while the highest three-monthly total, December 1994 to February 1995, was 751mm, also at Killaloe. There was no sustained dry spell during this period to allow water levels to recede - for example at Killaloe, there were only two days without precipitation in more than 100 days following 28th November 1994. This continuous heavy rainfall during December 1994 and January/February 1995 resulted in severe and prolonged flooding along the Shannon.

In general, the Winter 1994/1995 Flood can be considered as not significant on the Upper Shannon Catchment to Lough Allen. The maximum daily inflow to Lough Allen, $118.6\text{m}^3/\text{s}$, occurred on 11th March 1995. The daily discharge from Lough Allen was approximately $37\text{m}^3/\text{s}$ through Ballintra. The rainfall on the Upper Shannon Catchment during Winter 1994/1995 was not exceptional and the peak daily inflow was only a typical winter value. The response of the Upper Shannon Catchment to rainfall is fast and higher inflows would result from localised intense rainfall events rather than from the persistent rainfall that occurred during Winter 1994/1995.

Similarly on the Middle Shannon Catchment, flooding during Winter 1994/1995 was not exceptional. The estimated maximum flow at Athlone Weir was $322\text{m}^3/\text{s}$ on 3rd February 1995.

The effects of the flood were at their most severe in Lough Derg, with the highest levels, to that time, being recorded at both Killaloe and Portumna. The maximum estimated daily inflow to Lough Derg was $809\text{m}^3/\text{s}$ - the second highest daily inflow on record at the time. The maximum total Shannon Catchment daily inflow was $1,035\text{m}^3/\text{s}$ - the highest value on record at that time. The maximum average total daily discharge at Parteen was recorded as was $741.7\text{m}^3/\text{s}$ - the second highest value on record at that time. This comprised $385\text{m}^3/\text{s}$ spilling at Parteen Weir into the Shannon River and diversion of $356.7\text{m}^3/\text{s}$ to the Headrace to Ardnacrusha Power Station. This diversion of almost half of the maximum flow to the Headrace shows the benefits of the operation of Ardnacrusha Power Station to the areas downstream of Parteen Weir, during significant floods, particularly as there were also large flows in the Mulkear River, a downstream tributary.

2.2.3.2 Shannon Flood – Winter 1999/2000

Flooding was reported in many parts of Ireland during Winter 1999/2000. Rainfall was concentrated in the months of November and December 1999, with below average rainfall throughout the country in January 2000. Rainfall on the Shannon Catchment was above normal in November 1999. Following this, the December 1999 rainfall was up to 250% of normal and lead to extensive flooding in many parts of the Shannon Catchment, between Christmas 1999 and early January 2000.

In general, the Winter 1999/2000 Flood can be considered as not significant on the Upper Shannon Catchment to Lough Allen. The daily discharge from Lough Allen was calculated to be approximately $45.4\text{m}^3/\text{s}$ on 24th December 1999. The maximum daily inflow to Lough Allen during the flood, $156.5\text{m}^3/\text{s}$, occurred on 27th November 1999.

On the Middle Shannon Catchment, between Lough Allen and Athlone, flood levels were among the highest on record at that time. The level at Lough Ree was the then highest since ESB records began in 1932. There was extensive flooding of land along the river on this reach. The estimated maximum flow at Athlone Weir was $379\text{m}^3/\text{s}$ on 1st January 2000.

On the Lower Shannon Catchment, downstream of Athlone, this flood event was among the worst on record at that time. The effects of the flood were at their most severe just downstream of Athlone, where flooding is not influenced by spilling at Parteen Weir. Levels on Lough Derg were high but have been exceeded during previous significant floods. The maximum estimated Winter 1999/2000 daily inflow to Lough Derg was $757\text{m}^3/\text{s}$ on 24th December 1999. The maximum total catchment daily inflow to Parteen Weir was $1,019\text{m}^3/\text{s}$, which occurred on 24th December 1999. The maximum average daily discharge at Parteen was recorded as $70\text{m}^3/\text{s}$ on 28th December 1999. This comprises $325\text{m}^3/\text{s}$ discharge through Ardnacrusha and $376\text{m}^3/\text{s}$ spilling at Parteen Weir. Again this diversion of a significant proportion of the maximum flow to the Headrace shows the benefits of the operation of Ardnacrusha Power Station to the areas downstream of Parteen Weir.

2.2.3.3 Shannon Flood – Winter 2006/2007

Persistent heavy rainfall, during the second half of November and early December 2006, resulted in high flood levels along the Shannon.

Persistent heavy rainfall during the second half of November and early December 2006 resulted in high flood levels along the Shannon. In general the total rainfall in the Shannon Catchment in November 2006 was less than 150% of the average. However, most of this rainfall occurred in the second half of the month, with the first two weeks being dry for long periods. Heavy rainfall in many places on the 15th November 2006 was followed by continuous rainfall until the end of the month. While rainfall was above average throughout the Shannon Catchment in November 2006, the heaviest rainfall occurred between Athlone and Killaloe. The early part of December 2006 brought continuous spells of heavy rainfall throughout the Shannon Catchment. While much of the second half of December 2006 was generally dry, the monthly total rainfall was between 140% and 160% of the average throughout the catchment. Rainfall over the Shannon Catchment was again above average in January 2007.

In general, the Winter 2006/2007 Flood Event was not significant on the Upper Shannon Catchment to Lough Allen. Due to the fixed gate settings the daily discharge from Lough Allen was controlled in the range $20.4\text{m}^3/\text{s}$ to $32.1\text{m}^3/\text{s}$ throughout the three month period. The maximum daily inflow to Lough Allen during the flood, $104.3\text{m}^3/\text{s}$, occurred on 30th November 2006.

On the Middle Shannon Catchment, between Lough Allen and Athlone, flood levels were among the highest on record. The level at Lough Ree was the highest at that time, since ESB records began in 1932. There was extensive flooding of land along the river on this reach. The estimated maximum flow at Athlone Weir was $322\text{m}^3/\text{s}$ on 17th December 2006.

On the Lower Shannon Catchment downstream of Athlone the flood levels were similar to those which occurred in Winter 1999/2000. Levels on Lough Derg were again high but have been exceeded during previous significant floods. The maximum estimated Winter 2006/2007 daily inflow to Lough Derg was $771\text{m}^3/\text{s}$ on 13th December 2006. The maximum total catchment daily inflow to Parteen Weir was approximately $925\text{m}^3/\text{s}$ on 10th December 2006. The maximum average daily discharge at Parteen was recorded as $730\text{m}^3/\text{s}$ on the 17th December 2006, comprising $360\text{m}^3/\text{s}$ discharge through Ardnacrusha and $370\text{m}^3/\text{s}$ spilling at Parteen Weir. The diversion of almost half of the maximum flow to the Headrace has a considerable beneficial effect on flooding in the areas downstream of Parteen Weir.

2.2.3.4 River Shannon Flood – November/December 2009

Exceptionally heavy rainfall during November 2009 resulted in record flood levels along the Shannon. Persistent and sometimes heavy rain extended throughout Ireland from mid-October to the end of November causing unprecedented levels of flooding in the west and south of the country. Rainfall totals for November 2009 were the highest ever at most stations in Ireland, including stations with more than 100 years record. In the Shannon Catchment, monthly totals were on average 2.25 times the normal November rainfall. Rainfall was recorded on every day of the month, with the heaviest falls occurring on the 1st, 2nd, 15th to 19th and 22nd to 26th November. More than 100mm of rainfall was measured in some parts of the Shannon Catchment in the 5 day period between 15th and 19th November. Rainfall totals for the month of December 2009 were below normal at all stations in the Shannon catchment. Some rain at the start of the month was followed by a 15 day period from the 10th when there was very little rainfall throughout the catchment. There was some rainfall over the catchment towards the end of the month with 25mm being recorded at

Lough Allen on December 28th. Monthly total rainfall was on average only 60% of the normal December rainfall throughout the catchment.

The November 2009 Flood was one of the largest on the Upper Shannon Catchment to Lough Allen since records began. The maximum daily inflow to Lough Allen during the flood, $123.4\text{m}^3/\text{s}$, occurred on 19th November 2009. Due to the fixed gate settings the daily discharge from Lough Allen was controlled in the range $30\text{m}^3/\text{s}$ to $55\text{m}^3/\text{s}$ throughout the period from the 3rd November until the 17th December.

On the Middle Catchment, between Lough Allen and Athlone, flood levels were the highest on record. The peak level at Lough Ree was almost 0.5m higher than the previously highest recorded. There was extensive flooding of land along the river on this reach. The estimated maximum flow at Athlone Weir was $387\text{m}^3/\text{s}$ on 28th November 2009.



Figure 2.2 Parteen Weir (November 2009)

On the Lower Shannon Catchment, downstream of Athlone, the peak flood levels which occurred at Banagher, Victoria, Portumna and Killaloe were more than 0.3m higher than the highest ever recorded previously. The total discharge from Lough Derg was 12% greater than the previous highest. This total discharge comprised flow to the old channel at Parteen, which was 27% greater than the previous highest, and flow to the power station. The maximum total catchment daily inflow to Parteen Weir was approximately $1,243\text{m}^3/\text{s}$ on 19th November 2009. The maximum estimated Winter 2009 daily inflow to Lough Derg was $929\text{m}^3/\text{s}$ also on 19th November 2009. The maximum average daily discharge at Parteen

was recorded as 842m³/s on the 26th November 2009, comprising 345m³/s discharge through Ardnacrusha and 497m³/s spilling at Parteen Weir. While there was widespread flooding of areas downstream of Parteen Weir during November and December 2009, the diversion of a significant proportion of the maximum flow to the Headrace still had a considerable beneficial effect on the extent of the flooding.

2.2.3.5 River Shannon Floods – Summary

During significant floods on the River Shannon, the operation of the sluices at Ballintra on the outlet from Lough Allen and Parteen Weir, downstream of Lough Derg, provide significant beneficial effects in attenuating flooding for the areas downstream. Of particular interest in this regard are the following comparisons for historical floods between

- the maximum discharge at Ballintra Sluices and the estimated peak inflow into Lough Allen, which is summarised in Table 2.4 below and
- the maximum discharge to the River Shannon downstream of Parteen Weir, the estimated peak inflow into Lough Derg and the estimated peak total inflow into the catchment upstream of Parteen Weir, which is summarised in Table 2.5 below

	Winter 1994/1995	Winter 1999/2000	Winter 2006/2007	Nov/Dec 2009
Peak Inflow	119 m ³ /s	157 m ³ /s	104 m ³ /s	123 m ³ /s
Discharge	37 m ³ /s	45 m ³ /s	32 m ³ /s	55 m ³ /s

Table 2.4 Ballintra Sluices – Comparison of Peak Inflow to Lough Allen and Maximum Discharge for Significant Past Floods

	Winter 1994/1995	Winter 1999/2000	Winter 2006/2007	Nov/Dec 2009
Peak Lough Derg Inflow	809 m ³ /s	757 m ³ /s	771 m ³ /s	929 m ³ /s
Peak Catchment Inflow	1,035 m ³ /s	1,019 m ³ /s	925 m ³ /s	1,243 m ³ /s
Discharge to River Shannon	385 m ³ /s	376 m ³ /s	370 m ³ /s	497 m ³ /s

Table 2.5 Parteen Weir – Comparison of Peak Lough Derg Inflow, Peak Total Catchment Inflow and Maximum Discharge to River Shannon for Significant Past Floods

While these comparisons show the beneficial effects of the operation of Ballintra Sluices, Parteen Weir and Ardnacrusha Power Station on flooding in the areas downstream, they also shows the potential for significant flooding during significant rainfall events.

2.2.4 River Erne Floods

The River Erne is the second largest river in Ireland, with its course being dominated by a number of lakes, including Upper and Lower Loughs Erne, Lough Gowna and Lough Oughter. The total fall in the river from Lough Oughter to the outlet of Lower Lough Erne is only 4 to 5 metres, which can lead to frequent flooding. Since construction of the two dams and the associated drainage improvement works on the River Erne, the flooding situation has much improved, with the reduction of statutory high water levels in Upper and Lower Lough Erne. Lower Lough Erne is connected to Cliff Dam by the relatively narrow Beleek Channel. Discharges at the dam are restricted during floods by the capacity of this channel.

2.2.4.1 River Erne Flood – December 1991

The Erne catchment was subjected to two heavy rainstorms during December 1991 and January 1992. The rainstorm which occurred in December was particularly severe and it was this heavy rainfall which resulted in the then record daily inflow to Lower Lough Erne of $555\text{m}^3/\text{s}$ on 21st December 1991. No spilling was necessary at Cliff, the peak discharge through the sets was $269.9\text{m}^3/\text{s}$. Spilling at Cathaleens Fall occurred between 23rd and 29th December 1991. The peak daily inflow to Assaroe Lake, the reservoir for Cathaleen's Fall Dam, occurred on 25th December and amounted to $279.9\text{m}^3/\text{s}$. The peak daily discharge from Cathaleens Fall occurred on the same day, matching the inflow of $279.9\text{m}^3/\text{s}$, consisting of $222.2\text{m}^3/\text{s}$ through the sets and $57.7\text{m}^3/\text{s}$ spilling. This level of discharge from Cathaleen's Fall Dam did not give rise to any significant flooding downstream of the dam.

2.2.4.2 River Erne Flood – Winter 1999/2000

Heavy rainfall during the last week of November and throughout December 1999 resulted in the then highest recorded levels in Upper and Lower Loughs Erne since the Agreement between the ESB and the Northern Ireland Authorities became effective in 1956. Rainfall on the catchment during November 1999 was up to 150% of the normal rainfall in the northwest. At Ballyshannon, Co. Donegal it was the wettest November in more than fifty years. December 1999 was also exceptionally wet in the northwest, with more than twice the normal rainfall in parts of the Erne catchment. At Ballyshannon 250% of normal December rainfall was

recorded. In general rainfall was persistent throughout the month with rain recorded on all but 3 or 4 days.

The peak inflow to Upper Lough Erne was $350\text{m}^3/\text{s}$ on the 23rd December 1999, while the peak discharge through the inter lake channel was estimated at $315\text{m}^3/\text{s}$ on the 30th December 1999. It was the prolonged duration flood inflows that resulted in the then record peak Upper Lough Erne level. Inflow exceeded $100\text{m}^3/\text{s}$ for 55 days (32 days in 1991), $200\text{m}^3/\text{s}$ for 42 days (14 days in 1991) and $300\text{m}^3/\text{s}$ for 11 days (5 days in 1991).

The peak daily inflow to Lower Lough Erne, $359\text{m}^3/\text{s}$, on the 25th December 1999, was made up of $310\text{m}^3/\text{s}$ from Upper Lough Erne and $49\text{m}^3/\text{s}$ from the catchment feeding directly into Lower Lough Erne. This compares to a peak daily inflow of $555\text{m}^3/\text{s}$ recorded in December 1991. As for Upper Lough Erne, it was the prolonged duration of flood inflows that resulted in the then record levels in Lower Lough Erne. Inflow exceeded $100\text{m}^3/\text{s}$ for 67 days (38 days in 1991), $200\text{m}^3/\text{s}$ for 47 days (29 days in 1991) and $300\text{m}^3/\text{s}$ for 14 days (6 days in 1991). Spilling at Cliff Station was continuous from 4th December to 10th January. The maximum daily throughput at Cliff, $334\text{m}^3/\text{s}$, occurred on the 31st December. The discharge from Cliff Dam flows directly into Assaroe Lake, which is a balancing reservoir between Cliff and Cathaleen's Fall Dams.

Spilling at Cathaleen's Fall Dam commenced on 4th December 1999 and was continuous until 13th January 2000. The maximum daily throughput at Cathaleen's Fall was $335\text{m}^3/\text{s}$ on 31st December 1999. This level of discharge from Cathaleen's Fall Dam did not give rise to any significant flooding downstream of the dam.

2.2.4.3 River Erne Flood – November 2009

Persistent and sometimes heavy rain commenced in mid-October 2009 and continued throughout November 2009 causing unprecedented flood levels on both Upper and Lower Loughs Erne. November rainfall throughout the Erne catchment was twice the normal monthly rainfall. Monthly rainfall totals over the Erne catchment in October were around normal. It was the period of prolonged heavy rainfall throughout October and November 2009 which gave rise to the record flood levels. Rainfall was recorded on most days during November 2009, with the heaviest falls occurring between 13th and 25th November. More than 100mm of rainfall was measured at Swanlinbar in the 4 day period between 16th and 19th November 2009.

The peak inflow to Upper Lough Erne was estimated to have been 511m³/s on 23rd November 2009, while the peak discharge through the inter-lake channel was estimated at 428m³/s on 22nd November 2009. Inflow exceeded 100m³/s for 54 days (55 days in 1999, 32 days in 1991), 200m³/s for 39 days (42 days in 1999, 14 days in 1991), 300m³/s for 12 days (11 days in 1999, 5 days in 1991) and 400m³/s for 8 days (0 days in 1999, 1 day in 1991).

The estimated peak inflow to Lower Lough Erne, 419m³/s, on 27th November 2009 is a combination of flow from the Upper Lake and flow from the catchment feeding directly into the Lower Lough Erne. Inflow exceeded 100m³/s for 63 days (67 days in 1999, 38 days in 1991), 200m³/s for 42 days (47 days in 1999, 29 days in 1991), 300m³/s for 16 days (14 days in 1999, 6 days in 1991) and 400m³/s for 4 days (0 days in 1999, 0 days in 1991). The peak inflow to Cliff during the November 2009 flood was 419m³/s on 27th November 2009. Spilling at Cliff Station was continuous from 5th November to 15th December 2009. The maximum daily throughput at Cliff, 366m³/s, occurred on 27th November 2009. The discharge from Cliff Dam flows directly into Assaroe Lake, which is a balancing reservoir between Cliff and Cathaleen's Fall Dams.

Spilling at Cathaleen's Fall Dam commenced on 5th November 2009 and was continuous until 15th December 2009. The maximum daily throughput at Cathaleen's Fall was 387m³/s on 27th November 2009. This level of discharge from Cathaleen's Fall Dam did not give rise to any significant flooding downstream of the dam.

2.2.4.4 River Erne Floods – Summary

The above summaries indicate that while significant flooding does occur on the River Erne, the discharges during past floods did not cause any significant flooding downstream of Cliff and Cathaleen's Fall Dams.

2.2.5 River Clady Floods

The River Clady, in the north-west of Donegal, drains a small mountainous catchment to the sea at Bunbeg. Dunlewy Lough and Lough Nacung, which occupy the floor of the valley, are two small lakes lying at the foot of Errigal Mountain, and are fed by short steep mountain rivers which drain the slopes of Errigal and the other mountains which encircle the catchment. Upstream of Gweedore Weirs, the catchment is composed of open moor and bogland, except where the soil has been eroded from the upper slopes of the mountains. Since the construction of an auxiliary weir and the removal of the sluice gates in 1995, the system has been self regulating with regard to water flows.

2.2.5.1 River Clady Flood – August 1998

The peak discharge recorded in the River Clady, downstream of Gweedore Weir, during the August 1998 flood was $31.75\text{m}^3/\text{s}$. This was significantly less than the estimated peak inflow to Lough Nacung of $49.4\text{m}^3/\text{s}$. The report Clady Flood August 1998 Report concluded that “a flood wave passing through Lough Nacung and Lough Dunlewy is reduced in magnitude and lengthened in time (attenuated) as a result of the storage provided by the two lakes. Without knowledge of the pre-scheme configuration of the lakes, the degree of pre-scheme attenuation cannot be quantified. However, it can be stated that the presence of Cung Dam and Gweedore Weir and their associated embankments provide additional storage and would produce increased attenuation of a flood wave when compared with the pre-scheme configuration.” The report also concluded that, “the discharge in the Clady downstream of Gweedore Weir is significantly less than would have occurred had the scheme not been in place. This is due to the diversion of flow into the headrace canal and the attenuation of the flood provided by Cung Dam and Gweedore Weir”.

2.3 Floods around Reservoirs

During floods, the water levels in ESB reservoirs rise as inflows increase. To cater for this, as part of the development of the hydro-electric schemes, ESB acquired lands around the reservoirs and lakes upstream of the dams. The levels to which lands were acquired were based on the original designs for the schemes and the associated estimated maximum water level that would be likely to occur during the design flood. However, the current dam safety policy, under which the dams are operated, is more onerous than the original design. This requires that ESB's major dams must be capable of passing the 10,000-year flood without overtopping. This requirement could result in reservoir water levels exceeding the ESB's land acquisition levels during very extreme floods.

For each hydro-electric scheme, ESB generally acquired most (approx. 98%) of the land around lakes and reservoirs to the expected high water level contour for that location. In some instance small parcels of land were acquired in excess of this level, for example where it was more practical to include an area rather than leaving it stranded and possibly inaccessible when the lands were finally flooded.

The sections below present the land acquisition levels associated with each dam, the estimated maximum reservoir water levels for the design floods under the current operating regime and maximum reservoir water

levels that have occurred during some of the largest floods that have occurred for each river system on which ESB operates dams.

2.3.1 River Liffey

ESB operates three dams on the River Liffey, i.e. Pollaphuca, Golden Falls and Lexlip. Table 2.6 provides the land acquisition levels around the reservoirs and the maximum expected reservoir water levels during the design floods. Table 2.7 compares the land acquisition levels around the reservoirs with the maximum reservoir water levels that occurred during a number of significant previous floods.

Reservoir	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Pollaphuca	189.3	188.64	189.42
Golden Falls	139.0	139.00	140.18
Leixlip	45.6	45.60	46.30

Table 2.6 River Liffey Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

Reservoir	Land Acquisition Level (m O.D.)	Peak Flood Levels (m O.D.)		
		June 1993	November 2000	November 2009
Pollaphuca	189.3	187.51	187.53	187.41
Golden Falls	139.0	Operates as balancing reservoir between Pollaphuca and Golden Falls Dams - Maximum Normal Operating Level (139.00m O.D.) not generally exceeded		
Leixlip	45.6	45.38	45.47	45.35

Table 2.7 River Liffey Reservoirs - Land Acquisition Levels and Previous Maximum Flood Levels

The information provided in Table 2.7 indicates that there has not been a history of flooding outside ESB's land acquisition levels during significant past floods.

2.3.2 River Lee

ESB operates two dams on the River Lee, i.e. Carrigadrohid and Inniscarra. Table 2.8 provides the land acquisition levels around the reservoirs and the maximum expected reservoir water levels during the design floods. Table 2.9 compares the land acquisition levels around the reservoirs with the maximum reservoir water levels that occurred during a number of significant previous floods.

Reservoir	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Carrigadrohid	66.45	65.9	67.16
Inniscarra	51.21	51.08	51.63

Table 2.8 River Lee Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

Reservoir	Land Acquisition Level (m O.D.)	Peak Flood Levels (m O.D.)				
		Aug 1986	Feb 1997	Nov 2000	Dec 2006	Nov 2009
Carrigadrohid	66.45	65.74	64.63	65.09	64.98	65.34
Inniscarra	51.21	50.45	49.55	50.18	50.21	50.85

Table 2.9 River Lee Reservoirs - Land Acquisition Levels and Previous Maximum Flood Levels

The information provided in Table 2.9 indicates that there has not been a history of flooding outside ESB's land acquisition levels during significant past floods.

2.3.3 River Shannon

As part of the Shannon Hydro-electric Scheme, ESB constructed two water control structures, Bellantra Sluices at the outlet from Lough Allen and Parteen Weir downstream of Lough Derg. Parteen Weir distributes water flow between the River Shannon and Ardnacrusha Headrace Canal. Table 2.10 provides the land acquisition levels around the lakes and the maximum expected reservoir water levels during the design floods. Table 2.11 compares the land acquisition levels around the lakes with the maximum lake water levels that occurred during a number of significant previous floods.

Reservoir/Lake	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Lough Allen	52.43	51.23	51.78
Lough Derg (Killaloe)	34.44	35.34	36.08
Parteen Basin	35.05	32.70*	32.70*

Table 2.10 River Shannon Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

Reservoir/Lake	Land Acquisition Level (m O.D.)	Peak Flood Levels (m O.D.)			
		Winter 1994/1995	Winter 1999/2000	Winter 2006/2007	Nov 2009
Lough Allen	52.43	50.05	50.55	49.72	50.77
Lough Derg (Killaloe)	34.44	34.01	33.90	33.91	34.33
Lough Derg (Portumna)	34.44	34.40	34.30	34.40	34.76
Parteen Basin	35.05	32.70*	32.70*	32.70*	32.70*

Table 2.11 River Shannon Reservoirs - Land Acquisition Levels and Previous Maximum Flood Levels

* During significant floods the level immediately upstream of Parteen Weir is drawn down to 32.70m O.D. to optimise discharge through the channel restriction at Killaloe

The information provided in Table 2.11 indicates that around Lough Allen there has not been a history of flooding outside ESB's land acquisition levels. The information provided in Table 2.11 also indicates that around Lough Derg there has not been a significant history of flooding outside ESB's land acquisition levels, but that during large floods water levels can rise above the ESB's land acquisition levels at the upstream end of the lake. However, it should be noted that there is a channel restriction at Killaloe, which restricts the discharge from Lough Derg, while the discharge capacity at Parteen Weir is more than adequate to pass the design 10,000-year flood.

2.3.4 River Erne

ESB operates two dams on the River Erne, i.e. Cliff and Cathleen's Fall. Table 2.12 provides the land acquisition levels upstream of Cliff Dam and around Assaroe Lake, the reservoir for Cathleen's Fall Dam. Table 2.13

compares the land acquisition levels upstream of Cliff and Cathaleen's Fall Dams with the maximum water levels that occurred during a number of significant previous floods.

Reservoir/Lake	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Cliff	47.24	43.59	43.59
Cathaleen's Fall	35.05	34.14	34.14

Table 2.12 River Erne Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

Reservoir/Lake	Land Acquisition Level (m O.D.)	Peak Flood Levels (m O.D.)		
		Dec 1991	Winter 1999/2000	Nov 2009
Cliff	47.24	45.54	45.77	45.88
Cathaleen's Fall	35.05	33.84	33.70	33.80

Table 2.13 River Erne Reservoirs - Land Acquisition Levels and Previous Maximum Flood Levels

The information provided in Table 2.13 indicates that there has not been a history of flooding outside ESB's land acquisition levels during significant past floods. However, during large floods flooding can occur in Counties Fermanagh and Cavan due to rising water levels in the lakes and channels.. In this regard, it should be noted that there is a channel restriction at Belleek, which restricts the discharge from Lower Lough Erne, while the discharge capacity at Cliff Dam is more than adequate to pass the design 10,000-year flood.

2.3.5 River Clady

ESB has three structures on the River Clady i.e. Cung Dam; an earthfill embankment at the outlet from Dunlewey Lough, Gweedore Weir downstream of Lough Nacung and Dore Intake Structure. ESB's land acquisition levels for the Clady Scheme are 67.06m O.D. around Dunlewey Lough and 64.01m O.D. around Lough Nacung. These levels are above the estimated design 1,000-year flood levels of 66.03m O.D. for Dunlewey Lough and 62.88m O.D. for Lough Nacung.

There has not been a history of flooding outside ESB's land acquisition levels during significant past floods.

2.4 Breaches of Dams or Embankments

Catastrophic floods can result from the breach of a dam or embankments, as large uncontrolled discharges are released to the areas downstream. ESB has an excellent record with regard to dam safety and there has never been a breach of any of its dams or embankments.

2.5 Overtopping of Dams or Embankments

2.5.1 General

The water management procedures for all of ESB's Category A dams and embankments, and also lower category dams and embankments at Lough Allen and on the River Clady, require that extreme design floods can be passed safely without overtopping of the structures. Therefore, overtopping has never occurred at any of ESB's major dams or embankments.

2.5.2 Portumna Embankments

The Portumna Embankments were constructed over a length of 18km on the west bank of the River Shannon from Portumna and northwards to Meelick. These embankments differ from ESB's other dams and embankments, in that they were constructed along the bank of the river, to prevent adjacent low lying lands from flooding during the summer, due to higher Lough Derg and river levels due to the operation of the Shannon Scheme. Overtopping of these embankments did occur during two very large winter floods on the River Shannon, most recently in 2009.

There are three embankment systems and pumping stations associated with the scheme, i.e. Boula, near Portumna town, Whitesford, 6-7 km upstream of Portumna, and Meelick, further north again. The pumping stations pump water from the callows protected by the embankments into the River Shannon, thus keeping the low lying land drained.

ESB maintains these embankments and pumping stations on an ongoing basis and employs a works crew locally for this purpose. The design crest level of the embankments was set when they were built as part of the Shannon Hydro Electric Scheme by Siemens. Because the embankments are built on very poor ground they tend to settle over time. For this reason ESB surveys the embankments every 5 years and raises them as necessary on an ongoing basis, so that in general the crest or top of the embankments is maintained at original design level plus 300mm. No part

of the embankment is below the original design level. The next 5 year survey is due in September 2011.

As the flood of November/December 2009 was approaching its peak level seepage was noted at the downstream toe of Meelick Embankment, at two locations near the northern end of the embankment i.e. just south of Meelick Weir and near Meelick pump house. ESB immediately carried out running repairs – consisting of placing a geotextile membrane on top of soft spots near the embankment toe and placing ballast over the geotextile. No serious damage occurred to the embankments and subsequently ESB has constructed a berm 5m wide by 0.5m high, at the two locations to address this problem. In addition, significant grouting works have been carried out near Meelick pump house to seal seepage paths.

During the peak of the flood of November/December 2009, the embankments at Meelick and Whitesford were completely overtopped due to the exceptionally high River Shannon levels and also the associated high level of tributaries feeding into the Shannon in this area – namely Boula, Derryhiney and Fahy Rivers. Large areas of agricultural callows land were flooded as well as some minor roads. ESB staff did everything possible to prevent overtopping by means of sandbagging but the Shannon River levels were so high that in the end overtopping could not be averted. No houses were flooded but access to two houses was affected.

During the November/December 2009 flood, the Boula Embankment at Portumna was also partially overtopped. At Boula, ESB mobilised 20 large mobile diesel pumps and these together with the ESB pumping station at Boula and sandbagging kept the situation in the Boula area under control with no serious flooding occurring.

When river levels receded the mobile pumps at Boula were transferred to Meelick and the flooded area at Meelick was pumped out as quickly as possible. The flooded area behind Whitesford embankment was pumped out using the permanent ESB pumps at Whitesford pumping station.

It is understood that only one section of the Portumna Embankments, i.e. Meelick, was overtopped and flooded prior to 2009. This occurred during the large 1954 Shannon flood.

2.6 Operational Malfunctions

2.6.1 Introduction

As noted in Section 1.3.1 above, ESB's current dam safety procedures have been implemented since 1988. They protect against flooding arising from operational malfunctions. Frequent testing of water control equipment ensures that it is in satisfactory operational condition.

On only one occasion, prior to the implementation of the current dam safety procedures, has flooding arisen due to an operational malfunction at an ESB dam, i.e. Inniscarra Dam on the River Lee on 30th December 1987. This section summarises what happened during the flooding incident at Inniscarra and the actions that were subsequently taken to ensure that a similar incident could not happen again.

2.6.2 Summary of Incident

There was persistent rainfall on the Lee catchment for a period of 5 to 6 days before the incident and both sets at Inniscarra were continuously on full load to discharge inflows to the reservoir. On 29th December 1987, weather conditions worsened with continuous heavy rainfall and that night it became necessary to discharge at an increased rate of approximately $120\text{m}^3/\text{s}$, comprising $80\text{m}^3/\text{s}$ through the two turbines and $20\text{m}^3/\text{s}$ through each of Spillway Gates Nos. 1 and 2.

At approximately 15:00 on 30th December 1987, the water level was continuing to rise in Inniscarra Reservoir and it became necessary to further increase discharges through the dam. It was decided to open Spillway Gate No. 3 to discharge an additional $20\text{m}^3/\text{s}$.

At that time, the control equipment in Inniscarra Control Room for each spillway gate consisted of three buttons "Raise", "Stop" and "Lower". Indication of gate position was by a digital readout which indicated the gate opening over sill level. Indication of reservoir and tailrace water levels was by the Rittmeyer water level recorders. There was a single 50V D.C. supply to the gate opening indicators, and the Rittmeyer water level recorders.

The Shift Supervisor was instructed to open Spillway Gate No.3 to discharge an additional $20\text{m}^3/\text{sec}$. He pressed the "Raise" button and the gate opening indicator operated up to 5 cm and then stopped. The Shift Supervisor assumed that the supply to the gate had failed and pressed the

"Raise" button for Spillway Gate No.2. When the gate opening indicator for Spillway Gate No. 2 did not change, he then pressed the "Raise" button for Spillway Gate No.3. Again the gate opening indicator did not change.

It was discovered later that a fuse in the 50V D.C. supply to the indicators had failed and not the power supply to the gate motors as had been assumed by the Shift Supervisor. This was the first time that such a fault had occurred in Inniscarra, since the station was constructed in the 1950s.

All three spillway gates opened fully or near fully and the discharge over the spillway increased to approximately 700m³/sec. The Station Manager noted the level of the tail race and realised that all gates were open and immediately instructed the Shift Supervisor to close all gates. This took approximately 15 minutes. To further reduce the flooding both turbines were taken off load. The result of this high discharge was local flooding involving about 10 houses and a pre cast concrete plant operated by J.A. Woods.

2.6.3 Subsequent Actions Taken

Following the incident, an urgent investigation was immediately started to identify the cause of the flooding incident and to assess the possibility of a recurrence of such a problem at Inniscarra or at any of the other ESB dams. As a result of the incident and the subsequent investigation, the following actions were taken at Inniscarra and other ESB dams:

- Electrical circuits to instruments were modified to ensure against a recurrence of the problem.
- Additional operator alarms were installed.
- Critical DC systems were fitted with "Loss of DC" alarms
- Safety interlocks were installed to ensure that only one gate at a time can be operated.
- Critical instruments were duplicated with totally independent systems, where these did not already exist.
- "Dead-man" switches were installed to ensure that a single pressing of a button could not lead to the full opening of a spillway gate.
- All water control electrical switchgear panels were replaced and "Gate motor in service" warning lights were added.
- All spillway gate movements must now be witnessed by a person standing on the crest of the dam.

- CCTV was installed to also allow the spillways to be observed from the control room during operation.

In addition to these actions, ESB set up an internal Working Party on Water Control Equipment, during the late 1980s. This Working Party makes recommendations on the design philosophy, detailed design of components, physical condition of plant, operating procedures and staffing to provide the highest possible degree of certainty in operation of water control equipment at ESB dams.

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3 Potential Future Floods

3.1 Introduction

An assessment of potential future floods is also required by both the EU Floods Directive and the European Communities (Assessment and Management of Flood Risks) Regulations. This section will examine the role of ESB's dams and embankments on potential future floods under the following headings that were used above for the assessment of past floods:

- River Floods Downstream of Dams
- Floods around Reservoirs
- Breaches of Dams or Embankments
- Overtopping of Dams or Embankments
- Operational Malfunctions

3.2 River Floods Downstream of Dams

As has been the case for floods that have occurred in the past, the most likely potential future floods on the rivers, on which ESB's dams and embankments are constructed, are those caused by severe rainfall events. The water management procedures in place for ESB's Category A dams ensure that the design 10,000-year flood can be passed without overtopping the dams or embankments.

The water management procedures stipulate that, during a flood, the peak discharge from the catchment shall not be allowed to exceed the peak inflow to the catchment during the rising flood. Incremental increases in discharges as river flows or upstream water levels increase during a flood, provide for the beneficial use of the reservoir storage during a flood, with discharges being less than the inflows. While, these beneficial effects decrease as floods become larger, they still apply even during the extreme 10,000-year design flood.

As noted earlier, ESB International are commissioned to undertake studies of significant flood events and how they are managed. This practice will continue in the future. Where appropriate, lessons learned from actual significant floods will be used to assist with the management of future floods.

ESB has been working with the Office of Public Works and Local Authorities during the undertaking of the Catchment Flood Risk Assessment and Management Studies for rivers on which ESB dams and embankments have been constructed. In addition, ESB is participating in the implementation of Catchment Flood Risk Management Plans, which are intended to set out measures and policies that should be pursued to achieve the most cost effective and sustainable management of flood risks within relevant catchments. ESB will continue its involvement with Catchment Flood Risk Assessment and Management Studies and the implementation of Catchment Flood Risk Management Plans in the future.

3.2.1 River Liffey

As noted in the section on past floods, Pollaphuca Reservoir acts as a flood relief reservoir for the River Liffey. It is used to hold inflows to the Upper Liffey Catchment until the flood on the Middle Liffey Catchment has abated. During past floods, discharges to the Middle Liffey Catchment, downstream of Golden Falls Dam, and to the Lower Liffey Catchment, downstream of Leixlip Dam, have been significantly reduced. The water management procedures for the Liffey Dams provide for storing the inflows for extreme floods, such as the design 10,000-year flood, in Pollaphuca Reservoir until the peak of the flood has abated downstream. During the design 10,000-year flood, the estimated peak inflow to Pollaphuca Reservoir is 1,070m³/s. The estimated peak discharges are 300m³/s from Golden Falls Dam to the Middle Liffey Catchment and 415m³/s from Leixlip Dam to the Lower Liffey Catchment. While a 10,000-year flood is an extreme event, which would result in widespread flooding throughout the catchment, these figures display the benefits of the water management procedures at the dams with regard to flooding of downstream areas. Therefore, it is considered that the dams on the River Liffey do not create an increased risk of downstream flooding during potential future floods on the river.

3.2.2 River Lee

The review of past floods has shown that Inniscarra and Carrigadrohid reservoirs provide some flood relief to Cork City and other areas downstream of Inniscarra. However, as the reservoirs are relatively small, the degree of flood relief decreases as the magnitude of floods increases. Table 3.1 compares the estimated inflows to the reservoirs and the estimated discharges at the dams for the design 10,000-year flood.

Reservoir	Estimated 10,000-Year Flood Reservoir Inflow (m ³ /s)	Estimated 10,000-Year Flood Dam Discharge (m ³ /s)
Carrigadrohid	1,311	834
Inniscarra	1,157	1,075

Table 3.1 River Lee Reservoirs – Comparison of Estimated 10,000-Year Flood Inflows and Discharges

While these figures indicate that large discharges can be expected at the dams during extreme future floods, they also show that even during a 10,000-Year Flood event, the reservoirs still provide some benefit to the areas downstream. Therefore, it is considered that Carrigadrohid and Inniscarra Dams do not create an increased risk of downstream flooding during potential future floods on the River Lee.

3.2.3 River Shannon

During floods, the operation of the sluices at Ballintra, on the outlet from Lough Allen, and Parteen Weir, downstream of Lough Derg, provide benefits with regard to flooding in the areas downstream. This has been confirmed by the assessment of past floods. Inflows and discharges have been estimated for potential extreme future flood events, i.e. 1,000-year Flood for Lough Allen and 10,000-year flood for Lough Derg, and are summarised in Table 3.2 below.

Lake	Estimated Design Flood Reservoir Inflow (m ³ /s)	Estimated Design Flood Dam Discharge (m ³ /s)
Lough Allen	199	70
Lough Derg	1,733	1,390

Table 3.2 River Shannon – Comparison of Estimated Design Flood Inflows and Discharges for Lough Allen and Lough Derg

The discharge figure for Lough Derg is the total discharge required at Parteen Weir, i.e. discharge down the River Shannon channel and flow through the Headrace to Ardnacrusha Power Station. When Ardnacrusha Power Station is on full load, as would normally be the case during a flood, the flow down the River Shannon channel is reduced by approximately 350m³/s to 400m³/s.

These figures indicate that even during potential extreme flood events, the operation of the dams still provide some benefit with regard to flooding of the areas downstream. Therefore, it is considered that the dams

associated with the Shannon Hydro-electric Scheme do not create an increased risk of downstream flooding during potential future floods on the river.

3.2.4 River Erne

The section on past floods described how discharges at Cliff Dam are restricted by the capacity of the River Erne channel at Belleek. In addition, during large floods Assaroe Lake acts as a balancing reservoir between Cliff and Cathaleen's Fall Dams. During large floods, the discharges from both dams are essentially the same.

The estimated inflow to Lower Lough Erne during the design 10,000-year flood is $696\text{m}^3/\text{s}$. However, the inflow upstream of Cliff Dam is $530\text{m}^3/\text{s}$, which must be discharged through both Cliff and Cathaleen's Fall Dams. This inflow is not influenced by the presence of the dams but is related to the capacity of the river channel upstream of Cliff Dam. In any event, studies have indicated that the channel capacity downstream of Cathaleen's Fall Dam is adequate for passing the 10,000-year flood without major flooding. Therefore, it is considered that Cliff and Cathaleen's Fall Dams do not create an increased risk of downstream flooding during potential future floods on the River Erne.

3.2.5 River Clady

Gweedore Weir distributes the flow in the River Clady between the River Clady channel downstream of the weir and the Headrace to Clady Power Station. The estimated peak inflow for the catchment to Gweedore Weir during the design 1,000-year flood is $194\text{m}^3/\text{s}$. The estimated peak discharge down the Clady River channel during this design flood is $143\text{m}^3/\text{s}$. It can be seen from these figures, that even during a potential extreme future 1,000-year flood event, the dams on the River Clady would provide benefit with regard to flooding of areas downstream of Gweedore Weir. Therefore, it is considered that the dams constructed as part of the Clady Hydro-electric Scheme do not create an increased risk of downstream flooding during potential future floods.

3.3 Floods around Reservoirs

To cater for increased water levels during floods, as part of the development of the hydro-electric schemes, ESB acquired lands around the reservoirs and lakes upstream of the dams. The levels to which lands were acquired were based on the original designs for the schemes and the associated estimated maximum water level that would be likely to occur during the design flood. However, the current dam safety policy, under

which the dams are operated, is more onerous than the original design and requires that ESB's major dams must be capable of passing extreme 10,000-year floods without overtopping. ESB implements water management procedures to ensure that the water level upstream of the dams does not exceed the dam crest level, even during extreme design flood events. However, in some instances this extreme flood requirement could result in water levels, around reservoirs and lakes upstream of the dams exceeding the ESB's land acquisition levels.

3.3.1 River Liffey

There has not been a history of flooding outside ESB's land acquisition lines around Pollaphuca, Golden Falls or Leixlip Reservoirs during significant past floods. As indicated in Table 3.3, estimated reservoir levels during a 1,000-year flood are unlikely to exceed the ESB's land acquisition levels. However, estimated peak levels during the design 10,000-year flood would exceed the ESB's land acquisition level. Such an extreme flood event could lead to flooding of roads and possibly a small number of properties.

Reservoir	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Pollaphuca	189.3	188.64	189.42
Golden Falls	139.0	139.00	140.18
Leixlip	45.6	45.60	46.30

Table 3.3 River Liffey Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

3.3.2 River Lee

There has not been a history of flooding outside ESB's land acquisition lines around Carrigadrohid or Inniscarra Reservoirs during significant past floods. As indicated in Table 3.4, estimated reservoir levels during a 1,000-year flood are unlikely to exceed the ESB's land acquisition levels. However, estimated peak levels during the design 10,000-year flood would exceed the ESB's land acquisition level. Such an extreme flood event could lead to flooding of roads and possibly a small number of properties.

Reservoir	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Carrigadrohid	66.45	65.9	67.16
Inniscarra	51.21	51.08	51.63

Table 3.4 River Lee Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

3.3.3 River Shannon

As part of the Shannon Hydro-electric Scheme, ESB constructed two water control structures, Bellantra Sluices at the outlet from Lough Allen and Parteen Weir downstream of Lough Derg. There has not been a history of flooding outside ESB's land acquisition lines around Lough Allen or Lough Derg during significant past floods. As indicated in Table 3.5, estimated water levels in Lough Allen during a 1,000-year design flood, or even during a 10,000-year flood, are unlikely to exceed the ESB's land acquisition levels. However, flooding around Lough Derg can exceed ESB's land acquisition levels during large floods, including the design 10,000-year flood. Such large flood events could lead to flooding of roads and possibly a small number of properties.

Reservoir/Lake	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Lough Allen	52.43	51.23	51.78
Lough Derg (Killaloe)	34.44	35.34	36.08
Parteen Basin	35.05	32.70*	32.70*

Table 3.5 River Shannon Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

* During significant floods the level immediately upstream of Parteen Weir is drawn down to 32.70m O.D. to optimise discharge through the channel restriction at Killaloe

In relation to large floods on the River Shannon, it should be noted that the discharge capacity at Parteen Weir is more than adequate to pass the design 10,000-year flood and that there is a channel restriction at Killaloe, which restricts the discharge from Lough Derg. Therefore, the rise in levels in Lough Derg during large floods is primarily due to the discharge capacity at Killaloe rather than the operation of Parteen Weir.

3.3.4 River Erne

There has not been a history of flooding outside ESB's land acquisition lines upstream of Cliff or Cathaleen's Fall Dams during significant past floods. As indicated in Table 3.6, estimated peak water levels upstream of the dams are unlikely to exceed ESB's land acquisition levels during the design 10,000-year flood.

Reservoir/Lake	Land Acquisition Level (m O.D.)	Estimated 1,000-Year Flood Level (m O.D.)	Estimated 10,000-Year Flood Level (m O.D.)
Cliff	47.24	43.59	43.59
Cathaleen's Fall	35.05	34.14	34.14

Table 3.6 River Erne Reservoirs - Land Acquisition Levels and Estimated Maximum Design Flood Levels

During large floods on the River Erne, flooding can occur in Counties Fermanagh and Cavan due to rising water levels in the lakes and channels.. In this regard, it should be noted that there is a channel restriction at Belleek, which restricts the discharge from Lower Lough Erne, while the discharge capacity at Cliff Dam is more than adequate to pass the design 10,000-year flood.

3.3.5 River Clady

ESB's land acquisition levels for the Clady Scheme are 67.06m O.D. around Dunlewey Lough and 64.01m O.D. around Lough Nacung. These levels are above the estimated design 1,000-year flood levels of 66.03m O.D. for Dunlewey Lough and 62.88m O.D. for Lough Nacung. Therefore, flooding outside ESB's land acquisition levels would not be expected, even during extreme design floods.

3.4 Breaches of Dams or Embankments

ESB has an excellent record with regard to dam safety and there has never been a breach of any of its dams or embankments. As detailed in Section 1, ESB implements comprehensive dam safety procedures to ensure against potential future breaches. Frequent inspections and audits are carried out to ensure that these procedures are being implemented. These inspections and audits are carried out by both ESB inspectors and by a committee of international experts.

The dam safety standards applied to the dams and embankments, require that they are capable of withstanding extreme events, i.e. 10,000-year

floods and 10,000-year earthquakes. Therefore, it is considered that the probability of a significant breach occurring is less than 1 in 10,000 in any year.

Notwithstanding the low probability of a breach occurring at one of ESB's dams or embankments, inundation studies have been undertaken to assess the likely effects of a breach. The following is a list of the inundation studies that have been carried out:

- River Liffey Inundation Study, Part 1 : Leixlip
- River Liffey Inundation Study (Pollaphuca to Leixlip)
- River Liffey – Leixlip Inundation Study
- Turlough Hill Inundation Study
- River Lee Inundation Study (1988)
- River Lee, Carrigadrohid Inundation Study (Input to Local Authority Emergency Plan)
- Cork City Inundation Study (Input to Local Authority Emergency Plan)
- River Lee Levels - Cork City (Sensitivity to Inniscarra Discharges)
- River Shannon – Inundation Study for Dams and Embankments on Lower Shannon
- River Shannon, Lough Allen Inundation Study
- River Shannon Inundation Study – Parteen Weir to Limerick City
- River Shannon, Lough Allen – Inundation Resulting from an Embankment Breach
- River Erne Inundation Study : Cliff and Cathaleen's Fall

As well as the consequences of breaches, these studies assess the downstream flooding effects of extreme design floods.

Copies of inundation studies have been provided to the Office of Public Works and relevant Local Authorities.

3.5 Overtopping of Dams or Embankments

The water management procedures for all of ESB's Category A dams and embankments, and also lower category dams and embankments at Lough Allen and on the River Clady, are designed to prevent their overtopping, even during extreme design floods. Overtopping of a dam could lead to extensive damage of the structure and also of the foundation at the

downstream toe. The implementation of these procedures is mandatory during floods. Therefore, the likelihood of one of ESB's major dams or embankments being overtopped during a flood is extremely unlikely.

Water levels upstream of all of ESB's major dams are monitored continuously in the Hydro Control Centre, which is based in Turlough Hill. However, during flood periods, local control rooms and personnel manage and monitor water levels and flows.

High water level alarms are also provided upstream of the major dams. These provide warnings of increases in water levels upstream of the dams.

As noted in Section 2.5, the Portumna Embankments differ from ESB's other dams and embankments, in that they were constructed along the bank of the River Shannon, to prevent adjacent low lying lands from flooding during the summer, due to higher Lough Derg and river levels due to the operation of the Shannon Scheme. Two of these embankments, Meelick and Whitesford Embankments, near Portumna, on the River Shannon, have been overtopped in the past, most recently during the major flood in 2009. This overtopping resulted from unprecedented water levels in the River Shannon, even though the crests of the embankments were at or above their design levels. Improvement works have been carried out to ensure the stability of these embankments. In addition, additional pumping capacity is to be installed at the Portumna Embankments system, second pumps being provided for the Boula and Meelick embankments. The Whitesford Embankments already has two pumps, since the time of construction.

Despite these improvement works at the Portumna Embankments, there remains the possibility of the embankments becoming overtopped during future large floods. An inundation study is being carried out to identify the extent of flooding resulting from different extents of overtopping of the embankments. However, during previous overtopping events, while some roads were affected, no properties were flooded.

Apart from the embankments at Portumna, it is considered extremely unlikely that any of ESB's other dams or embankments could be overtopped to cause flooding to the areas downstream.

3.6 Operational Malfunctions

ESB's dam safety procedures help to protect against flooding arising from operational malfunctions. These procedures are governed by the "ESB Dam Safety Organisational Structure", the original version of which was approved by the ESB Board of Directors in 1988, since when there have been no incidents of flooding caused by operational malfunctions.

As described in Section 2.6, there has been only one occasion, prior to 1988, when has flooding arisen due to an operational malfunction at an ESB dam, i.e. Inniscarra Dam on the River Lee on 30th December 1987. However, remedial measures have been put in place to ensure that such an incident does not recur. In addition, further improvement works have been undertaken to ensure the reliable operation of water control equipment or to warn of unexpected events. The remedial measures and improvements include:

- Modern control systems have been installed to manage the operation of water control equipment.
- Back-up diesel generators have been installed to ensure the operation of critical water control equipment in the event of a loss of normal power supplies.
- Alarms have been installed to warn of unexpected events in relation to water control, e.g. upstream and downstream water level alarms, gate movement alarms, etc.
- Safety interlocks have been installed to ensure that only one gate at a time can be operated.
- "Dead-man" switches have been installed to ensure that a single pressing of a button could not lead to the full opening of a spillway gate.
- Frequent test operations of water control equipment are carried out to ensure their satisfactory operation at all times.
- All spillway gate movements must now be witnessed by a person standing on the crest of the dam.
- Regular reports are produced on the status of testing and maintenance of water control equipment.
- Annual dam safety inspections include an inspection by mechanical and electrical engineers of the water control equipment at each dam.
- The External Dam Safety Committee, set up under the "ESB Dam Safety Organisational Structure", includes an Expert for Mechanical, Electrical and Control Equipment.

Under the current dam safety procedures being implemented by ESB, it is considered extremely unlikely that future flooding downstream of a dam could be caused by operational malfunctions.

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4 Conclusions

ESB operates hydro-electric power plants on five rivers in Ireland, i.e. Rivers Liffey, Lee, Shannon, Erne and Clady, and a pumped storage scheme at Turlough Hill. Dams and embankments form part of the infrastructure associated with these schemes. A preliminary flood risk assessment for ESB's dams and embankments has been undertaken to address the requirements of the following legislation:

- EU Directive 2007/60/EC on the Assessment and Management of Flood Risks
- S.I. No. 122 of 2010 – European Communities (Assessment and Management of Flood Risks) Regulations

This preliminary flood risk assessment for ESB's dams and embankments was undertaken under the following broad headings:

- Past Floods
- Potential Future Floods

In relation to both past and potential floods the following flooding scenarios were investigated:

- River Floods Downstream of Dams
- Floods around Reservoirs
- Breaches of Dams or Embankments
- Overtopping of Dams or Embankments
- Operational Malfunctions

For river floods downstream of dams, the preliminary flood risk assessment has indicated that the construction of dams and embankments on the Rivers Liffey, Lee, Shannon, Erne and Clady has not lead to increased flooding downstream of the dams. In fact, the operation of the dams has beneficial effects with regard to flooding of the areas downstream. Similarly for potential future river floods downstream of dams, the water management procedures that are implemented by ESB are such that even for very extreme design floods, the operation of the dams will have some beneficial effects for downstream flooding.

To cater for increased upstream water levels, ESB acquired lands around reservoirs and lakes upstream of its dams and embankments. There has not been a history of significant flooding above the ESB's land acquisition levels upstream of the dams and embankments. However, during extreme floods, such as the design 10,000-year flood, there is potential for some future flooding above ESB's land acquisition levels.

ESB has an excellent record regarding dam safety and there has never been a breach of any of its dams or embankments. ESB implements comprehensive dam safety procedures and potential future breaches are considered extremely unlikely.

The water management procedures, in place for ESB's major dams and embankments, require that the extreme design 10,000-year flood can be passed without overtopping the structures. Overtopping of one of ESB's major dams or embankments has never occurred and potential future overtopping is considered extremely unlikely.

The embankments on the River Shannon, near Portumna, differ from ESB's other dams and embankments, in that they were constructed along the bank of the river, to prevent adjacent low lying lands from flooding during the summer. Overtopping of these embankments has occurred during very large winter floods, the most recent in 2009, when water levels in the River Shannon exceeded the design crest level for the embankments. Low lying land and some roads, but no properties, were flooded during this event. While it is not feasible to prevent overtopping of the Portumna Embankments during large floods, improvement works are regularly implemented to ensure their stability.

No operational malfunctions of water control equipment have occurred under the current dam safety procedures being implemented by ESB. These procedures will also protect against potential future operational malfunctions of water control equipment.

ESB has been working with the Office of Public Works and Local Authorities in relation to Catchment Flood Risk Assessment and Management Studies and the implementation of Catchment Flood Risk Management Plans. One of the issues being investigated during these studies is how ESB infrastructure on the rivers might be used to manage or reduce the flood risk from river floods. ESB will continue to work with these bodies during future cycles of this process for the Rivers Liffey, Lee, Shannon, Erne and Clady.

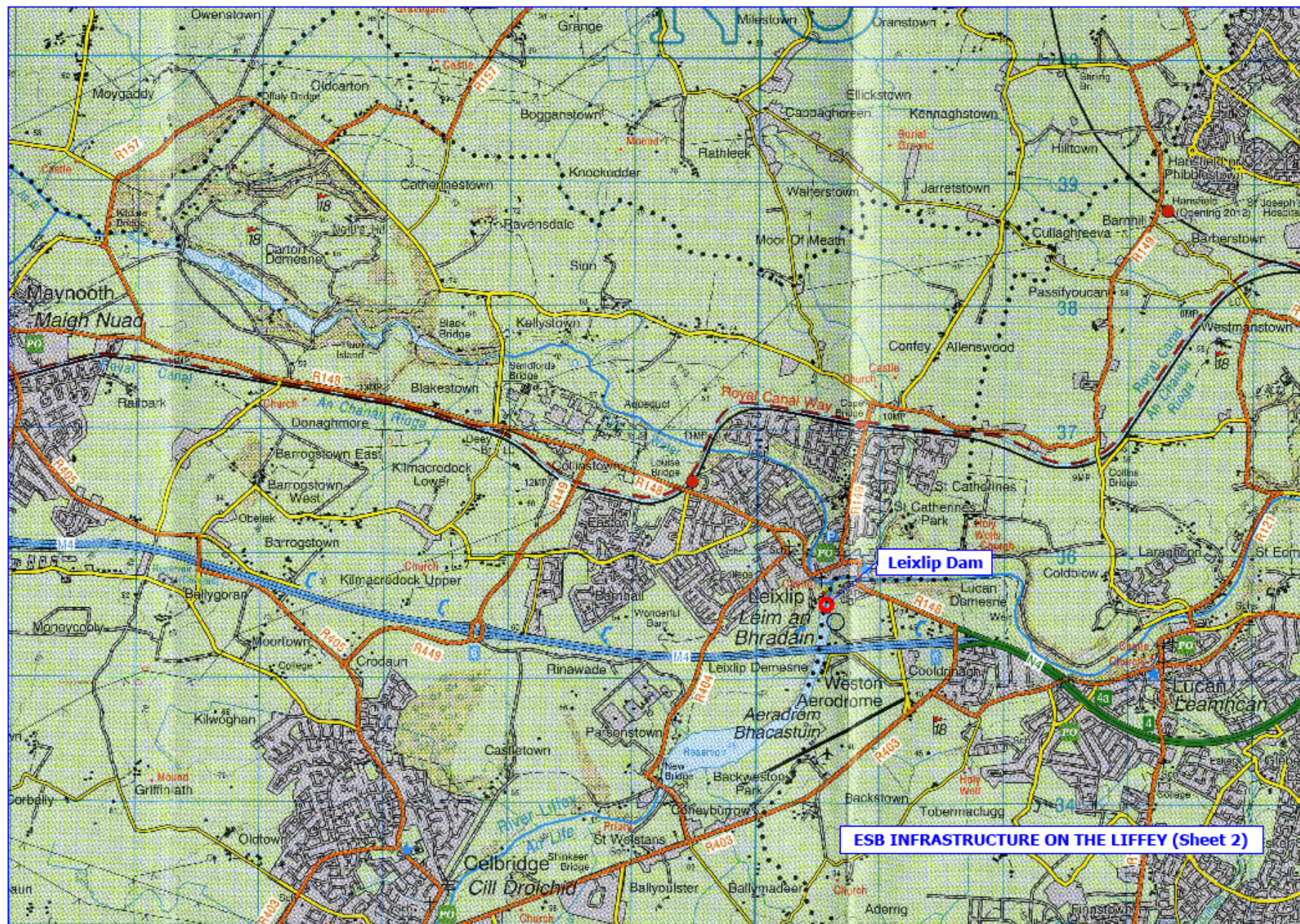
The integrity of the dams and reservoirs and safe water management on the rivers are serious priorities for ESB. The implementation of comprehensive procedures will continue to ensure the safety of the dams and embankments at all times. These procedures include the independent evaluation of ESB's dam safety activities by the External Dam Safety Committee of international experts. Contacts will be maintained with international experts, through the External Dam Safety Committee, and with international dams organisations through the International Commission on Large Dams. Where identified, advances in the state-of-the-art with regard to dam safety will be implemented to ensure that procedures continue to be improved.

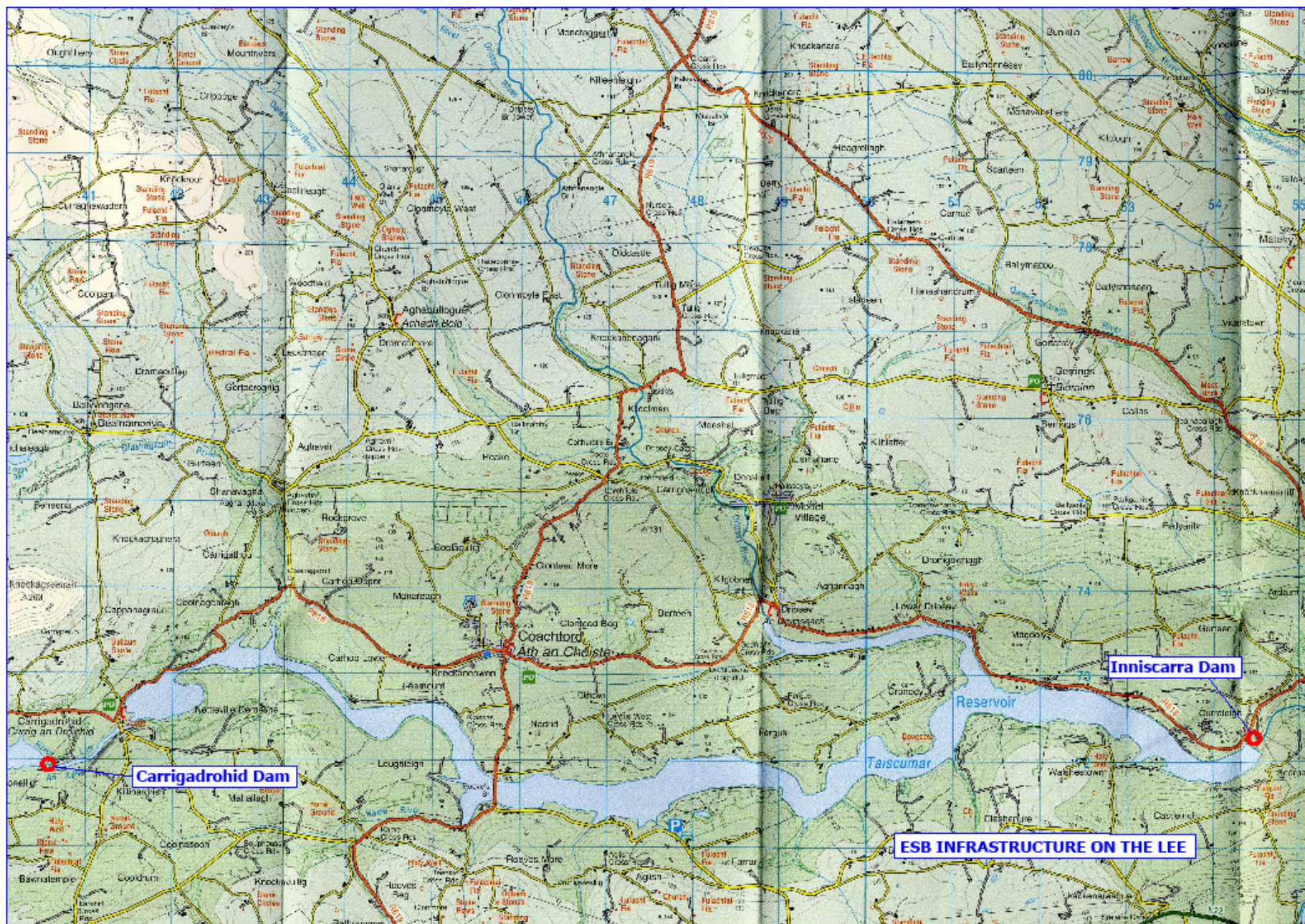
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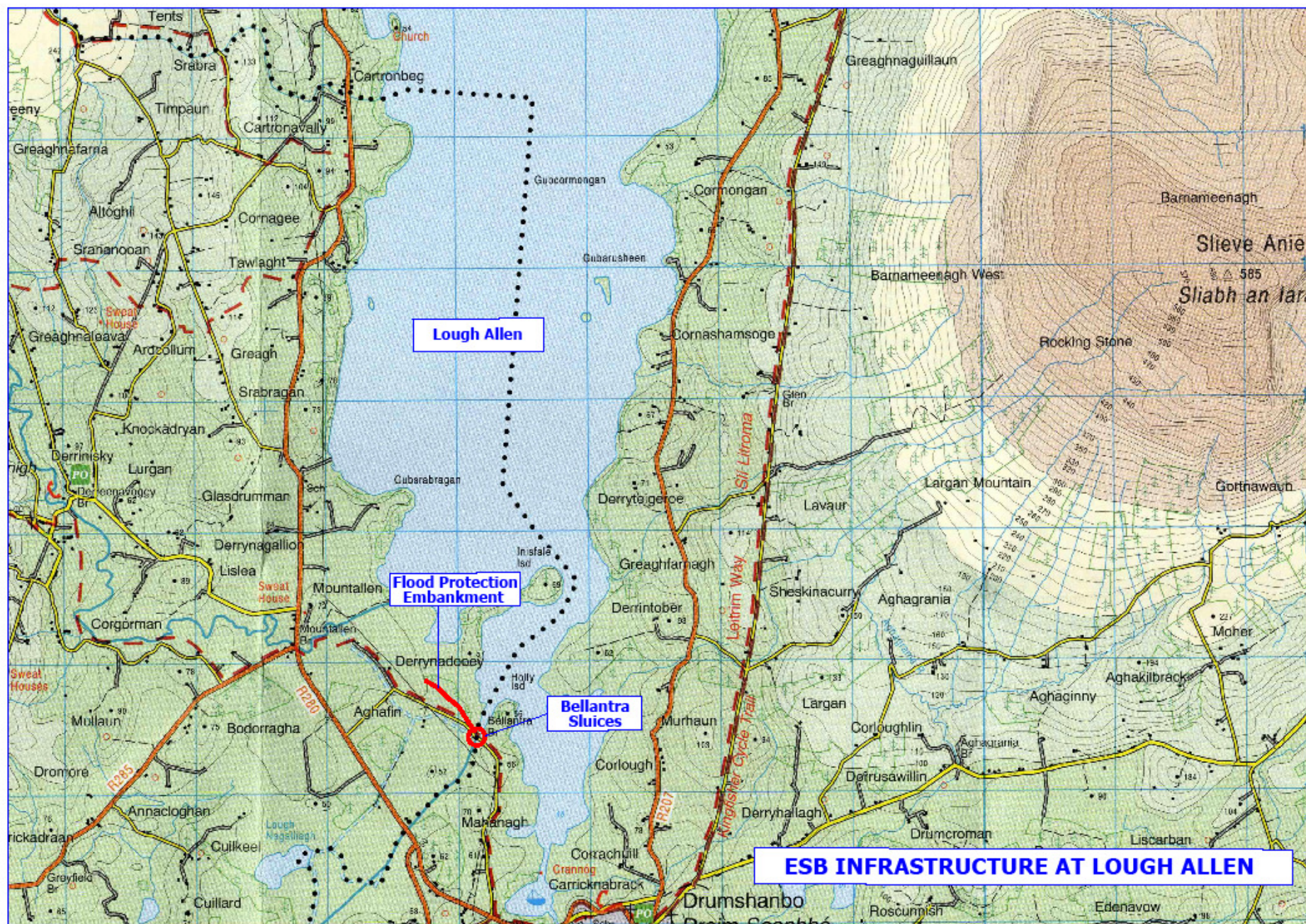
Appendix A Locations of ESB's Dams and Embankments

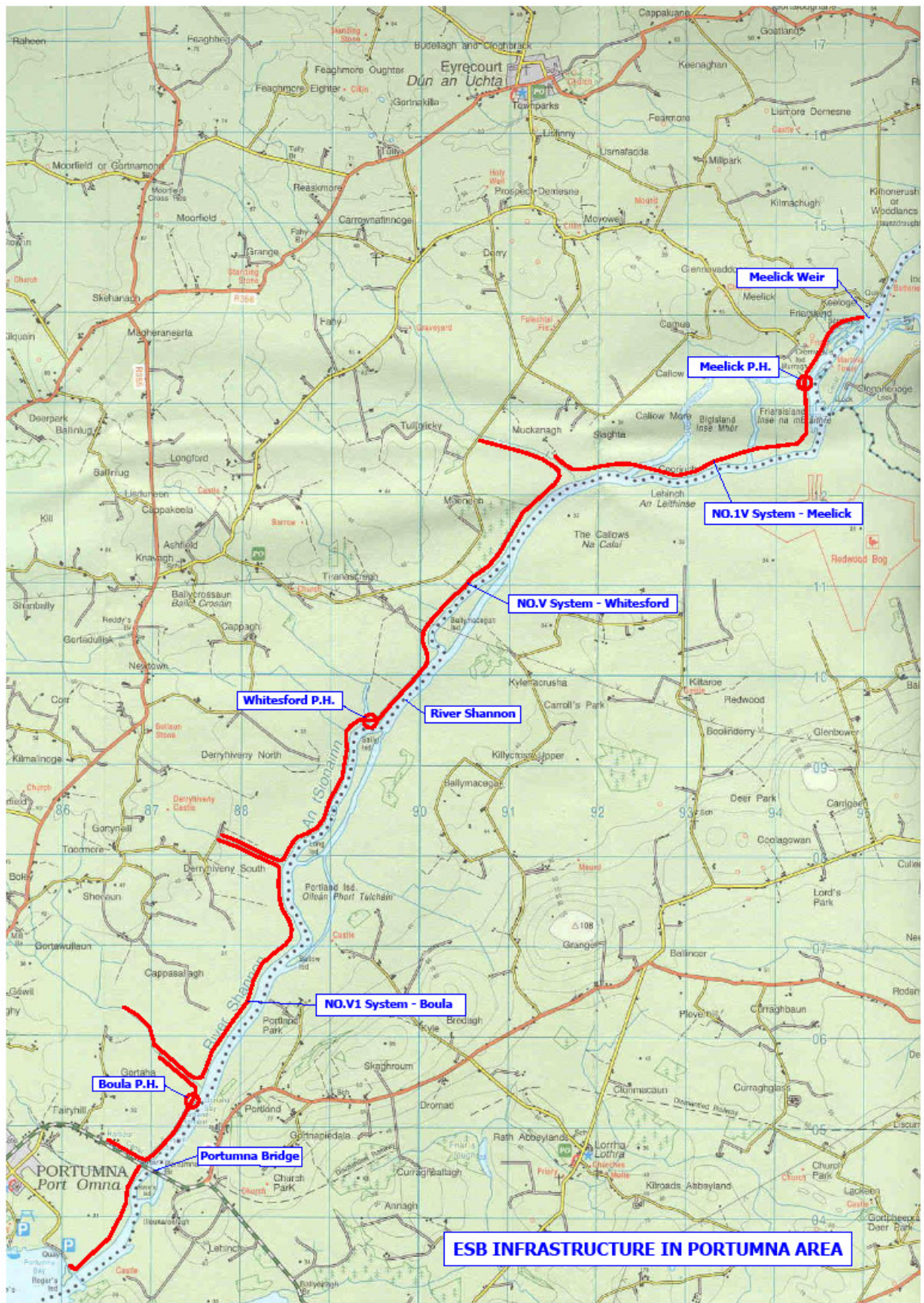
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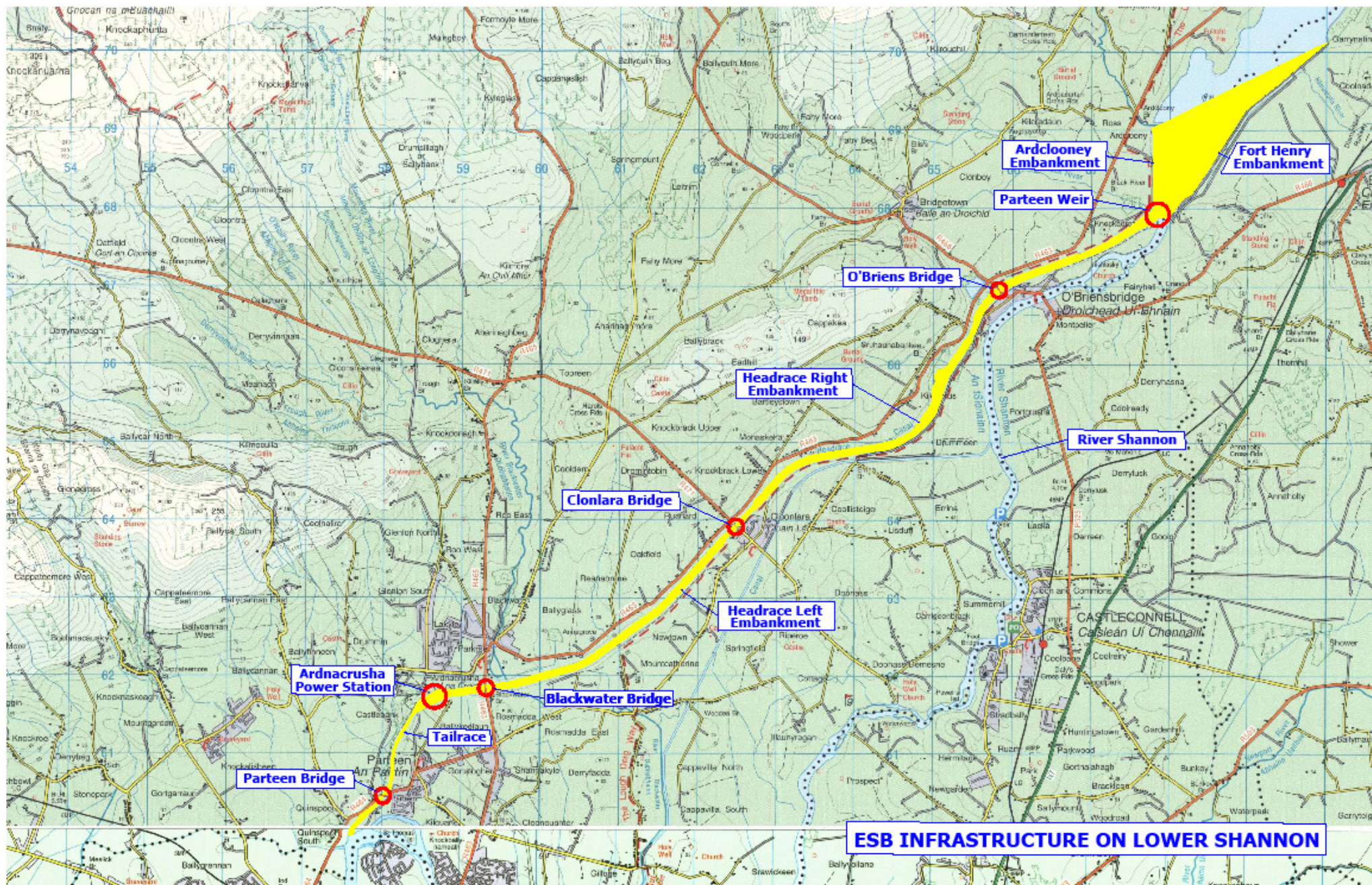




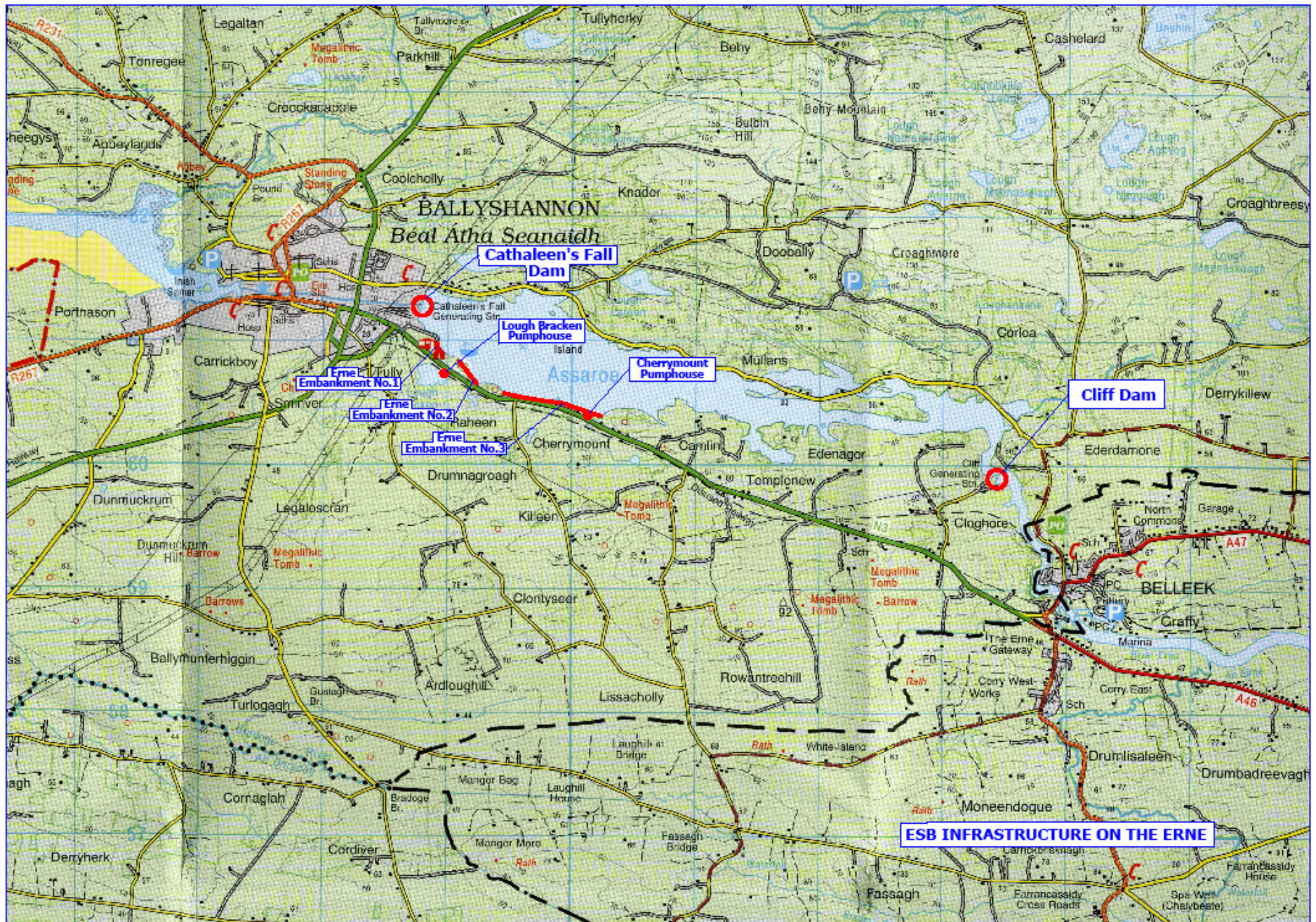


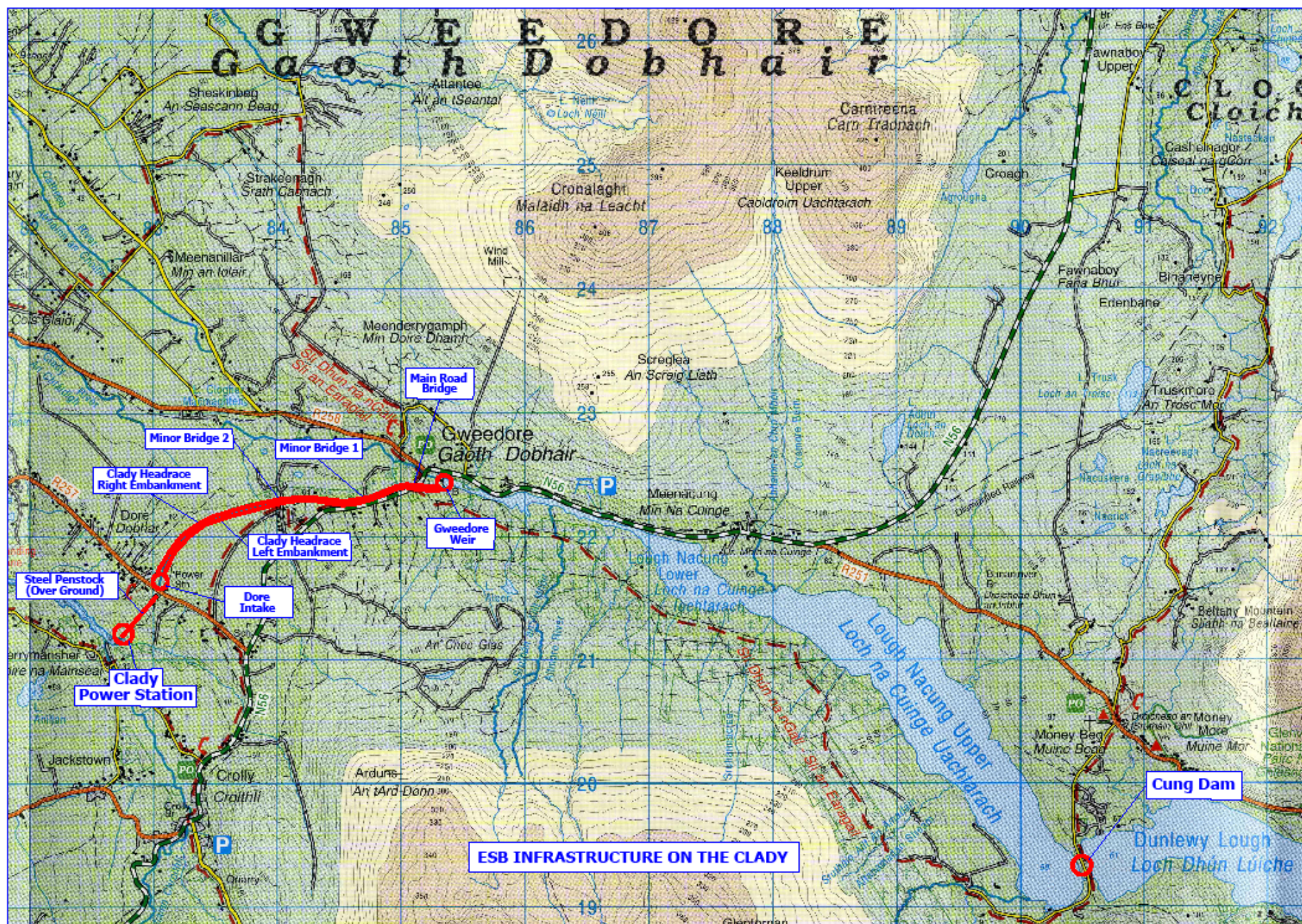






ESB INFRASTRUCTURE ON LOWER SHANNON





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