Oifig na nOibreacha Poiblí
The Office of Public Works

Lower Lee (Cork City) Flood Relief Scheme
(Drainage Scheme)

Supplementary Report on Option of Raising Existing Dams

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Lower Lee (Cork City) Flood Relief Scheme

Supplementary Report – Option of Raising Existing Dams

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Contents

Appendices

Executive Summary

The Lower Lee Flood Relief Scheme (LLFRS) was commissioned by the Office of Public Works (OPW) with the objective of delivering a flood relief scheme for Cork City and environs to provide protection against the 1 in 100 year fluvial/1 in 200 year tidal flood events.

The project followed on from the pilot Lee CFRAM Study which identified the preferred scheme as being a combination of a flood forecasting system, optimised dam operating procedures and raised waterside defences.

Following extensive study and assessment, a proposed scheme was developed which consisted of a modified version of the above measures together with a flow control structure on the south channel to rebalance flows between the north and south channels.

The proposed scheme was subsequently brought to Statutory Exhibition stage through the Arterial Drainage Act (as amended) in late 2016/early 2017.

A fundamental component of the exhibited scheme is revised operational procedures for control of the existing dams during extreme flood events. These revised rules will allow the dam operator to safely draw down the reservoirs in advance of a flood, which will maximise the storage available, and safely manage discharges during the event without causing flooding.

A number of exhibition submissions suggested that the existing dams have sufficient storage to avoid fluvial defences entirely. Such submissions are premised on a number of incorrect assumptions and are based on a proposed operating philosophy which would jeopardise dam safety by significantly increasing the risk of overtopping. They do not sufficiently address the residual risks associated with events greater than the 1 in 100 year event. The prevailing dam safety regulations at the Lee dams dictates that events up to the 10,000 year event must be safely passed at all times. The magnitude of a developing flood event cannot be established with enough certainty beforehand to advocate an approach that completely fills the reservoirs during events up to the 1 in 100 year event as has been proposed by others.

The Lower Lee FRS (as exhibited) proposes revised rules, which have been optimised following extensive detailed analysis of all the real-world constraints, to maximise the benefit of the dams. These revised rules result in almost a 40% reduction in peak flows reaching the city, thus meaning that required defence heights can be minimised. However, due to the limited size of the reservoirs, the revised rules cannot on their own provide the required standard of protection and therefore these rules can only be utilised in conjunction with raised waterside defences as proposed.

It has been established that the existing reservoirs have insufficient storage to safely manage events up to the required 1 in 10,000 year standard whilst at the same time limiting discharges to a rate which does not cause downstream flooding.

Whilst it was not part of the brief for the Lower Lee FRS to assess the merits of raising the existing ESB dams, as a result of the number of submissions received, it became clear that it would be in the public interest to provide further detail and assessment of this option. This report therefore addresses in detail the potential to create additional storage through increasing the height of one or both of the existing dams and or creating an additional reservoir at Dromcarra.

In order to allow the reservoirs to fully mitigate the existing fluvial (river) flood risk in Cork City, i.e. avoiding the need for direct fluvial defences, significant additional storage would be required.

A number of options to achieve this have been considered and while some options may be technically viable, they all have significant shortcomings compared with the exhibited scheme as summarised below:

- Raising of Carrigadrohid dam would give rise to significant alterations to the natural regime of the Gearagh Special Area of Conservation/Special Protection Area. Accordingly there is a significant risk that a dam-raising scheme may not gain statutory consent when alternatives exist which do not impact on Natura 2000 sites.
- A minimum of 80 properties would need to be displaced due to the increased reservoir area. This could critically damage communities such as Toonsbridge.
- A minimum of 8km of existing roads would need to be raised/relocated. Several bridges would also need to be raised/reconstructed and significant alterations would be required to the proposed new Macroom bypass.
- A minimum of 5km^2 of substantially productive agricultural land would be sterilised
- Even if all of the above was undertaken, it would only eliminate or reduce a small proportion of the overall direct defences as protection would still be required in the city centre.
- It is therefore evident that such a proposal would have an unacceptable and inappropriate impact on an area and community not currently at risk of flooding, in order to protect others elsewhere.
- It has been established that such an alternative scheme is less attractive on technical, social and environmental grounds, than the exhibited scheme.
- All of the options considered are significantly more expensive than the exhibited scheme, and crucially none of the options are cost beneficial.

1 Introduction

1.1 Background and Context

The Lower Lee Flood Relief Scheme (LLFRS) was commissioned by the Office of Public Works (OPW) with the objective of delivering a flood relief scheme for Cork City and environs to provide protection against the 1 in 100 year fluvial/1 in 200 year tidal flood events.

The project followed on from the pilot Lee CFRAM Study which identified the preferred scheme as being a combination of a flood forecasting system, optimised dam operating procedures and raised waterside defences.

Following extensive study and assessment, a proposed scheme was developed which consisted of a modified version of the above measures together with a flow control structure on the south channel to rebalance flows between the north and south channels.

The proposed scheme was subsequently brought to Statutory Exhibition stage through the Arterial Drainage Act (as amended) in late 2016/early 2017.

Details of the scheme were available for inspection to members of the public between the 12th December 2016 and the 20th January 2017 at four locations around Cork City. The scheme has also been available to view online on the project website www.lowerleefrs.ie. Submissions were invited up to the 7 April 2017.

During the exhibition stage, members of the public were invited and encouraged to submit their views in relation to the preferred scheme. As part of the process, a number of submissions were received which suggested that the option of physical modifications (and associated operational rule changes) to the existing ESB dams at Inniscarra and Carrigdrohid could eliminate the need for direct fluvial defences in Cork City.

Among the above submissions, OPW received a submission (March 2017) prepared by Emeritus Professor Philip O' Kane. Professor O'Kane submitted two subsequent follow-on submissions which he put in the public domain and distributed widely. These submissions considered in some detail the available and potential storage at both reservoirs and suggested alternative operational rules.

It should be noted that a key part of the proposed flood relief scheme as exhibited is the implementation of revised operating rules (supported by a new flood forecasting system and downstream defence measures) which will allow the dam operator to draw down the reservoirs at a safe rate in advance of a flood, which will maximise the storage available, and management of discharges during the event.

Whilst it was not part of the brief for the Lower Lee FRS to assess the merits of raising the existing ESB dams, as a result of the number of submissions received, it became clear that it would be in the public interest to provide further detail and assessment of this option.

This report therefore addresses in detail the potential to create additional storage through increasing the height of one or both of the existing dams and or creating an additional reservoir at Dromcarra.

This report should be read in conjunction with the main Lower Lee FRS Exhibition Report and the Lower Lee FRS Options Report.

1.2 Scope of the Study

The scope of the study includes the following:

- Identification of potential technically viable engineering options for raising the crest levels of both dams;
- Assessment of the elevated reservoir water levels on the properties and infrastructure surrounding both reservoirs and an assessment of the engineering works required to mitigate the flood risk associated with such elevated water levels;
- Preliminary environmental assessment of the elevated water levels with particular reference to the Gearagh in Macroom;
- Multi-criteria assessment of the dam raising options versus the preferred option;
- Estimation of the costs associated with undertaking the various engineering works;
- Cost Benefit Analysis of the dam raising options versus the preferred option;

This report should be read in conjunction with the various reports produced as part of the Lower Lee FRS, all of which are available to download from the project website at www.lowerleefrs.ie.

1.3 Datums

This report contains numerous references to the vertical elevation (or level) of items such as flood levels, crest levels etc.

In Ireland, various reference levels, known as datums are used to allow comparison against to a consistent reference point. Generally, the ESB quotes levels relating to the Lee dams in Ordnance Datum Poolbeg (Dublin) which was historically the main datum.

In recent times, the main datum has changed to Ordnance Datum Malin Head, and is the main datum used in all other reports and drawings for this scheme.

Therefore, for consistency, all vertical elevations (or levels) referred to in this report are to Ordnance Datum Malin Head, unless noted otherwise.

To convert levels between the datums, the following conversions can be applied:

- To convert Malin to Poolbeg datum, add 2.701m to quoted levels
- To convert Poolbeg to Malin datum, subtract 2.701m from quoted levels

1.4 Consultation with ESB

The ESB sits on the steering group for the Lower Lee Flood Relief Scheme, and has been actively involved in assisting with the development of potential options, with particular reference to optimisation of the dams.

ESB has provided the project team with structural drawings and information regarding the existing dam structures to assist with the preparation of this report.

Arup also carried out a site visit to Inniscarra dam and Carrigadrohid dam during the preparation of this report, during which we were accompanied by senior ESB engineering staff who are familiar with all of the key issues, which would need to be considered if the dams were to be raised. The purpose of the site visit was to gain a further understanding of potential site-specific issues associated with dam-raising works.

2 Hydrology

2.1 Catchment Characteristics

The Lower Lee has a catchment area of 1,151 km2 by the time it reaches Waterworks Weir in Cork City. There are two large reservoirs situated on the River Lee at Inniscarra and Carrigadrohid and the Lee's flow regime downstream of these reservoirs is greatly impacted by the operating rules of the reservoirs.

Critical storm duration in the catchment is in the region of 48 hours and the critical storm would be a widespread catchment scale event, similar to the event in 2009. It is not sensitive to short duration fluctuations in rainfall intensity.

The Lower Lee catchment is very wet. The SAAR values vary from 1700mm in the western side of the catchment to 1100m in the eastern extent of the catchment.

The Carrigadrohid and Inniscarra reservoirs have 69% of the Lower Lee catchment flowing into them. Carrigadrohid and Inniscarra reservoirs, alter the natural flow regime of the River Lee. The two dams are operated for hydropower, but also offer some flood protection to Cork.

It is evident that the flow in Cork City during an event can be greatly affected by the starting level of the reservoir at the beginning of an event. Therefore, flow in Cork depends on reservoir levels and operating rules.

Downstream of Inniscarra two significant tributaries join the Lee upstream of Waterworks weir; the Shournagh from the north at Leemount, and the Southern Bride joins the Lee at Ovens. The time to peak of the tributaries is slightly faster than the main Lee, especially during intense rainfall events.

2.2 Calculation of Design Flows for Cork

Design flows for Cork have been derived primarily through a process known as Continuous Simulation Modelling (CSM). This process uses inputs from calibrated rainfall runoff models to route storm events through a hydrological routing model that can replicate the operation of the dams under various control rules.

The models were calibrated against historic events as well as other methodologies for a theoretical 'non-reservoir-ed' case, with good calibration being achieved.

CSM was then utilised to test numerous versions of alternative dam rules to optimise the use of the reservoirs during a flood event, and thus reduce the peak flow passed on to Cork.

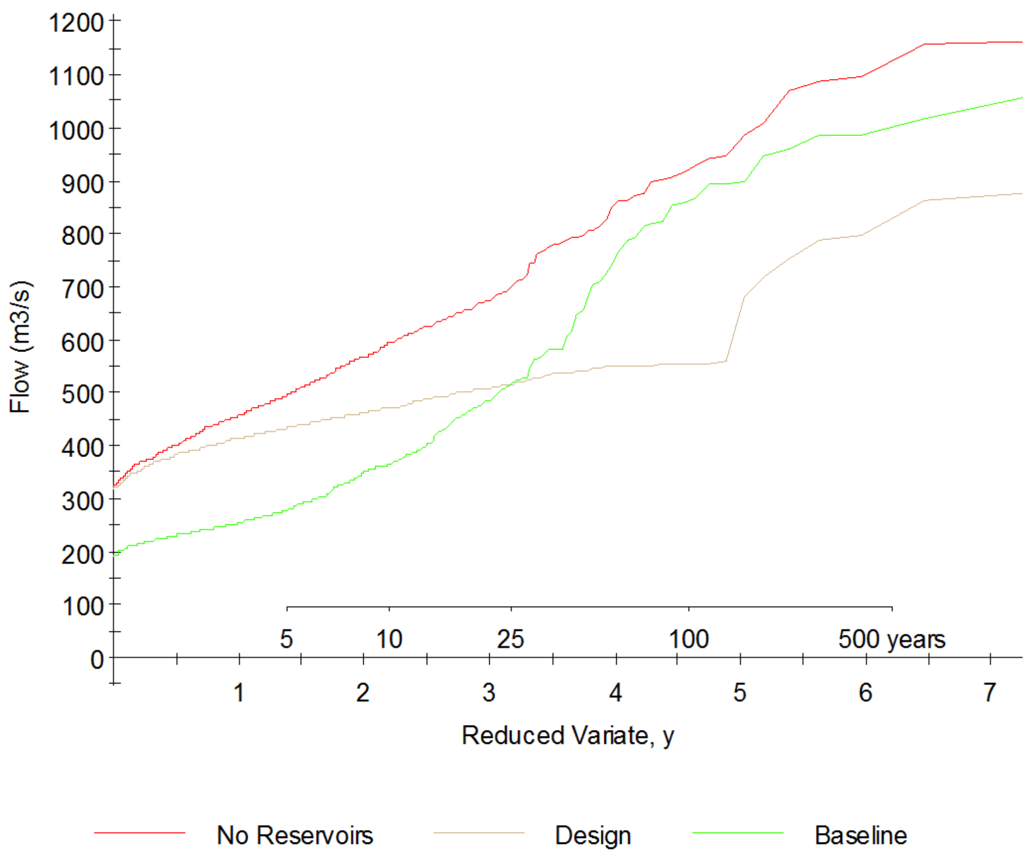
Full details of the hydrological assessment of the Lee catchment can be viewed in the Lower Lee FRS – Hydrological Report.

Table 1 below presents the peak flow for varying return periods at Waterworks weir for varying return periods. The information is shown graphically in Figure 1.

Table 1: Peak Flow (m^3/s) at Waterworks Weir for return period (years)

	Peak Flow (m^3/s) at Waterworks Weir for return period (years)								
Continuous simulation Scenario	**2**	**5**	**10**	**20**	**30**	**50**	**100**	**150**	**200**
No reservoirs	386	510	599	674	765	820	921	953	1039
Existing Scenario (Baseline)	234	284	351	452	536	705	861	892	906
Exhibited Scheme Design	372	440	472	507	530	547	555	575	734

Figure 1: Flood frequency curves at Waterworks Weir for the three scenarios



The 1 in 100year peak flow at Waterworks weir for the theoretical no reservoirs case is 921m^3/s. The existing rules serve to reduce this to circa 861m^3/s. Under the proposed rules as exhibited, the peak flow will be reduced significantly to

555m^3/s, a reduction of almost 40% versus the existing situation. This reduction is achieved by maximising the attenuation capacity of the existing reservoirs. However, this flow still results in a requirement for direct defences as the threshold of flooding in Cork is circa 350m^3/s.

Table 2 below illustrates the peak flows in terms of discharges from Inniscarra and on the two major downstream tributaries in the exhibited design case for the 1 in 100 year flood.

Table 2: Peak Flows downstream of Inniscarra

AEP and peak flow (m^3/s)								
	50%	20%	10%	5%	2%	1%	0.5%	0.1%
Discharge from Inniscarra Dam	361	416	445	471	495	515	676	788
River Bride (West)	37	47	54	63	76	83	92	103
River Shournagh	80	101	120	136	162	182	193	224

It can be seen that the combination of peak discharge from Inniscarra and peak inflows from both tributaries, if coincident would give rise to a significantly greater peak flow at Waterworks weir. However, because the peak discharge from Inniscarra is for a short duration and occurs significantly later than the peak on the Shournagh and Bride (as a result of the optimised rules), the peak flow at waterworks weir can be limited to the design flow of 555m^3/s.

2.3 Estimation of additional storage volume required to avoid direct defences

The proposed rules as exhibited allow for advance discharges from Inniscarra of up to 300m^3/s in advance of the peak, with increased discharges during the event, once the peak on the Bride and Shournagh has passed.

A number of submissions have suggested that raising of the dams could provide the necessary storage to eliminate the need for direct defences in the fluvial reach in Cork. (Tidal defences would still be required).

To achieve this scenario, the design flow at Waterworks weir would need to be reduced from 555m^3/s to circa 350m^3/s, a significant decrease of some 200m^3/s. This reduction has to be achieved primarily by reducing the discharge from Inniscarra and significantly increasing the period of discharge. This will have the impact of increasing the likelihood of the peak discharge on the Shournagh and Bride becoming critical and coinciding with the average discharge from Inniscarra. Based on the flows in Table 2 above, it is likely that a peak flow of 200m^3/s to 250m^3/s would need to be allowed for inflow from the tributaries. This would mean limiting discharges from Inniscarra to circa 100m^3/s to 150m^3/s (Higher discharges will be possible at certain times outside of the peaks on the tributaries). This is a significant change from the exhibited scenario, which facilitates advance discharges of 300m^3/s and above.

To achieve this reduction, a very significant additional storage volume would be required. The required volume is estimated below.

Section 9.2 of the scheme Options Report[1] contains an analysis of the residual fluvial flood volume for the design event at Cork City based on the revised operational rules proposed under the exhibited Lower Lee scheme. This analysis is written in the context of potential ancillary storage on the tributaries downstream of Inniscarra dam. The analysis is based on the predicted performance of the dams under the proposed revised operational procedures (refer to appendix G of the Hydrology Report[2] for details of same).

This detailed analysis can also be used to approximate the potential increased storage needed at the existing dams to avoid downstream fluvial defences. It is therefore partly reproduced hereunder. The following points should be read in conjunction with Figure 2 below.

- The existing reservoirs (with the proposed revised operating rules during flood conditions) can reduce/attenuate the peak of the 1% AEP flood event by circa 21 million m^3 at Waterworks weir (compared with the theoretical scenario where the existing reservoirs do not exist). Note that this volume reduction is less than the theoretical maximum storage volume available in the reservoirs during this event[3] (circa 35 million m^3). This suggests an "inefficiency factor" of 35/21 = **1.67**. (This relates to inefficiencies arising out of two dams rather than 1, top sluices in Inniscarra, etc.)
- In the design scenario (existing dams with revised operating rules), the residual flood volume at Waterworks weir above the threshold at which property would begin to flood (threshold of approximately 350m^3/s flow) is circa 22 million m^3. This is the additional volume that would need to be attenuated by further storage in order to remove the need for raised flood defences in the fluvially affected reaches in Cork City.
- To allow for inefficiency in any raised dams, it is prudent to assume a greater volume would be needed. Therefore, conservatively assuming a similar inefficiency factor to above, an upper bound increase in storage volume of circa 22 x 1.67 = **36.7 million m^3** could be required at the existing reservoirs to limit the peak flow at Waterworks weir to circa 350m^3/s (which would facilitate the omission of the majority of the proposed direct fluvial defences from the scheme[4]). This simple volume balance calculation is sufficient for the purposes of establishing the order

[1] Arup/JBA Consulting (March 2017) Lower Lee (Cork City) Drainage Scheme (Flood Relief Scheme) Options Report

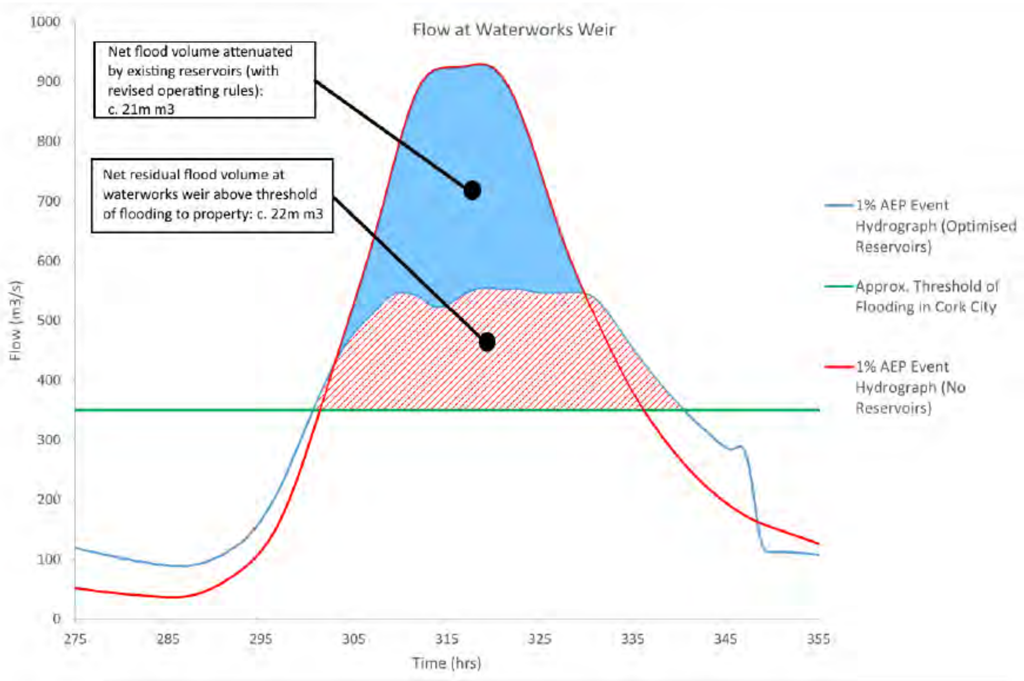
[2] Arup/JBA Consulting (March 2017) Lower Lee (Cork City) Drainage Scheme – Hydrology Report"

[3] This is the reservoir storage volume between the minimum acceptable levels at the start of the event (at the end of the advance discharge phase) and the maximum acceptable peak levels in the reservoirs which do not give rise to dam safety discharges greater than the design discharge.

[4] Defences around existing properties in the area of the proposed washlands, and the proposed south channel flow control structure would still be required, refer to Section 5.5

of magnitude storage volume required, but detailed modelling would be needed to confirm the actual required volume, if such an option were to be carried forward.

Figure 2: Comparative Hydrographs at Waterworks weir (Source: Lower Lee FRS Options Report)



In summary, any dam raising option would need to provide between 22Mm^3 and 37Mm^3 of additional storage to avoid the need for downstream defences. In simple terms, this would require the doubling of useable storage currently available.

3 Description of Existing Dams and Reservoirs

3.1 Introduction

Carrigadrohid dam and Inniscarra dam were constructed between 1952 and 1957 as part of the Lee Hydroelectric scheme. The scheme was approved by the Minister for Industry and Commerce via the "River Lee Hydro-Electric Scheme Approval Order", 1949 (S.I. No. 321/1949). This section provides an overview of the existing dam structures and impounded reservoirs.

3.2 Carrigadrohid Dam and Reservoir

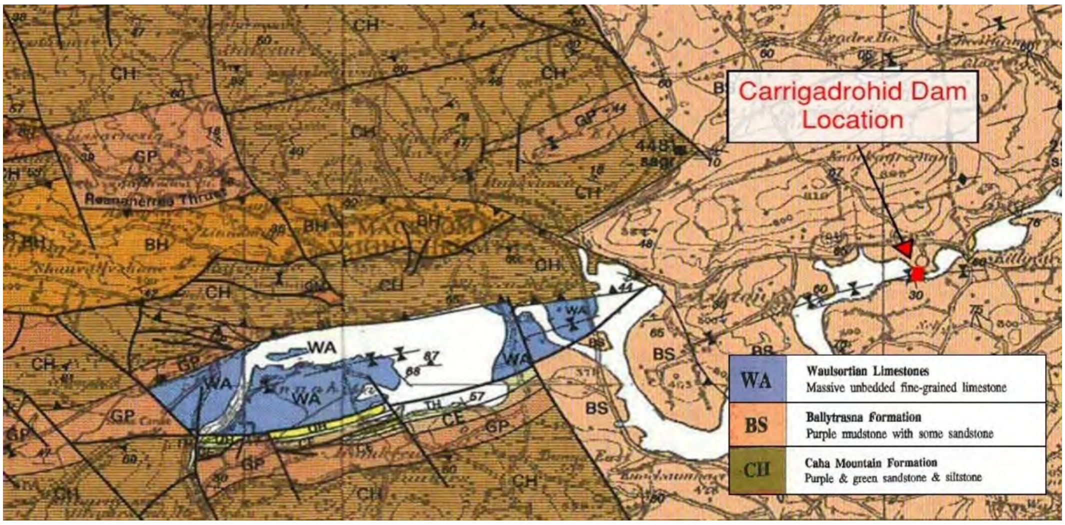
3.2.1 Site Geology

The principle bedrock formation in the area of Carrigadrohid dam and reservoir is the Upper Devonian, Old Red Sandstone. Carrigadrohid dam is located within the Ballytrasna Formation[5] a dusky-red to purple mudstones and siltstones with subordinate fine-grained pale-red sandstones.

The reservoir area is predominately bounded by the Ballytrasna Formation with the eastern areas bounded by Waulsortian Limestone, a massive unbedded fine-grained limestone and the Caha Mountain Formation, a purple and green sandstone and siltstone.

It is noted that the left abutment (as viewed looking downstream) of Carrigadrohid dam is constructed in glacial moraine material.

Figure 3: Extract from Bedrock Geology Map



[5] Geology of Kerry – Cork, A geological description to accompany the bedrock geology 1:100,000 Scale Map Series, Sheet 21, Kerry Cork, Geological Survey of Ireland, 1997.

3.2.2 Hydrology

When considering the potential for raising the existing dams, extreme events greater than the 1 in 100 year design standard of the OPW flood scheme also need to be considered. ESB has advised that the dams are required to safely pass the 1 in 10,000 year event without overtopping.

The ESB's design peak flood flows and volumes for the 1 in 10,000 year extreme event was obtained from publically available ESB reports downloaded from www.floodmaps.ie and are presented in Table 3 below:

Table 3: Carrigadrohid Peak Flood Flows and Flood Volume (Existing Scenario)

Return period	Peak Inflow (m^3/s)	Peak Discharge (m^3/s)	Approximate Inflow Volume (m^3)
1 in 10,000	1311 m^3/s	834 m^3/s	109,000,000 m^3

In preparing this report, the peak inflows were checked by carrying out flood estimation calculations using the "rapid assessment" method outlined in Floods and Reservoir Safety (FRS), 4th Edition, published by the Institution of Civil Engineers in 2015. The calculated flows compared well against ESB's stated design flows.

It should be noted that the above design events are for theoretical single-peaked events. As has been established as part of the Lower Lee Hydrology study, a multi-peaked event with lesser peak inflow but larger flood volume could also be a critical scenario for the reservoirs. The likelihood of the occurrence of such events has been taken into account in the design of the exhibited scheme.

3.2.3 Dam Structure

Carrigadrohid dam (Figure 4) is a concrete gravity dam, located circa 27km west of Cork City and circa 16.3km upstream of Inniscarra dam. It has a maximum height of 22m and a length of 130m. The dam crest is at approximately 64.51mOD (Malin). The main features of the dam can be summarised as follows:

- The main dam wall consists of 9no. structurally independent concrete gravity blocks.
- The hydroelectric station is constructed integrally with the dam wall on the left bank (looking downstream). The hydroelectric generator is powered by a Kaplan turbine. The dam has a hydroelectric generation capacity of 8 MW (Figure 5).
- A Borland-type fish lift.
- 3no. deep sluice gates, each 3m wide x 4.8m high.
- An auxiliary spillway on the right bank consisting of a 50 m long lateral ogee weir with a weir crest level of 62.49mOD (Malin datum) discharging to a trapezoidal channel spillway. The spillway was retrofitted in the early 1990's following a major dam safety review of the Lee system by ESB in 1987,

which took account of recent developments in International Dam Safety practice at that time.

Figure 4: Carrigadrohid Dam

Figure 5: Carrigadrohid Hydropower Station (deep sluices in foreground)

3.2.4 Reservoir

The reservoir impounded by the dam follows the natural path of the River Lee from the dam to a point approximately 8.5km to the west, as shown in Figure 6 below. The width of the reservoir generally varies between 100m and 600m. Towards the western end of the reservoir, there are two causeways which support the N22 National Road and a local road, the Sleaveen Road. The total surface area of the reservoir is approximately 9km^2.

Figure 6: Carrigadrohid Reservoir

3.3 Inniscarra Dam and Reservoir

3.3.1 Site Geology

Similar to Carrigadrohid dam, Innisccarra dam is located within the Ballytrasna Formation[6], a dusky-red to purple mudstones and siltstones with subordinate fine-grained pale-red sandstones.

The reservoir area is predominately bounded by the Ballytrasna Formation with a proportion upstream bounded by the Gyleen Formation, a sandstone with mudstone and siltstone and the Cuskinny Member Formation, a flaser-bedded sandstone and mudstone.

The bedrock is generally overlain with till and gravels derived from Devonian sandstones.

3.3.2 Hydrology

When considering the potential for raising the existing dams, extreme events greater than the 1 in 100 year design standard of the OPW flood scheme also needs to be considered. ESB have advised that the dams are required to safely pass the 1 in 10,000 year event without overtopping.

The ESB's design peak flood flows and volumes for the 1 in 10,000 year extreme event was obtained from publically available ESB reports downloaded from www.floodmaps.ie and are presented in Table 4 below.

[6] Geology of Kerry – Cork, A geological description to accompany the bedrock geology 1:100,000 Scale Map Series, Sheet 21, Kerry Cork, Geological Survey of Ireland, 1997.

Table 4: Inniscarra Peak Flood Flows and Flood Volume (Existing Scenario)

Return period	**Peak Inflow[7]**	**Peak Discharge**	**Approximate Inflow Volume (m^3)**
1 in 10,000	1157m^3/s	1,075m^3/s	138,000,000

It should be noted that the peak design inflows into Inniscarra are limited by the discharge capacity of Carrigadrohid which serves to limit the peak inflow to Inniscarra during extreme events.

It should be noted that the above design events are for theoretical single-peaked events. As has been established as part of the Lower Lee Hydrology study, a multi-peaked event with lesser peak inflow but larger flood volume could also be a critical scenario for the reservoirs. The likelihood of the occurrence of such events has been taken into account in the design of the exhibited scheme.

These peak inflows were checked by carrying out flood estimation calculations using the "rapid assessment" method outlined in Floods and Reservoir Safety (FRS), 4th Edition, published by the Institution of Civil Engineers in 2015. The calculated flows compared well against ESB's stated design flows.

3.3.3 Dam Structure

Inniscarra dam is a concrete buttress dam, located circa 14km west of Cork City. It has a maximum height of 42m and a length of 250m. The dam crest is at approximately 49.33mOD (Malin) (approximately 45m high). The main features of the dam can be summarised as follows:

- The main dam wall consists of 19no. structurally independent concrete buttress blocks.
- The hydroelectric station is constructed adjacent to the dam wall on the left bank. The two hydroelectric generators are each powered by Kaplan turbines. The dam has a hydroelectric generation capacity of 19 MW.
- A Borland-type fish lift.
- The overflow spillway consists of three vertical sluice gates, each 12m in width x circa 5m high. The sill of the spillway is at approximately 42.4mOD (Malin).
- A deep scour valve is located close to the right bank.

[7] Peak inflow is limited by the maximum discharge from Carrigadrohid

Figure 7: Inniscarra Dam

Figure 8: Inniscarra Hydropower Station

3.3.4 Reservoir

The reservoir impounded by the dam follows the natural path of the River Lee and spans approximately 12.2km between both dams, as shown in Figure 9 below. The width of the reservoir generally varies between 120m and 450m. Towards the western end of the reservoir, there is a causeway which supports the R619 Regional Road. The total surface area of the reservoir is approximately $5km^2$.

Figure 9: Inniscarra Reservoir

4 Overview of Objective and Possible Options

4.1 General Objective

The overriding principle of the various submissions received at exhibition stage is that the capacity of Carrigadrohid reservoir and Inniscarra reservoir should be increased to allow a sufficient volume of flood water to be attenuated in the design flood event. Thus reducing the peak flow downstream and avoiding the need for direct fluvial flood defences through the Ballincollig area into Cork City centre. It is worth noting that even if this were achieved, it would not eliminate the need for measures to protect against tidal flooding in the City.

It has been suggested that the additional capacity could be created by some combination of one or all of the following:

a) Lowering the initial water levels in the reservoirs in advance of a flood, and/or

b) Revised operational rules and discharge patterns over the course of an extreme event and/or.

c) Raising of the existing dam crest levels.

It should be noted that items a) and b) already form a key part of the exhibited scheme. The proposed revised operational rules are facilitated by downstream defence measures, designated washlands and flood forecasting and take due account of real-world constraints and dam safety requirements.

4.2 Overview of Constraints/Assumptions

The following sections outline some of the overarching physical and operational constraints which must be taken into account when designing a scheme to increase capacity at the existing reservoirs.

4.2.1 Dam Safety

Dam safety must remain the paramount priority for the operator of the dams. Both existing dams are classified as "Category A" dams. Under ESB standards, they are required at all times, to be capable of the following:

- Safely passing the 1 in 10,000 year event without overtopping
- Safely passing the 1,000 year flood with one spillway gate unavailable and with a freeboard allowance for wave run-up.

Therefore, the storage volume available above the level at which ESB's prescribed dam safety discharges apply needs to be preserved in any proposed solution to allow the 1 in 10,000 year event to be safely passed.

Any dam-raising solution will therefore effectively "push up" this volume and thus the starting level at which the dam safety rules would apply. Therefore, the additional useable flood storage would be created between the 'existing' and any 'new' starting level for the dam safety rules.

4.2.2 Uncertainty

Some submissions have suggested the 1 in 100 year event could be managed by allowing water levels in the reservoirs to reach dam crest level during such an event.

However, it simply would not be acceptable to design operational rules which would allow either reservoir to fill completely during the 1 in 100 year event for the following reasons:

- Due to the inherent uncertainties in meteorology, hydrology and hydrometrics, it is not possible to have perfect foresight of a developing flood event, i.e. a flood event initially predicted to be a 1 in 100 year event could grow more severe throughout the course of the event. Due to the limitations in discharge capacity of the gates and spillway at Carrigadrohid, dam safety rules require a significant storage volume to be retained for the more extreme events (to store the difference between the actual inflow and discharge capacity for events up to and including the 1 in 10,000 event). If the reservoir had already been filled on the assumption of a 1 in 100 year event (based on a forecast with inherent uncertainty), then the 1 in 10,000 year peak flow could not be safely passed without overtopping, and dam safety would be compromised.
- A multi-peaked event consisting of two or more lesser-magnitude events could occur, from which a similar situation to above could arise.

4.2.3 Impact on Hydraulic Performance of Existing Sluice Gates at Carrigadrohid Dam

High water levels in Inniscarra reservoir would have a significant knock-on effect on the discharge capacity of the deep sluices at Carrigadrohid. To demonstrate this effect, the discharge capacity of the deep sluice gates at different headwater/tailwater depths was calculated using the following equation[8]:

$$Q = C_d bw\sqrt{2g(y_1 - y_2)}$$

Where:

$$C_d = coefficient\ of\ discharge = \sqrt{\frac{C_c}{1 + C_c(\frac{w}{Y_1})}}$$

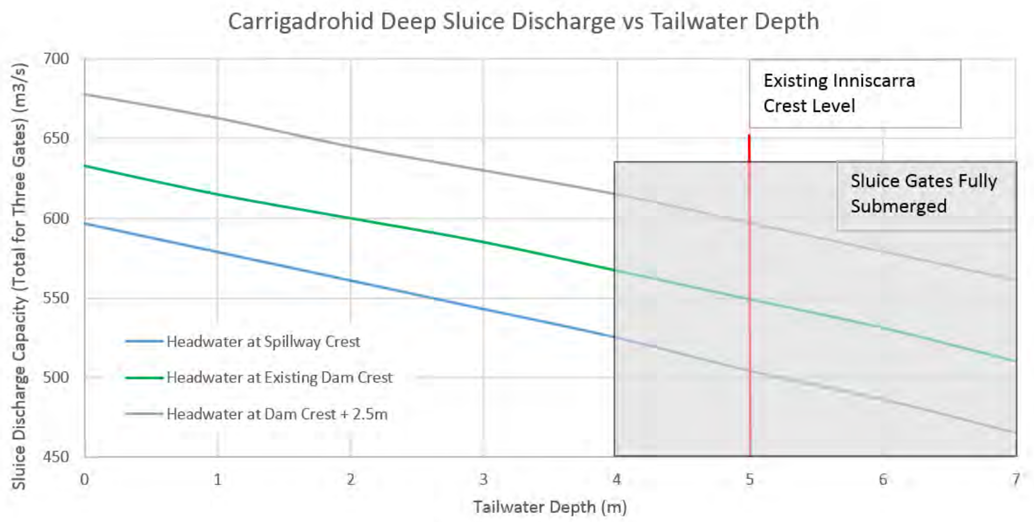
Q = Discharge (m^3/s)
C_c = Coefficient of contraction, taken as 0.61
b = gate width (m)
w = gate opening (m)

[8] Chow, V.T. (1959), *Open Channel Hydraulics,* Blackburn Press, p.508

g = acceleration due to gravity, 9.81m/s^2
y_1= headwater depth (m)
y_2= tailwater depth (m)

Figure 10 shows the result of the above calculations.

Figure 10: Carrigadrohid Deep Sluice Discharge vs Tailwater Depth

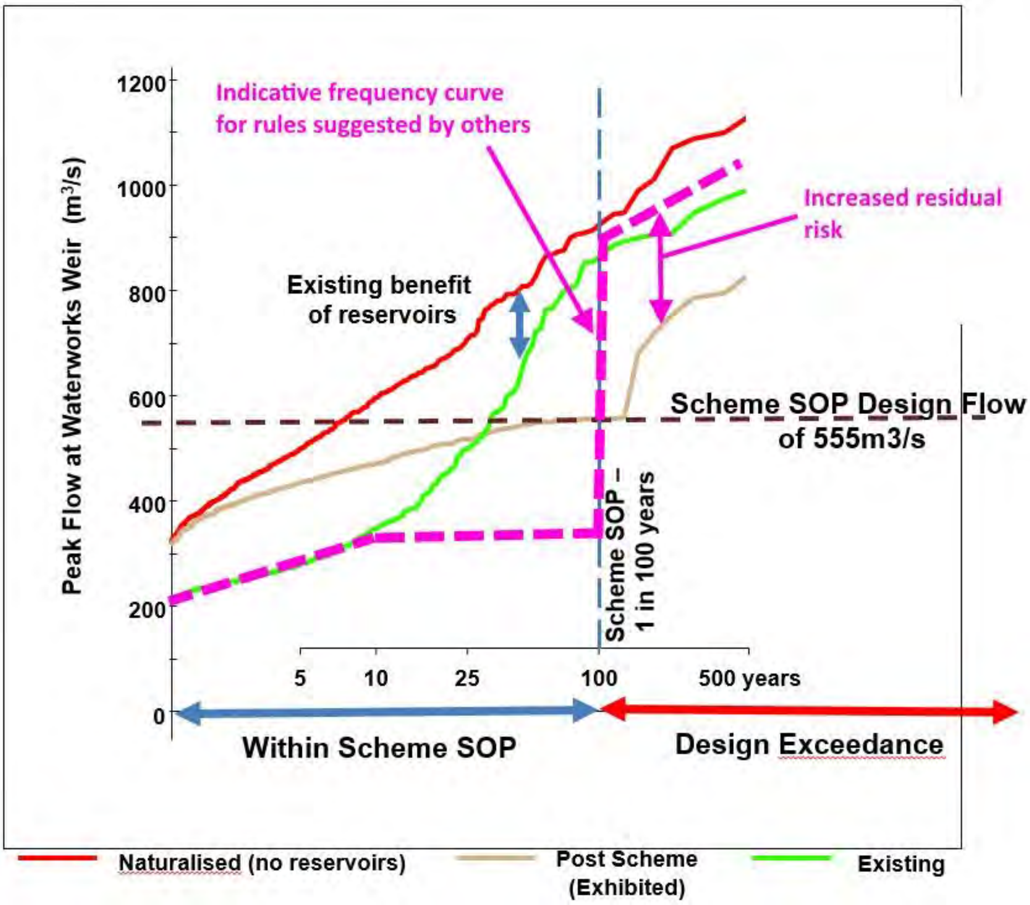


Based on the above it can be seen that when water in Inniscarra reservoir reaches crest level, the discharge capacity through the sluices at Carrigadrohid would be reduced by circa 10 - 15% compared with more normal tailwater depths in the range of 2 - 3m. The discharge capacity would continue to be eroded at higher tailwater depths (in the scenario if Inniscarra was raised). In extreme events, this could critically hamper the ability of Carrigadrohid to pass on the incoming flow. For the purposes of this report, this impact is deemed to be allowed for through the inefficiency factor noted in Section 2.3 above.

4.2.4 Residual Risk

Even if a 1 in 10,000 year event did not develop, the residual risk with the operational approach suggested by others (i.e. completely filling the reservoirs during a 100 year event) would be very high. Any marginal increase in inflow above the 100 year would lead to a rapid increase in discharge from Inniscarra, as the inflow would need to be discharged immediately. This step-change from circa 350m^3/s to >500m^3/s would be extremely dangerous to people downstream. See Figure 11 for an illustration of this concept. This would represent an unacceptable residual risk.

Figure 11: Indicative Flood Frequency Curve at Waterworks Weir



4.2.5 Miscellaneous Assumptions

The following sets out a number of other assumptions in terms of constraints that would need to be considered.

- The dams will continue their existing statutory function as a hydroelectric scheme. The generating units in the Lee Scheme contribute to meeting Ireland's renewable energy targets and reducing greenhouse gas emissions, as energy from hydro generation does not produce CO_2. The generating units provide electricity grid system support through frequency response, flexible minimum loads and black start capability. In addition, income from electricity generation offsets the significant cost of dam operation (refer to Section 6.3.7 for further information).
- The reservoir at Inniscarra serves to provide water supply to local authorities in Cork. The reservoir at Carrigadrohid forms part of the Gearagh Special Area of Conservation. For these reasons, and also the requirement of electricity generation, the reservoirs cannot be maintained in an empty state or at exceptionally low levels on an ongoing basis.
- It cannot be assumed that the turbines would be available to discharge water during an extreme flood event.

As an example, during the recent Storm Ophelia, the Lee stations could not generate hydroelectricity for a period of time due to damage to the distribution network. While Storm Ophelia was not an extreme rainfall event, a similar extreme storm could result in flood conditions coinciding with extreme wind and similar damage to the electricity network.

- ESB have advised that releases from Carrigadrohid are constrained by a maximum drawdown rate of 0.6m per 24 hours when the reservoir is above 60.3mOD Malin and 1.0m per 24 hours when it is below this level. These limits are required to ensure that excess pore water pressures in the various embankments around the perimeter of the reservoir do not cause a collapse.

4.3 Identification of Potentially Feasible Options

4.3.1 Extrapolation of Reservoir Storage Curves

In order to examine the range of possible combinations which would meet the objective, it was necessary to extrapolate the storage curves upwards for each reservoir. This was carried out using a digital terrain model (DTM) created from a combination of LiDAR data and IfSAR data supplied by OPW. A GIS procedure called Surface Volume was utilised, which calculates a volume contained on a DTM below a specified plane. This procedure was run at 1m intervals in order to develop the curve. As LiDAR/IfSAR cannot penetrate water, the volume available below the DTM water surface was based on ESB storage curves.

The extrapolated storage curves are shown in Figure 12 and Figure 13 below.

Figure 12: Carrigadrohid Extrapolated Storage Curve

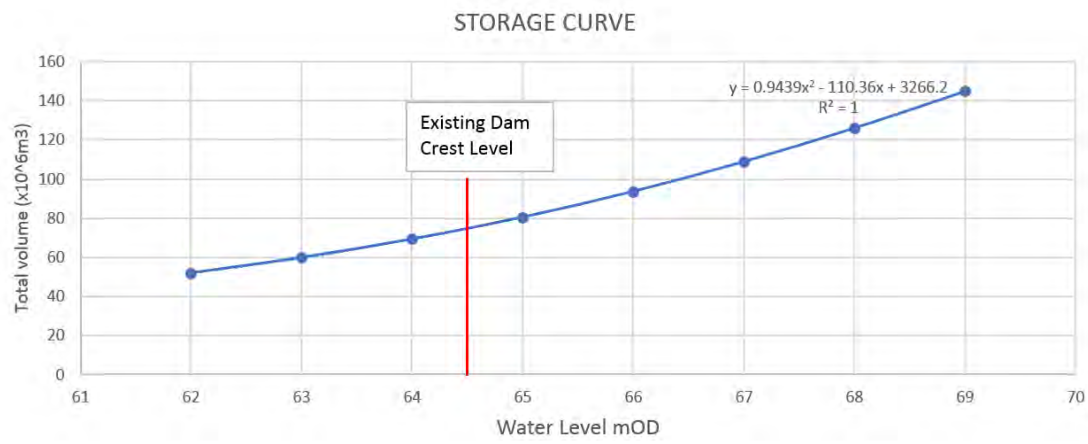
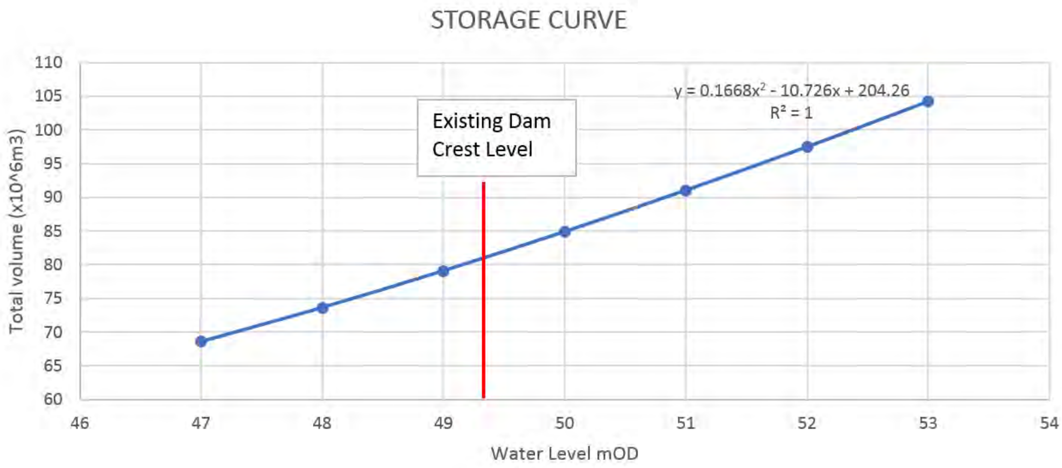


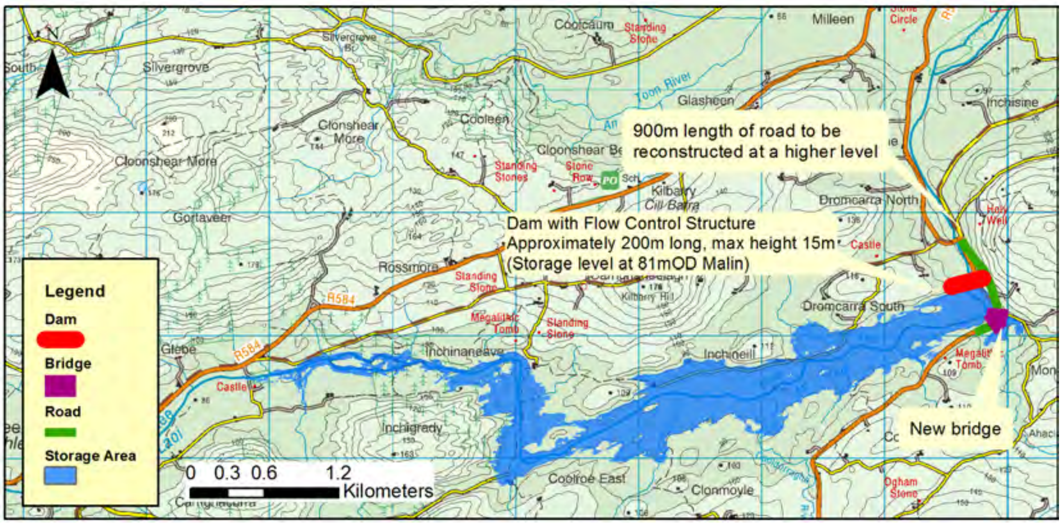
Figure 13: Inniscarra Extrapolated Storage Curve



4.3.2 New Reservoir at Dromcarra

As part of the public consultation process, the option of creating a third reservoir on the River Lee was suggested by members of the public. The proposed location was on the Lee upstream of Carrigadrohid reservoir. Following a review of the topography and land use, a potentially suitable site for a reservoir was identified in an area of pastoral land located just upstream of Dromcarra Bridge (7km southwest of Macroom). The storage area would have the capacity to store up to 11 million cubic metres at a maximum depth of 14m. It was envisaged that the reservoir would only be filled during flood conditions to maximise the volume of water, which could be stored during a flood event. See Figure 14 below.

Figure 14: Potential Storage at Dromcarra on the Upper Lee



This option has been assessed separately in an addendum[9] to the Options Report. While the assessment of the option concluded that it should not be taken forward as a standalone measure, it was deemed appropriate to review it again in combination with potential raising of the existing dams as part of this report.

4.3.3 Potentially Feasible Combinations

The following table identifies a selection of possible combinations of dam raising required to meet the objective set out in Section 4.1. The assessment of the likelihood of the option meeting the objective is based on the upper bound estimation of additional storage required to avoid direct defences, as calculated in Section 2.3.

Table 5: Identification of Potentially Feasible Options

Option	Increased Dam Height			Additional Live Storage Volume vs existing (m^3)	Likely to Meet Objective?
	Carrigadrohid	Inniscarra	Dromcarra		
A	1.5m	-	-	19.1×10^6	Unlikely
B	2.5m	-	-	34.4×10^6	Likely*
C[10]	3.75m	-	-	56.2×10^6	Likely
D	-	1.5m	-	9.0×10^6	Unlikely
E	-	2.5m	-	15.4×10^6	Unlikely
F	-	3.75m	-	23.8×10^6	Unlikely
G	1.5m	2.5m	-	34.5×10^6	Likely*
H	2.5m	1.5m	-	43.4×10^6	Likely
I[8]	2.5m	2.5m	-	49.8×10^6	Likely
J	1.5m	-	14m	30.1×10^6	Unlikely
K	2.5m	-	14m	45.4×10^6	Likely

* As the additional volume in these options is within 10% of the estimated upper bound required, 37 million m^3, it is considered appropriate to include in the set of potentially feasible options, but further detailed volumetric analysis would be required to confirm technical viability.

[9] Arup/JBA Consulting (April 2017) *Lower Lee (Cork City) Drainage Scheme - Addendum to Options Report - Assessment of Potential Storage Area at Dromcarra (Upper Lee)*
[10] This option was included in the context of potential climate change adaptability

5 Development of Dam-Raising Options

5.1 Introduction

Based on the analysis in Section 4.3, it appears that the optimum solution could involve raising of one or both dams within an envelope of circa 1.5m to 3m. This section describes the structural works involved in such projects and associated design and construction issues which would influence cost and constructability. A simple global stability check of the dams in the raised scenarios is also carried out.

5.2 Design/Construction Issues

There are a number of structural and constructability issues that need to be taken into account when considering a dam-raising project such as this. These are described below:

- Appropriate factors of safety in terms of global stability of the dam must be maintained in sliding, overturning and bearing. Note that the additional hydrostatic loads on the dam structures will increase in proportion to the square of the height increase. Therefore, while a small amount of raising may be manageable with appropriate strengthening works, larger amounts of raising may become unviable or impractical. The table below shows the load combinations and factors of safety which ESB uses in the analysis of its dams.

Table 6: ESB Load Combinations for "Category A" Dams[11]

Load Case	Water Level	Uplift	Other Loads	Required Factor of Safety
Normal Load Case	MNOL	Actual	-	1.5
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

- In the dam raised scenario, it is envisaged that the reservoirs would be operated within the existing bands during non-flood times (i.e. up to existing MNOL).

[11] Normal load case criteria were advised by ESB. Other load cases as per ESBI (2011), *Preliminary Flood Risk Assessment – ESB Dams and Embankments*

However, by designating additional storage which may need to be used on a semi-regular basis, ESB has advised that this would effectively increase MNOL. This would further add to the necessary dam strengthening in order to maintain appropriate factors of safety in global stability in the normal load case.

- Even if hydropower generation is suspended during the works, the dams will still need to actively manage reservoir inflows and maintain dam safety throughout construction, i.e. the dams must remain capable of passing a 1 in 10,000 year event during construction. Since the works would by necessity involve taking one or more of the sluice gates out of service for some time, water management would be a difficult issue, requiring significant temporary measures to address. Each dam would have particular complicating factors in relation to this issue. For example at Inniscarra, the arrangement of the structure supporting the sluice gate lifting gear means that works on either of the central piers would disable two of the gates. This would significantly reduce the ability of Inniscarra to discharge large flows safely, and would leave no redundancy for the possibility of malfunction of the remaining operational gate.
- The existing dams are complex structures with many varying cross sections and structural details.
- Increasing the height of the dams will potentially increase the risk of seepage beneath and around the dam wall, due to the increased differential hydrostatic head across the dam. This may be a particular issue at the left abutment of Carrigadrohid dam, where higher than average rates of seepage have been observed historically due to the underlying and adjoining moraine material.
- Most raised dams have difficulty with leakage at the new/old joint[12]. It is notoriously difficult to attach new mass concrete to old mass concrete due to different shrinkage and temperature effects.
- In addition to raising of the existing dam walls, the dams would also need to be extended laterally to meet high ground on each bank.
- Construction access to carry out these works would be extremely difficult. It is likely that the downstream faces of the dams would require extensive temporary scaffolding, long reach cranes and concrete pumps.
- The existing sluice gates and lifting gear may not be capable of operating under an increased head without modification.
- The design would need to take account of any relevant international developments in the area of dam safety and recent updates to flood estimation methodologies in Ireland at the time.

[12] CIRIA (1996), *Engineering Guide to the Safety of Concrete and Masonry Dam Structures in the UK*, p.72

5.3 Preliminary Stability Analysis

5.3.1 Description of Analysis

A preliminary stability analysis was carried out for both dams for several scenarios (existing situation, raising each dam crest by 1.5m and 2.5m and for Carrigadrohid only, 3.75m). Only sliding and overturning were analysed as further ground investigation data would be required to undertake a bearing a capacity analysis.

A single typical cross section of each dam was analysed which was deemed appropriate for this level of study. The analysis was carried out on a "per metre run" basis, and on the assumption that the cross section is completely solid. In a more detailed assessment, the voids within the section (i.e. galleries, shafts etc.), would need to be taken into account, and the dam analysed on a block-by-block basis rather than per-metre run.

The dams were analysed using ESB load cases and required factors of safety (refer to Section 5.2).

The overturning analysis consists of the sum of all of the restoring moments about the downstream toe (at any level) divided by the sum of the overturning moments to give a factor of safety.

In terms of sliding, it was assumed that the bedrock beneath the dam and immediately downstream is strong and competent, and therefore the sliding failure plane would occur within the concrete section just above the bedrock level. Therefore, it was assumed that sliding is primarily resisted by the concrete shear strength.

Seismic forces were calculated in accordance with Eurocodes. The horizontal force at the toe and at the crest of each dam was calculated by applying a predicted ground acceleration (return period 1:10,000).

5.3.2 Analysis Results and Possible Mitigation Measures

It was found that the overturning factors of safety generally fell below the requirements in several cases where only the crests were raised. Therefore mitigation measures would be required in order to maintain stability. Some possible measures are discussed briefly below.

A method that has been used widely in the past for gravity dams (i.e. dams similar to Carrigadrohid) has been to add a new "skin" of concrete on the downstream face of the dam. This would essentially provide additional dead weight to counteract the overturning moment.

However, there appears to be no international examples where the above approach has been applied to a buttress dam similar to Inniscarra. This is likely due to the practical difficulty associated with adding new concrete to the relatively narrow and complicated shape of the buttresses (see Figure 19).

Another possible alternative means of mitigating the impact on stability would be to install post-tensioned anchors down through the body of the dam to bedrock. However, the scope to add further anchoring to Carrigadrohid dam is expected to be very limited for the following reasons:

- Carrigadrohid dam has already been retrofitted with 10no. anchors, as part of a previous dam safety upgrade. See Figure 15 below.
- Any additional anchors would need to be positioned to give appropriate clearance to a multitude of large voids and obstacles within each block, including the existing inspection galleries, deep sluices and associated shafts, penstock and associated shafts, fish pass, uplift relief pipes, the existing anchors etc.

Figure 15: Downstream face of Carrigadrohid Dam, showing existing anchor heads in close proximity to each other

It may be possible in principle to add such anchors to some blocks at Inniscarra, however it is not clear how they could be installed on blocks such as the two intake blocks which contain large voids for the penstocks. Also, installation of anchors on the spillway blocks would likely result in the need for partial reconstruction of the spillway itself.

Without further more detailed structural analysis (which would be outside the scope of this report), it is not possible to determine with certainty the full detail of the required strengthening works at either dam. There will be practical constructability difficulties (e.g. at blocks where the power house is in close proximity), where some solutions may prove unfeasible or impractical. Therefore the costs associated with the strengthening works are subject to a high degree of uncertainty.

5.4 Description of Dam Raising Works

5.4.1 Carrigadrohid Dam Works Items

It is envisaged that the most feasible solution for raising of this dam will be the addition of a concrete extension on top of the existing crest, along with additional concrete on the downstream face of the dam. This section should be read in conjunction with the set of indicative cross sections contained in Appendix A, which demonstrate some of the various issues at each of the various blocks at the dam.

The following is a general description of the major work items which would be involved in the dam raising works:

Preparatory Works

- Temporary measures would be put in place to manage reservoir inflows during the event. This may include measures such as drawing down the reservoir, limiting works to dry summer periods, creating a temporary notch in the weir feeding the auxiliary spillway, etc. This is a very significant consideration in terms of dam safety as discussed in Section 5.2. It is envisaged that due to these restrictions, the construction programme would likely extend over at least two years.
- It is considered likely that hydroelectric generation would need to temporarily cease for the full duration of the construction works.
- The new wing blocks on the left bank would likely clash with the existing substation. It may be necessary to reconfigure part of the substation as a result.

Extension of Existing Dam wall:

- The existing crest walkway and parapets would be demolished.
- The existing 2no. gantry cranes on the dam crest at the turbine intake and the deep sluices would be dismantled and temporarily removed. These would need to be reconfigured off site (or replaced if necessary) and then reconstructed on the raised dam crest. See Figure 16 below.

Figure 16: Carrigadrohid Dam Crest Gantry Crane

- Other mechanical/electrical items on the dam crest would be temporarily removed, including fish lift equipment and then will be reconstructed on the raised dam crest.
- As the existing power house and control building are constructed directly abutting the dam wall, it is highly likely that these buildings would need to be partially demolished and reconstructed on completion of the dam raising works.
- The concrete surfaces to receive new concrete would be prepared, including scabbling, installation of anchor bars, waterbars and installation of drainage membranes as necessary.
- New supplementary reinforced concrete sections would be poured on the dam crest and downstream face.
- A new crest walkway and concrete parapet walls would be constructed.

Construction of New Wing Dam Block(s)

New dam block(s) would need to be constructed at the northern end of the existing dam. This may consist of the following works:

- A temporary cofferdam would need to be constructed locally at the upstream face of the dam wall.
- The area of the new dam block(s) would be excavated, including installation of temporary works to mitigate risks of slope stability and seepage. A certain quantity of bedrock would need to be broken out to ensure that the new block(s) are founded on competent rock
- It is assumed that a certain quantity of foundation grouting would be required.

- The new reinforced concrete dam blocks would be cast, after which temporary works would be removed.

Extension of Auxiliary Spillway

- The existing concrete ogee weir (see Figure 17 below) would be prepared to receive additional concrete, including potential partial demolition, scabbling, and installation of anchor bars.
- An additional 1.5m to 3.75m height of reinforced concrete would be cast on the existing weir. An alternative to the above as suggested by others would be to install Fusegates on the crest of the existing weir (or to replace the existing weir entirely with Fusegates). Refer to Section 5.4.3 for a review of this option.
- The upstream wall of the spillway structure may need to be raised and extended to ensure that the spillway structure itself is not bypassed by high water levels in the dam-raised condition.
- Modifications to the spillway chute may be necessary to accommodate the safe discharge of higher energy flows (as a result of the increased upstream head).

Figure 17: Carrigadrohid Auxilary Spillway Ogee Weir

Ancillary works

- The existing intake gate and 3no. deep sluice gates would need to be temporarily removed and remedial works carried out to ensure that they would be capable of opening under the increased design hydrostatic load. This is expected to include replacement of the bearings/rollers and lifting gear.
- The concrete scour apron downstream of the dam would need to be extended.

Other Risk Items

- Local flood protection walls around the powerhouse may need to be raised.
- The intake penstock may need to have a new liner installed to mitigate potential seepage under the increased hydrostatic head.

- Additional rock anchors may need to installed on the downstream face of the dam to ensure global stability is maintained during extreme load cases. This will be especially complicated at the blocks containing the deep sluices, fish lift and intake penstocks, as the anchors would need to avoid these large openings.
- The existing turbine house and control building are constructed abutting/integral to the dam wall, which would complicate the solution for these blocks. To facilitate the addition of concrete to the downstream face of these blocks, it is possible that the superstructures of these buildings would need to be partially demolished and reconstructed. It is possible that other solutions may exist which would reduce the cost at these blocks, but development of such options is beyond the scope of this report.

5.4.2 Inniscarra Dam Works Items

It is envisaged that the most feasible solution for raising of this dam will be the addition of a concrete extension on top of the existing crest, along with additional concrete and rock anchoring added to the buttresses on the downstream face of the dam. This section should be read in conjunction with the set of indicative cross sections contained in Appendix A, which demonstrate some of the various issues at each of the various blocks at the dam.

The following is a general description of the major work items which would be involved in the dam raising works:

Preparatory Works

- Temporary measures would be put in place to manage reservoir inflows during the event. As discussed in Section 5.2, Inniscarra presents a particular difficulty in this regard. Some of the possible options would be major civil engineering projects in themselves, e.g. a new auxiliary spillway etc. A possible alternative approach to management of this issue might be as follows:
    - Since each of the technically viable options under development in this report also involve raising of Carrigadrohid dam, there would be significant new capacity created upstream to attenuate incoming floods. Therefore it is likely that the raising of Carrigadrohid would be completed before commencement of Inniscarra raising.
    - Both Inniscarra and Carrigadrohid reservoirs could be temporarily drawn down to minimum levels to maximise flood attenuation capacity.
    - Works would only be carried out during summer periods.
    - During times where two of the Inniscarra sluice gates would be inoperable, it is possible that free discharge could be allowed through one gate.
    - It is envisaged that due to these restrictions, the construction programme may need to take place over say 2 years.
- It is considered likely that hydroelectric generation would need to temporarily cease for the full duration of the construction works.

- A temporary access road to the southern abutment of the dam may be required.

Extension of Existing Dam wall:

- The existing crest walkway and parapets would be demolished.
- The existing gantry crane on the dam crest at the turbine intakes would be dismantled and temporarily removed. These would need to be reconfigured off site (or replaced if necessary) and then would be reconstructed on the raised dam crest.
- The existing spillway gate cranes including 4no. reinforced concrete piers would need to be demolished and reconstructed to a higher level. It is likely that new lifting gear would be required due to the additional weight of the taller gates. Refer to Section 5.2 for the particular water management difficulties associated with this work. Figure 18 shows the arrangement of the lifting gear on the Inniscarra dam crest.

Figure 18: Inniscarra dam crest, showing sluice gate lifting gear and supporting concrete piers

- Other miscellaneous mechanical/electrical items on the dam crest would be temporarily removed, including fish lift equipment.
- The surfaces to receive new concrete would be prepared, including scabbling, installation of anchor bars, waterbars and installation of drainage membranes as necessary.

- Mitigation measures required in order to maintain stability would be constructed. As discussed in Section 5.3.2, the appropriate mitigation measures could not be identified for Inniscarra with adequate certainty at this level of study. This is a large uncertainty in terms of the feasibility of raising this dam. However, for the purposes of preparing an indicative cost for the works, it has been tentatively assumed that new supplementary reinforced concrete sections could be added to the dam crest and downstream face. Figure 19 demonstrates part of the difficulty with adding supplementary concrete to the downstream face of the dam.

Figure 19: Downstream face of Inniscarra Dam, demonstrating complicated buttress geometry

- A new crest walkway and concrete parapet walls would be constructed

Construction of New Wing Dam Block(s)

New dam block(s) would need to be constructed at the northern and southern ends of the existing dam. This may consist of the following works

- A temporary cofferdam would need to be constructed locally at the upstream face of the dam wall.
- The area of the new dam block(s) would be excavated, including installation of temporary works to mitigate risks of slope stability and seepage.

A certain quantity of bedrock would need to be broken out to ensure that the new block(s) are founded on competent rock.

- It is assumed that a certain quantity of foundation grouting would be required.
- The new reinforced concrete dam blocks would be cast, after which temporary works would be removed.

Ancillary works

- The existing intake gates and spillway gates would need to be temporarily removed and remedial works carried out to ensure that they would be capable of opening under the increased design hydrostatic load. This is expected to include replacement of the bearings/rollers and lifting gear. Additional steelwork would also need to be added to the existing spillway gates to match the height of the raised dam.

Figure 20: Typical Inniscarra Spillway Gate

- The concrete scour apron downstream of the dam would need to be extended.

Other Risk Items

- Local flood protection walls around the powerhouse may need to be raised.
- The intake penstocks may need to have new liners installed to mitigate potential seepage.

- New rock anchors may need to installed on the downstream face of the dam to ensure that global stability is maintained during extreme load cases. This will be especially complicated at the blocks containing the deep sluices, fish lift and intake penstocks, as the anchors would need to avoid these large openings.
- The existing turbine house and control building are constructed abutting/integral to the dam wall, which would complicate the solution for these blocks (see Figure 21). To facilitate the addition of concrete to the downstream face of these blocks, it is possible that the superstructures of these buildings would need to be partially demolished and reconstructed. It is possible that other solutions may exist which would reduce the cost at these blocks, but development of such options is beyond the scope of this report.

Figure 21: Downstream face of Inniscarra Dam at the intake blocks, demonstrating lack of working room between the dam and the turbine house

5.4.3 Fusegate Options

5.4.3.1 Introduction

Submissions received suggested that the weir feeding the existing auxiliary spillway at Carrigadrohid dam could be replaced with a wall of "fusegates" in order to increase the volume of storage available in the reservoir for flood control.

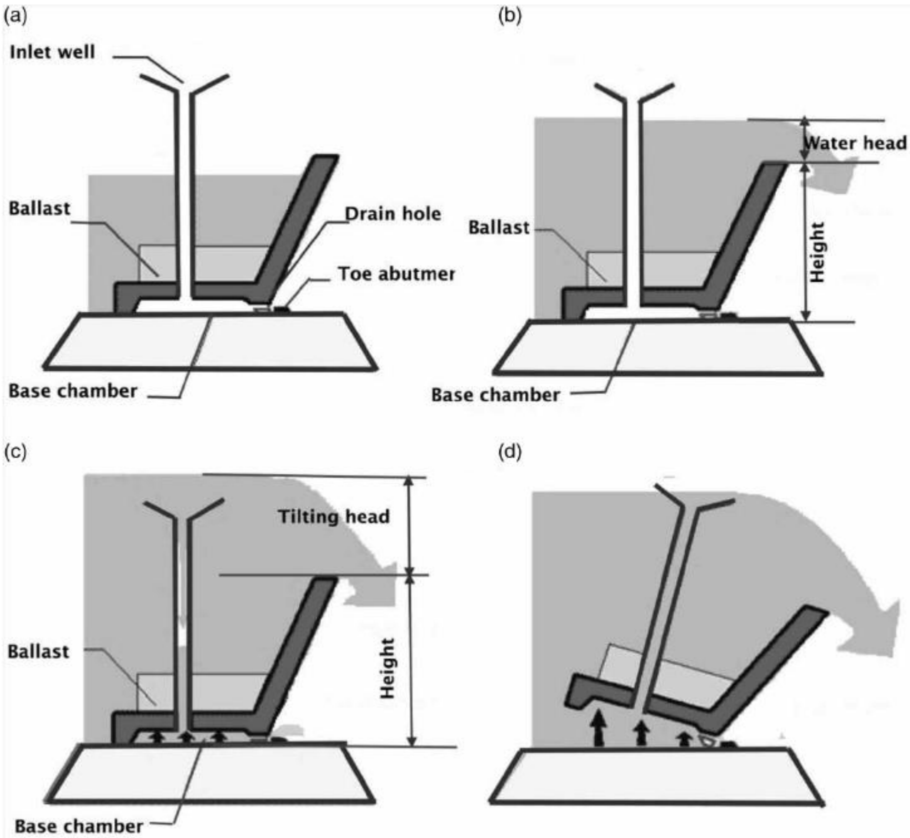
Fusegates are a technology used worldwide with many applications in dam-raising projects. The technology is mainly used on dam spillways. The Fusegate system is based on the following concept:

- Fusegates are free-standing units installed side-by-side on a spillway sill to form a watertight barrier.
- They bear against small abutment blocks set in the sill to prevent them from sliding before they are required to rotate (under extreme flood conditions).

- There is a chamber in the base of each Fusegate, with drain holes to discharge incidental inflow (due to leaking seals for example).
- An inlet well on the upstream side of the Fusegate crest discharges water into the chamber when the headwater reaches a predetermined level. (Well lips on individual Fusegates are set at different levels).
- During very large floods, water entering the chamber over the inlet well causes an uplift pressure to develop in the chamber. The uplift pressure, combined with the hydrostatic pressure (acting from left to right Figure 22 below) is sufficient to overcome the restraining forces and the imbalance causes rotation of the unit off the spillway. The Fusegate is then washed away clear of the spillway by the flood.
- If the water level continues to rise after the first breach more Fusegates can rotate, all according to pre-determined upstream water levels until eventually, there are no more units remaining and the spillway is free to pass the original maximum design flood. Until rotation of the first Fusegate, (for floods of extremely low risk of occurrence), the user has the benefit of the additional storage. Each Fusegate has a different overturning level, precisely determined by the height of the water inlet and its own unique stability.
- Fuse gates are usually not reusable because of the damage due to falling over a considerable height.

Figure 22 shows the typical operation of a Fusegate system

Figure 22: Typical Fusegate during operation



5.4.3.2 Preliminary Review of Fusegate Option at Carrigadrohid Dam

A preliminary review of the potential for the installation of fusegates at the auxiliary spillway of Carrigadrohid dam was carried out with input from the designer of the system, Hydroplus.

Having reviewed the reservoir data, the designer of the system noted that the available reservoir volume is small compared with the design flood volumes, which makes the design of a fusegate solution very sensitive in terms of input data (i.e. the reservoir-volume curve, the flood hydrographs and the spillway hydraulic characteristics). This is in line with the findings of the hydraulic analysis carried out during the development of the exhibited scheme.

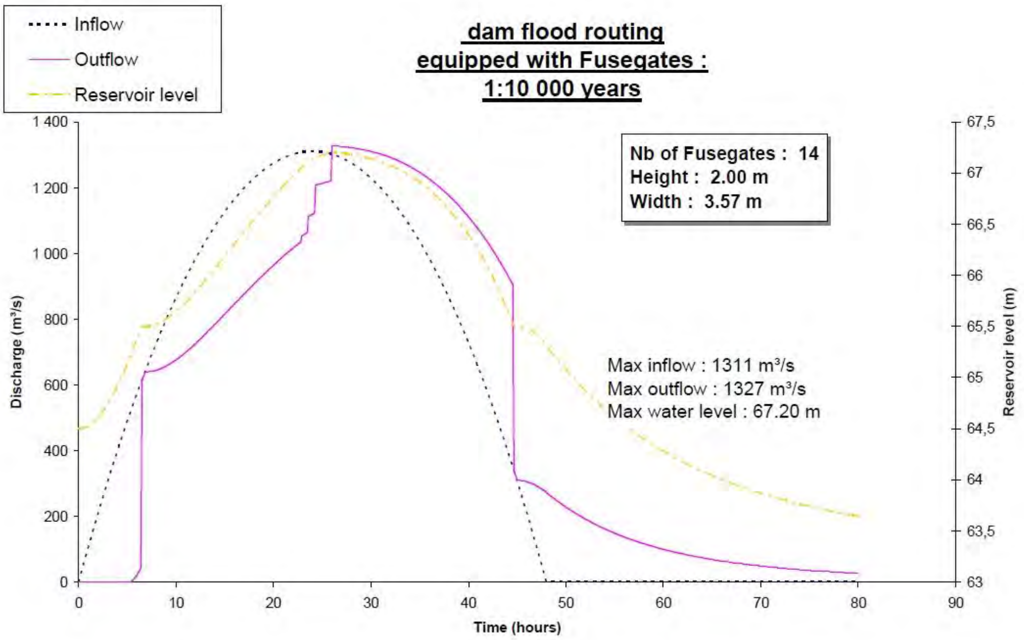
Various combinations of gate arrangements were tested by the designer of the system to an indicative level of detail (using simplified assumptions in relation to the gate control logic and flood hydrographs). An example of the results of this analysis is shown in Figure 23 below. Based on the results supplied, the following was established:

- It was found that fusegates could provide an enhancement of flood attenuation for a range of floods including the 100 year event (similar to other dam-raising options).
- However, during the 10,000 year event, all of the fusegates would be tipped and peak discharge capacity would be limited by the fixed size of the deep sluice gates and the capacity of the auxiliary spillway. It can be seen in the results graph below that the required peak discharge is close to the magnitude of the peak inflow. This required discharge is significantly greater than the current maximum discharge capacity of the dam (circa 830m^3/s). This is a fundamental issue, which would need to be addressed in parallel with the installation of the fusegate system at Carrigadrohid. In order to mitigate this issue, there appear to be two alternative approaches:
    a) The spillway weir could be lowered by circa 2m – 2.5m to increase the ultimate capacity of the auxiliary spillway, which would allow Carrigadrohid to discharge the inflow upon tipping of all fusegates. This would have significant knock-on effects at Inniscarra dam and would need to be carefully considered for the following reasons:
        - The peak pass-on flow to Inniscarra would be increased by circa 36% during the 10,000 year event. Inniscarra is already predicted to be close to peak discharge capacity in the existing scenario during the 10,000 year event. Therefore it could not cater for any increase in pass-on flow from Carrigadrohid without significant mitigation works such as a new auxiliary spillway (possibly tunnelled through the rock on the right bank). Note that while raising of Inniscarra dam could also be considered, the associated impact on the performance of the deep sluices at Carrigadrohid may prove to be critical as discussed in Section 4.2.3.
        - Tilting fusegates during an extreme event could cause sudden increases in flows being passed on to Inniscarra reservoir. The

operational rules may need to be adapted to suit this new potential inflow pattern.

b) The spillway weir could be maintained close to its existing level (i.e. maintain the existing maximum discharge capacity), and Carrigadrohid dam could be raised to allow the residual inflow volume to be temporarily stored. In this option, it is likely that dam raising of a similar magnitude to the options identified in Section 4.3.3 would still be required in order to provide the necessary storage to avoid overtopping in the 10,000 year event.

Figure 23: Example model results for possible fusegate arrangement at Carrigadrohid



The following particular design issues were also noted:

- Similar to other dam raising options, it is envisaged that the reservoirs would be operated within the existing bands during non-flood times (i.e. up to existing MNOL). However the installation of fusegates effectively designates additional storage which may be used on a semi-regular basis. ESB have advised that this would effectively increase MNOL for the purpose of stability analysis. This would further add to the necessary dam strengthening/raising in order to maintain appropriate factors of safety in global stability in the normal load case.
- It is notable that the vast majority of international examples of fusegate installations have been constructed on spillways arranged generally perpendicular to the flow, i.e. tipping fusegates have a straight path to clear the spillway chute. At Carrigadrohid, the auxiliary spillway is fed by a side-weir arrangement feeding a relatively narrow chute, therefore the gates would tip perpendicular to the spillway flow. This scenario has the potential to cause difficulty with passing the fusegate through the spillway, depending on the size of the fusegate. If a fusegate became lodged in the chute, this would be a major dam safety issue. This would need to be tested and verified, using a

physical hydraulic model. It is possible that in order to mitigate this risk, significant reconfiguration or complete reconstruction of the auxiliary spillway would be required.

The above risk would be expected to increase with increasing size of the fusegate. For example, if the existing ogee weir were to be completely demolished and replaced with a full height wall of fusegates to the existing dam crest (or higher), they would need to be at least 5.5m high with a greater base width. This size of gate would be very large compared to the spillway dimensions. It is not clear whether such size of a fusegate could reliably and safely pass through the spillway chute in this scenario.

- Tipping fusegates would likely result in exceedance of the maximum permissible drawdown rate of 0.6m/day in the Carrigadrohid reservoir, which could result in instability of the various road embankments around the perimeter of the reservoir.

5.4.3.3 Summary

Based on the above, it appears that the option of installing fusegates at the Carrigadrohid auxiliary spillway could potentially form part of a solution for providing the required additional storage. However, significant additional works would be required as follows:

- Strengthening of Carrigadrohid dam in order to maintain sufficient factors of safety in the “normal” load case.
- Potential measures to mitigate the risk to road embankments in a rapid drawdown scenario, following tipping of fusegates.
- Potential significant modifications or reconstruction of the entire auxiliary spillway in order to ensure that tipping fusegates could be passed through the spillway chute safely.
- One of the following options:
  a) Reduction in the height of the existing ogee weir at Carrigadrohid by circa 2m – 2.5m, along with measures to mitigate knock-on impacts on dam safety at Inniscarra dam (e.g. Inniscarra dam raising or new auxiliary spillway at Inniscarra).
  b) Raising of Carrigadrohid dam to provide sufficient storage to allow the 10,000 year event to be passed safely. This would include works to mitigate reservoir impacts, similar to other options developed in this report.

Considering all of the above, it appears highly unlikely that a fusegate option would be significantly less expensive than the other options under development in this report, and therefore has not been developed further.

5.5 Residual Fluvial Defences

The above options are predicated on the assumption that the reservoirs can be drawn down to a similar level as the exhibited scheme in advance of a flood event. The exhibited scheme facilitates advance discharges of between 150m^3/s and 350m^3/s through the construction of direct defences around vulnerable properties in the “washlands”. With the absence of fluvial defences in Cork City, it is unlikely that the same advance discharge pattern could be implemented, as it would potentially cause flooding when combined with flows from the Bride and Shournagh. However, it is possible that discharges up to circa 250m^3/s to 300m^3/s would be feasible, as it is unlikely that the Bride and Shournagh would peak continuously for the duration of the advance discharges. Therefore, it will be necessary to install some lower defences in the washlands reach as shown in Figure 24 and Figure 25 below.

Hydraulic modelling also confirms that a peak flow of 350m^3/s at Waterworks weir would still result in some flooding along the River Lee South Channel. Therefore the proposed flow control structure at the head of the south channel would still be required.

Figure 24: Residual Washlands Defences – Inniscarra Bridge Area

Figure 25: Residual Washlands Defences – Inchigaggin to Thomas Davis Bridge

5.6 Residual Tidal Defences

It should be remembered that the dam raising works would not mitigate the risk of tidal flooding in Cork City. Therefore, in order to achieve the design standard of the scheme (i.e. 1 in 100 year fluvial/1 in 200 year tidal protection), the cost of tidal-only defence measures also needs to be included in the cost of the project.

To establish the extent of reduced tidal defences needed, a 1D- hydraulic simulation was carried out in the city reach, by applying the following boundary conditions

- Maximum 150m^3/s discharge from Inniscarra
- 10-year flows on the tributaries
- 200-year tidal boundary (3mOD)

Figure 26 below shows the estimated extent of the required tidal defences based on the above model run.

Figure 26: Approximate Extent of Tidal-Only Defences

6 Identification of Reservoir Impacts

6.1 Introduction

In addition to the works at the dams themselves, the impacts on the reservoir areas must also be assessed. The potential direct impacts have been identified under the following categories:

- Land use impact
- Property impact (residential and commercial buildings)
- Infrastructure impact (roads and bridges)
- Environmental impact

6.2 Carragadrohid Reservoir

6.2.1 Land-use Impact

The surface area of Carrigadrohid reservoir at each increment in level is outlined in Table 7 below. The area of each major land use type within the reservoir areas was established in GIS software using CORINE land use data.

Table 7: Land Use Impact - Carrigadrohid

Description	Level (mOD Malin)	Reservoir Surface Area	Agriculture (km^2)	Forest (km^2)	Urban Fabric (km^2)	Sport & leisure facilities (km^2)
ESB ownership level	63.74mOD	9.82km^2	~0	~0	0	0
Current dam crest	64.51mOD	11.16km^2	1.11	0.18	0	0
Current crest + 1.5m	66.01mOD	14.24km^2	3.97	0.33	0.02	0
Current crest + 2.5m	67.01mOD	16.26km^2	5.90	0.36	0.05	0.01
Current crest + 3.75m	68.26mOD	18.48km^2	8.01	0.38	0.08	0.05

It can be seen that increasing the level of Carrigadrohid leads to a very large increase in the surface area of the reservoir. While this land would not be permanently inundated, it is likely that transient inundation of these areas would occur on a semi-regular basis.

It should also be noted that currently dry areas of the Gearagh SAC/SPA would be inundated more frequently in each of the above options. Refer to Section 6.2.4 for discussion of this environmental impact.

6.2.2 Property Impact

Increasing the reservoir levels would increase flood risk at a number of properties around the reservoir perimeter.

In order to estimate the exact number of properties effected in each scenario, a comparison was carried out using GIS software between the reservoir extent (as per the previous section) and the An Post Geodirectory address points database. Table 8 below shows the number of properties likely to be impacted due to increased reservoir level and the number of properties within a 25m buffer of the proposed reservoir when raised. The 25m buffer was chosen as being indicative of properties which could be indirectly affected by reservoir raising. Figure 27, Figure 28 and Figure 29 show the main areas where property would be affected.

It can be seen that even with modest raising of the level of Carrigadrohid dam, a very significant number of properties are brought into the reservoir area. These properties are dispersed around the perimeter of the reservoir, with the largest concentration being at Toonsbridge village.

Table 8: Property impact – Carrigadrohid

Description	Level (mOD Malin)	Dwellings within reservoir area	Dwellings within 25m buffer around reservoir
ESB ownership level	63.74mOD	0	26
Current dam crest	64.51mOD	5	29
Current crest + 1.5m	66.01mOD	62	110
Current crest + 2.5m	67.01mOD	84	151
Current crest + 3.75m	68.26mOD	117	211

Figure 27: Property Impact – South of Macroom with dam raising of 3.75m

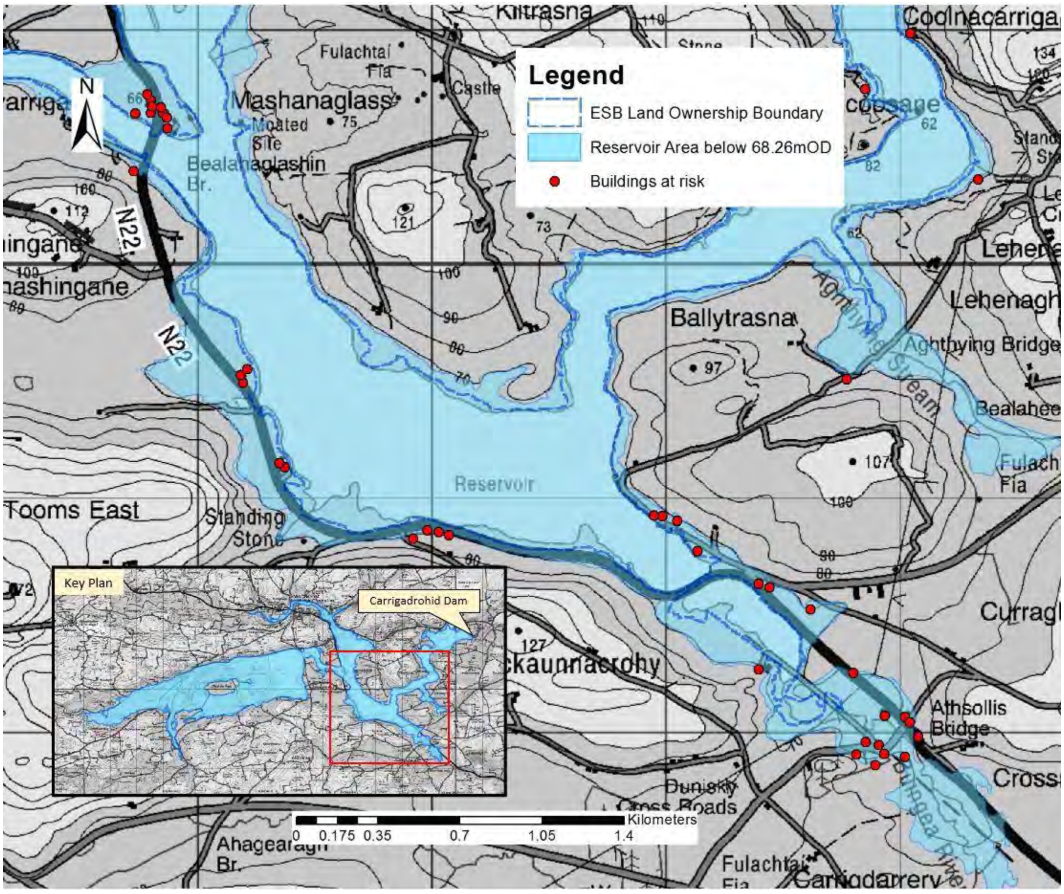


Figure 28: Property impact – Toonsbridge area with dam raising of 3.75m

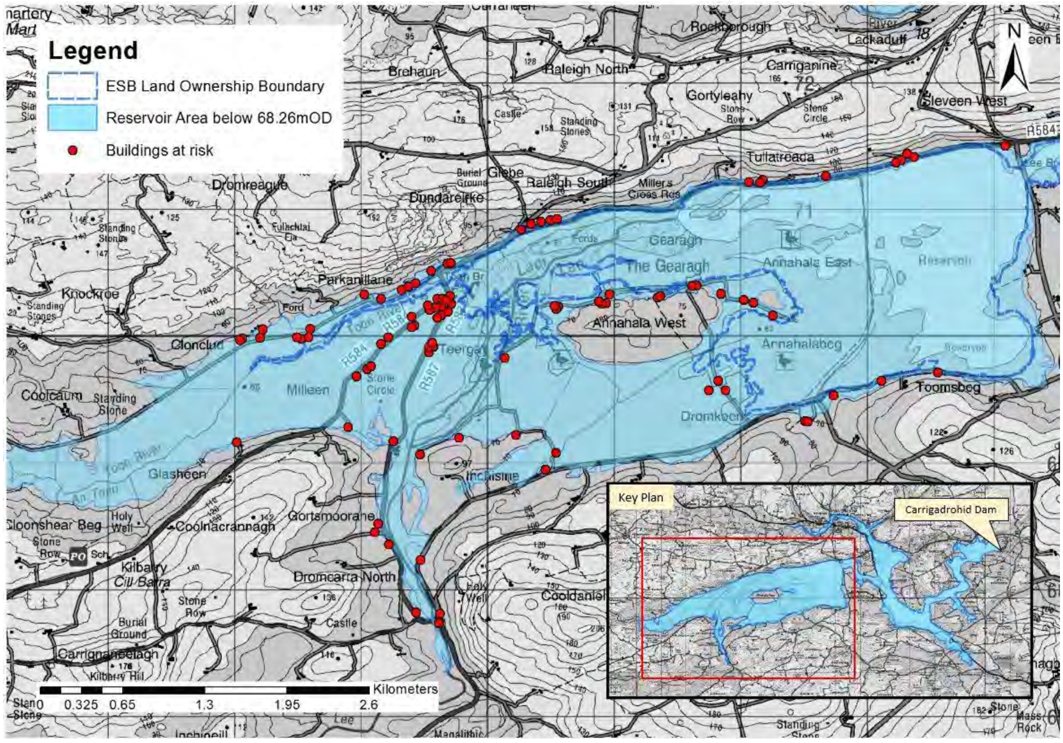
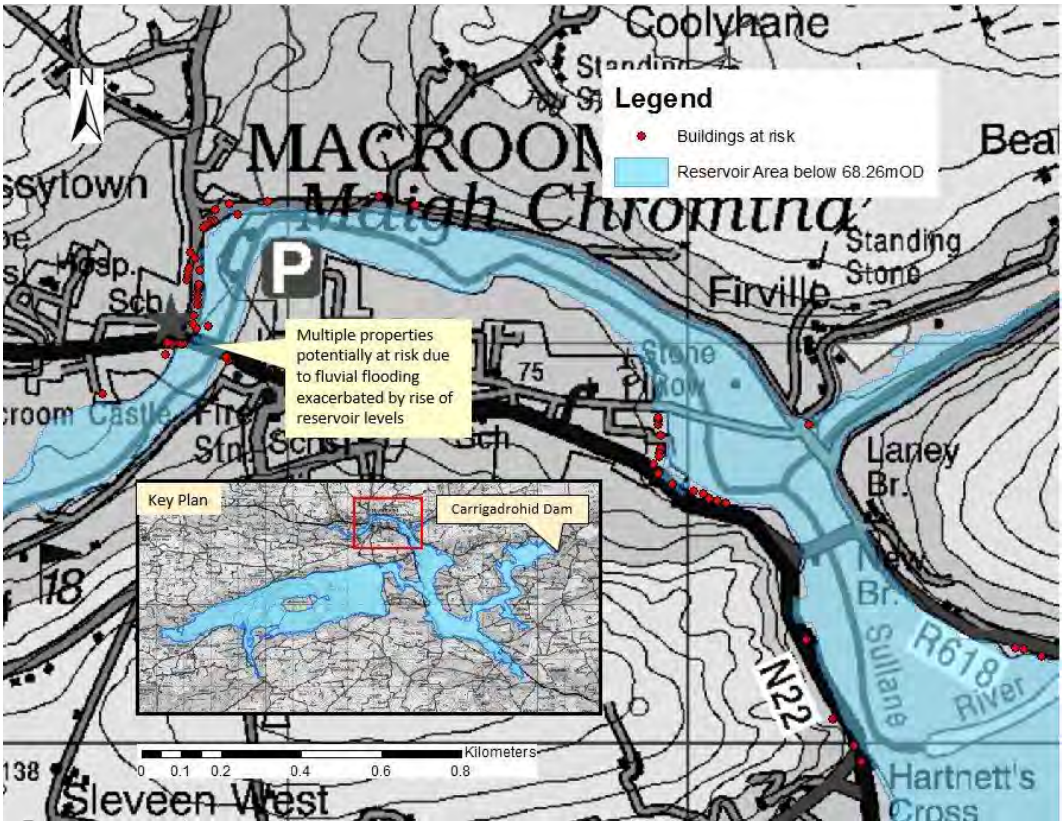


Figure 29: Property Impact – Macroom area with dam raising of 3.75m



6.2.3 Infrastructure Impact

6.2.3.1 Direct Inundation

As well as impacting a number of houses, raising the reservoir levels would have a significant impact on public infrastructure. Although a more detailed study would be required to determine the impact on utilities etc., the impact on roads and bridges can be readily determined. Table 9 below shows the existing road infrastructure likely to be impacted by the raised reservoirs.

It should also be noted that the proposed N22 Macroom bypass would also be significantly affected by raising of reservoir levels. The proposed road alignment crosses part of the reservoir and as such would need to be raised to have sufficient freeboard above the design water levels.

Table 9: Infrastructure impact – Carrigadrohid

Description	**Level (mOD Malin)**	**Length of Roads Inundated**				**Number of road bridge structures inundated (national/regional)**
		National (km)	**Regional (km)**	**Local (km)**	**Total (km)**	
ESB ownership level	63.74mOD	0	0	0	0	0
Current crest	64.51mOD	0.39	2.74	3.42	6.54	0
Current crest + 1.5m	66.01mOD	2.75	6.21	9.19	18.15	0
Current crest + 2.5m	67.01mOD	3.95	7.41	12.44	23.80	1/1
Current crest + 3.75m	68.26mOD	4.91	8.68	16.25	29.83	1/1

Figure 30 and Figure 31 show the locations of the above roads.

Figure 30: Infrastructure Impact – South of Macroom

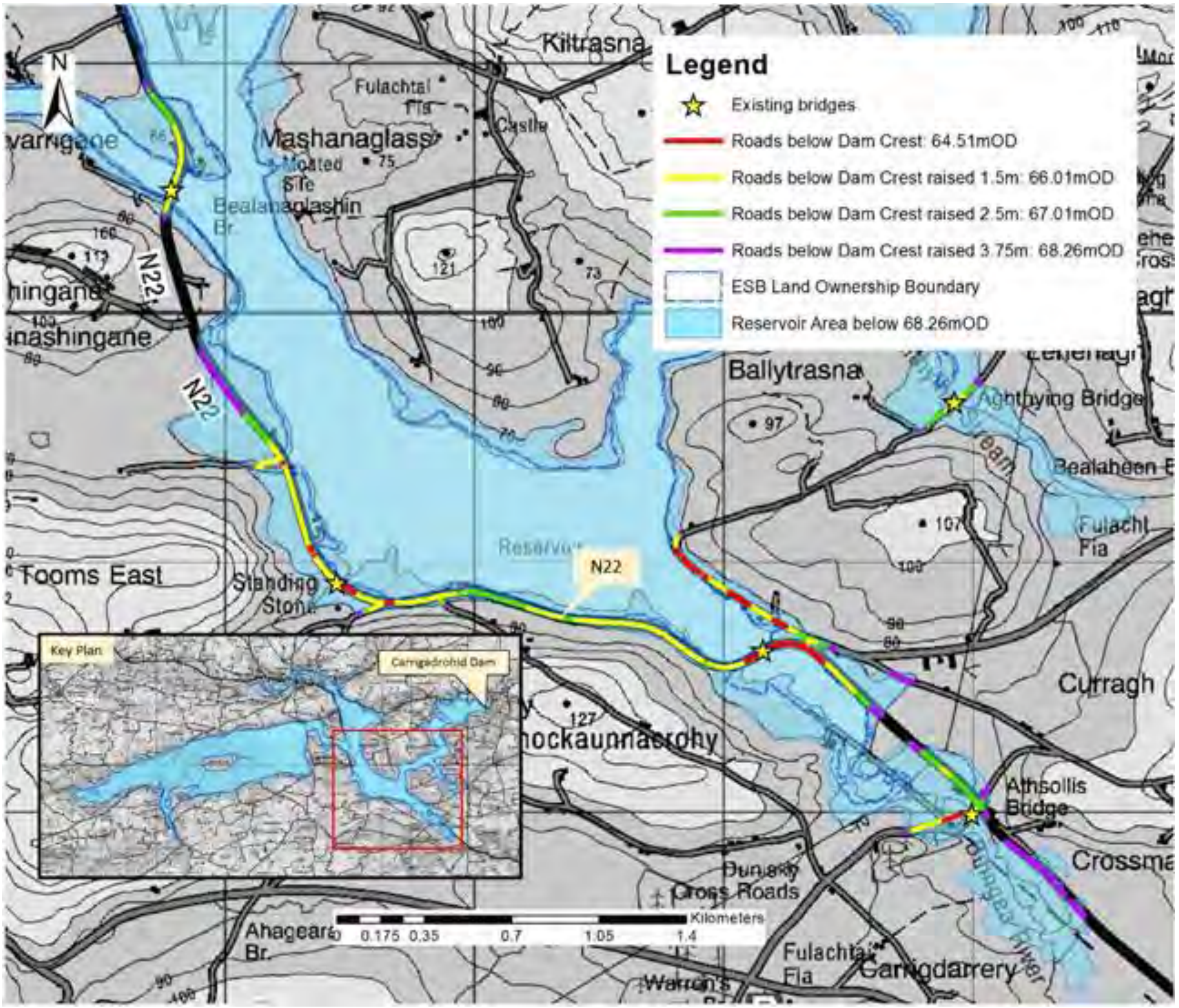
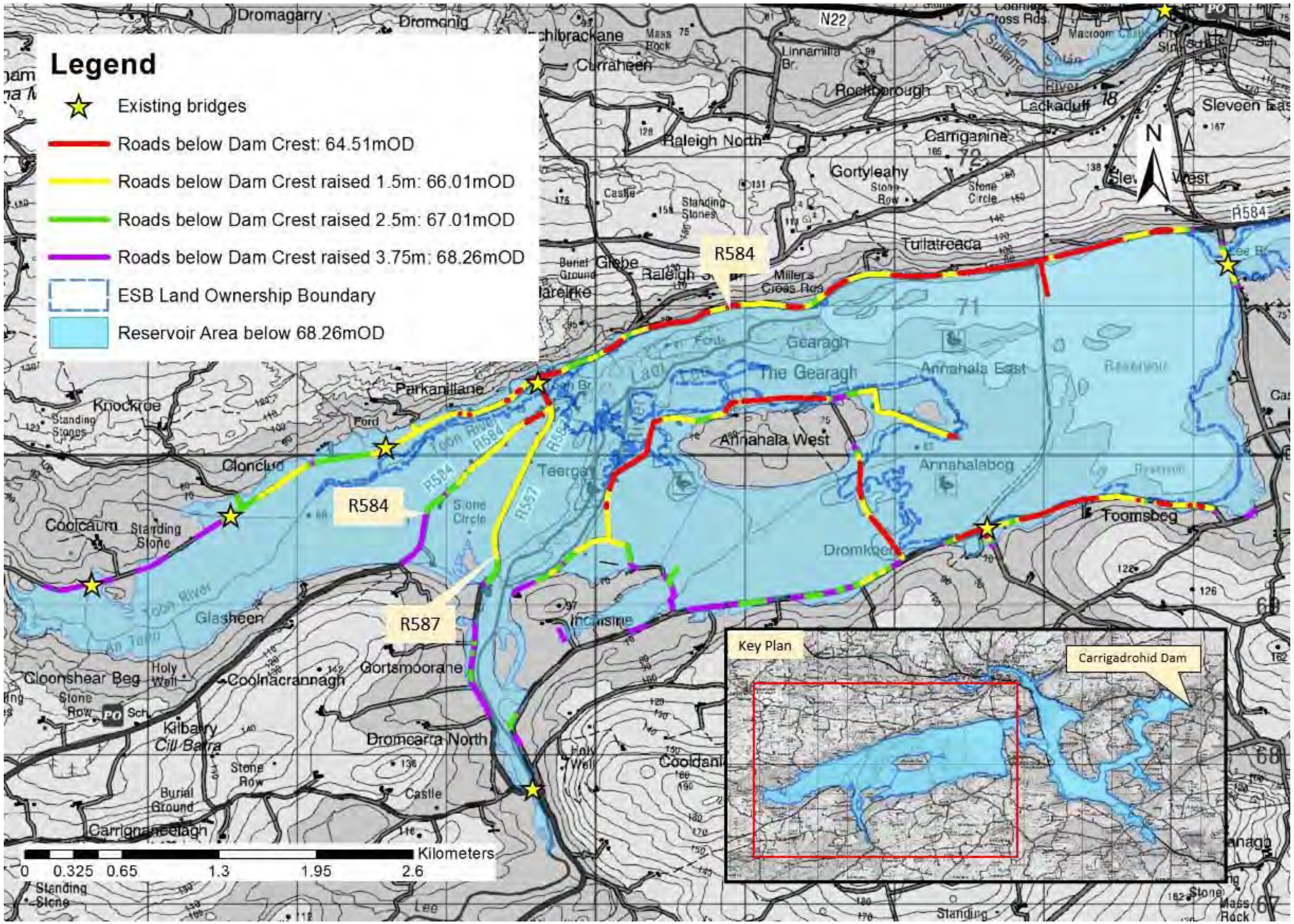


Figure 31: Infrastructure impact – Toonsbridge area



6.2.3.2 Indirect Impact

Further work to assess potential indirect geotechnical and hydrogeological impacts would be needed during the detailed design. Some key points for further and detailed investigation and assessment are:

- Slope stability assessment surrounding the reservoir. The composition and geometry of the slopes should be investigated, since the changing water reservoir elevation and the increased groundwater levels may affect the stability of the surrounding ground. In areas of potential instability, the risk could potentially be minimised by locally excavating and replacing unsuitable material or installing a geotextile to prevent erosion.
- Impact on the groundwater regime. Within the Carrigadrohid reservoir the GSI maps indicate the presence of limestone bedrock which is susceptible to karst. Therefore there may be a risk of preferential flow paths emerging as a result of increased groundwater levels.

6.2.4 Environmental Impacts

The upstream end of the Carrigadrohid reservoir contains the Gearagh Special Area of Conservation (SAC) and Special Protection Area (SPA), which are designated sites under the EU Habitats Directive and EU Birds Directive. The extent of these sites is identified in Figure 32. As part of this study, the project environmental consultant carried out an ecological assessment of the potential impact of a dam-raising project on existing designated sites. This assessment is contained in Appendix D, with main findings summarised below.

The Gearagh SAC is an area of woodland, river and reservoir in a wide, flat valley of the River Lee. It is noted for its alluvial and wet woodland within an anastomosing channel and is the only such site remaining in Ireland. As the Gearagh represent the only extensive alluvial woodland in Ireland, Britain or west of the Rhine in Europe, the site is also designed as a Statutory Nature Reserve. The international importance of the Gearagh is recognised by its designation both as a Ramsar site and a Biogenetic Reserve. The reservoir is also a Wildfowl Sanctuary and designated as a Special Protection Area (SPA).

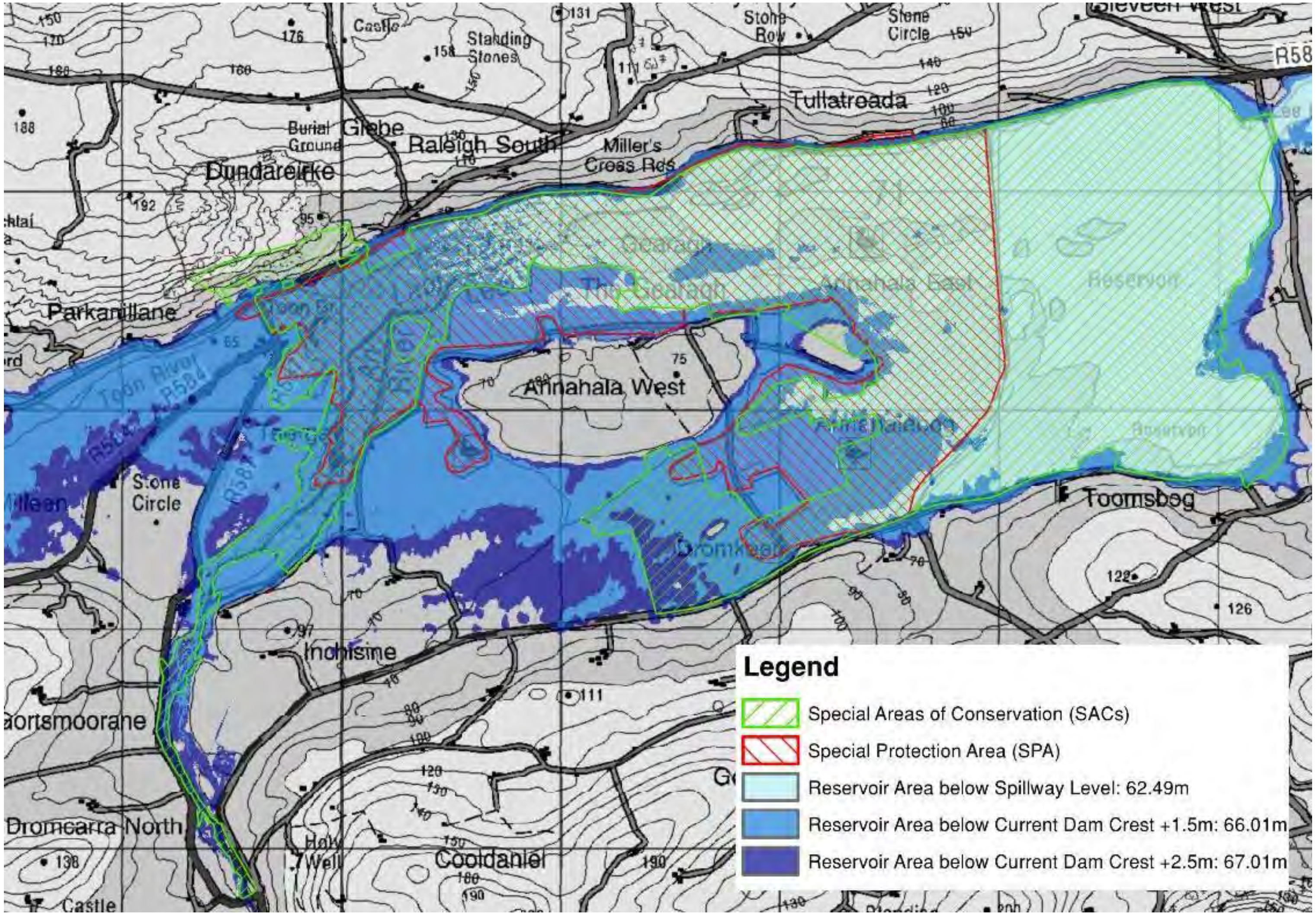
The ecological assessment identified the potential for increased floodplains to result in a risk to mammal habitat and breeding success. Given that the impact is long term, it is possible that the newly flooded areas would no longer be suitable for breeding holts and therefore a significant loss of habitat and range would be consequent. A Natura Impact Statement (NIS) would be required to fully assess the impact of the project on otter populations.

The assessment also identified potential impacts on existing alluvial woodland and floating river vegetation, which would also trigger the requirement for a Natura Impact Statement, potentially including a Stage 3 assessment of alternatives.

Therefore, it is not clear at this level of study whether a dam-raising proposal would gain statutory consent due to the impact on designated sites, particularly given that there are viable alternatives which do not impact on these sites. At a minimum, it is expected that extensive environmental mitigation measures will be required, and therefore a robust allowance for such measures has been included in the bottom-up cost buildups for the various options (see Section 7).

Note that a dam raising project will also have a significant human and socio-economic impact due to the increased reservoir. These impacts are significant and can be inferred from the physical impact on land, property and infrastructure as outlined in Section 6.2. It is likely that the impacts would result in strong local opposition to such a scheme, which could cause extended delay to the project, during which time Cork City would remain at risk.

Figure 32: Existing SPA/SAC at the Gearagh



6.3 Inniscarra Reservoir

6.3.1 Land Use Impact

The surface area of Inniscarra reservoir at each increment in level is outlined in Table 10 below. The area of each major land use type within the reservoir areas was calculated in GIS software using CORINE land use data.

Table 10: Reservoir Surface Areas – Inniscarra

Description	Level (mOD Malin)	Reservoir Surface Area	Agriculture (km^2)	Forest (km^2)	Urban Fabric (km^2)	Mineral Extraction (km^2)
ESB ownership level	48.49mOD	5.45 km^2	0	0	0	0
Current crest	49.32mOD	5.72 km^2	0.2	0.01	0	0
Current crest + 1.5m	50.82mOD	6.24 km^2	0.60	0.02	0.01	0.03
Current crest + 2.5m	51.82mOD	6.53 km^2	0.80	0.03	0.01	0.07

It can be seen that increasing the level of Inniscarra leads to a relatively modest increase in the surface area of the reservoir compared to Carrigadrohid. Similar to the discussion in Section 6.2.2, the cost associated with this inundation will need to be accounted for in the project cost.

6.3.2 Property Impact

Increasing the reservoir levels would increase flood risk at a number of properties around the reservoir perimeter. Table 11 below shows the number of properties likely to be impacted due to increased reservoir level and the number of properties within a 25m buffer of the proposed reservoir when raised. Figure 33 and Figure 34 show the main areas where property would be affected.

It can be seen that a considerable number of properties are brought into the reservoir area with even modest raising of the dam. These properties are dispersed around the perimeter of the reservoir.

Table 11: Property impact – Inniscarra

Description	Level (mOD Malin)	Buildings within proposed reservoir area	Buildings within 25m buffer around reservoir
ESB ownership level	48.49mOD	0	25
Current crest	49.32mOD	4	33
Current crest + 1.5m	50.82mOD	23	50
Current crest + 2.5m	51.82mOD	31	59

Figure 33: Property Impact – Dripsey area with dam raising of 2.5m

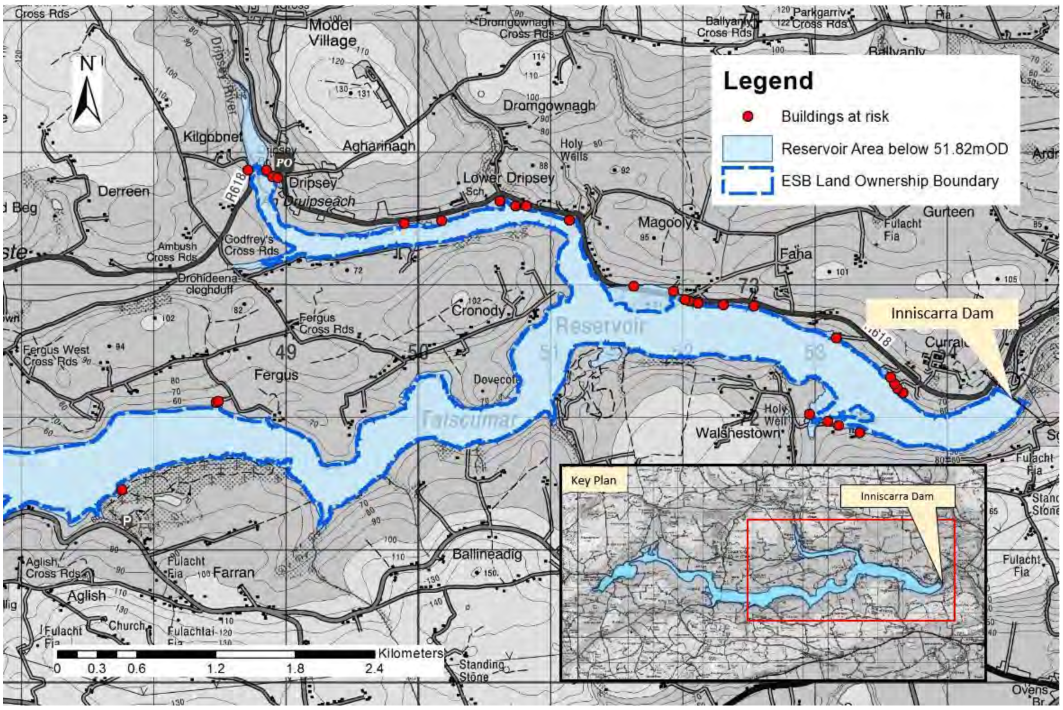
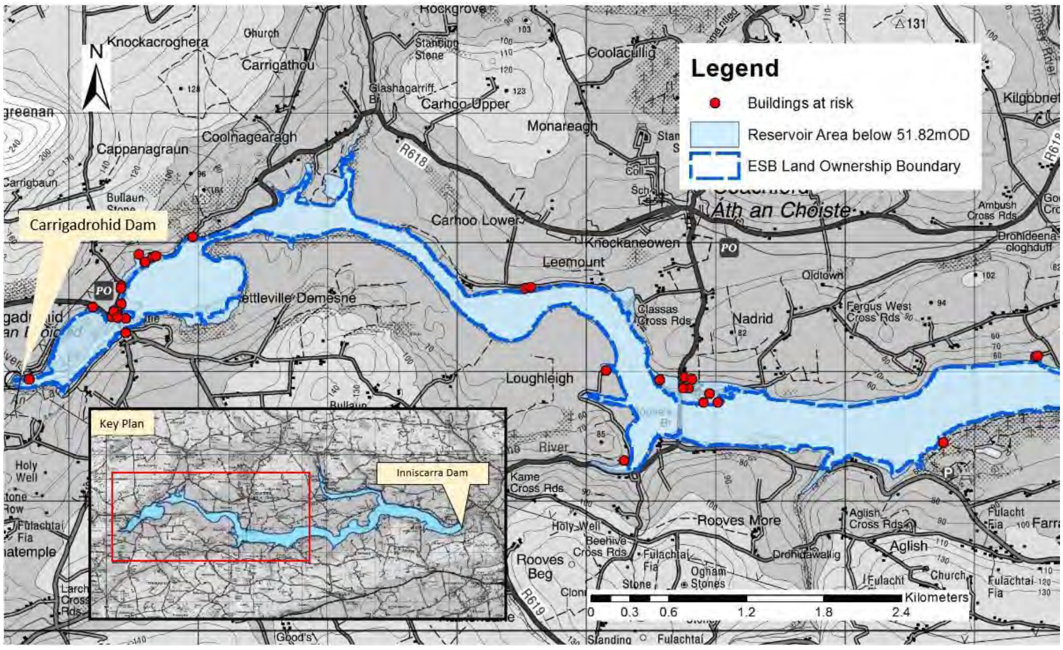


Figure 34: Property Impact – Coachford area with dam raising of 2.5m



6.3.3 Infrastructure Impact

As well as impacting a number of houses, raising the reservoir levels would have a significant impact on public infrastructure. Although a more detailed study would be required to determine the impact on utilities etc., the impact on roads and bridges can be readily determined. Table 12 below shows the infrastructure likely to be impacted by the raised reservoir.

Table 12: Infrastructure Impact - Inniscarra

Description	**Level (mOD Malin)**	**Length of Roads Inundated**				**Number of road bridge structures inundated (national/regional)**
		National (km)	**Regional (km)**	**Local (km)**	**Total (km)**	
ESB ownership level	48.49mOD	0	0	0	0	0/0
Current crest	49.32mOD	0.00	0.70	0.40	1.10	0/0
Current crest + 1.5m	50.82mOD	0.00	2.35	1.11	3.46	0/2
Current crest + 2.5m	51.82mOD	0.00	2.80	1.34	4.15	0/2

Figure 35: Infrastructure impact – Dripsey area

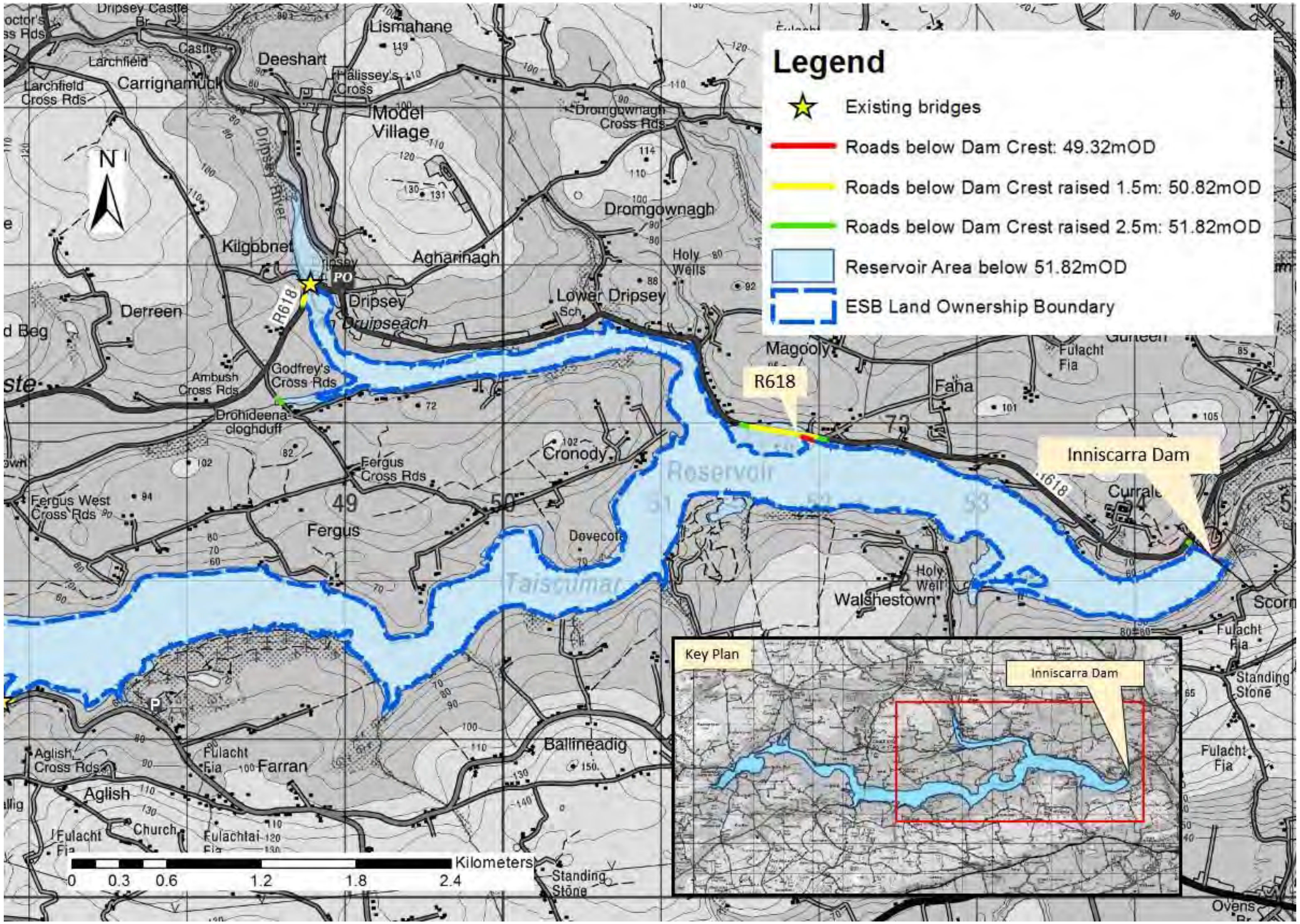
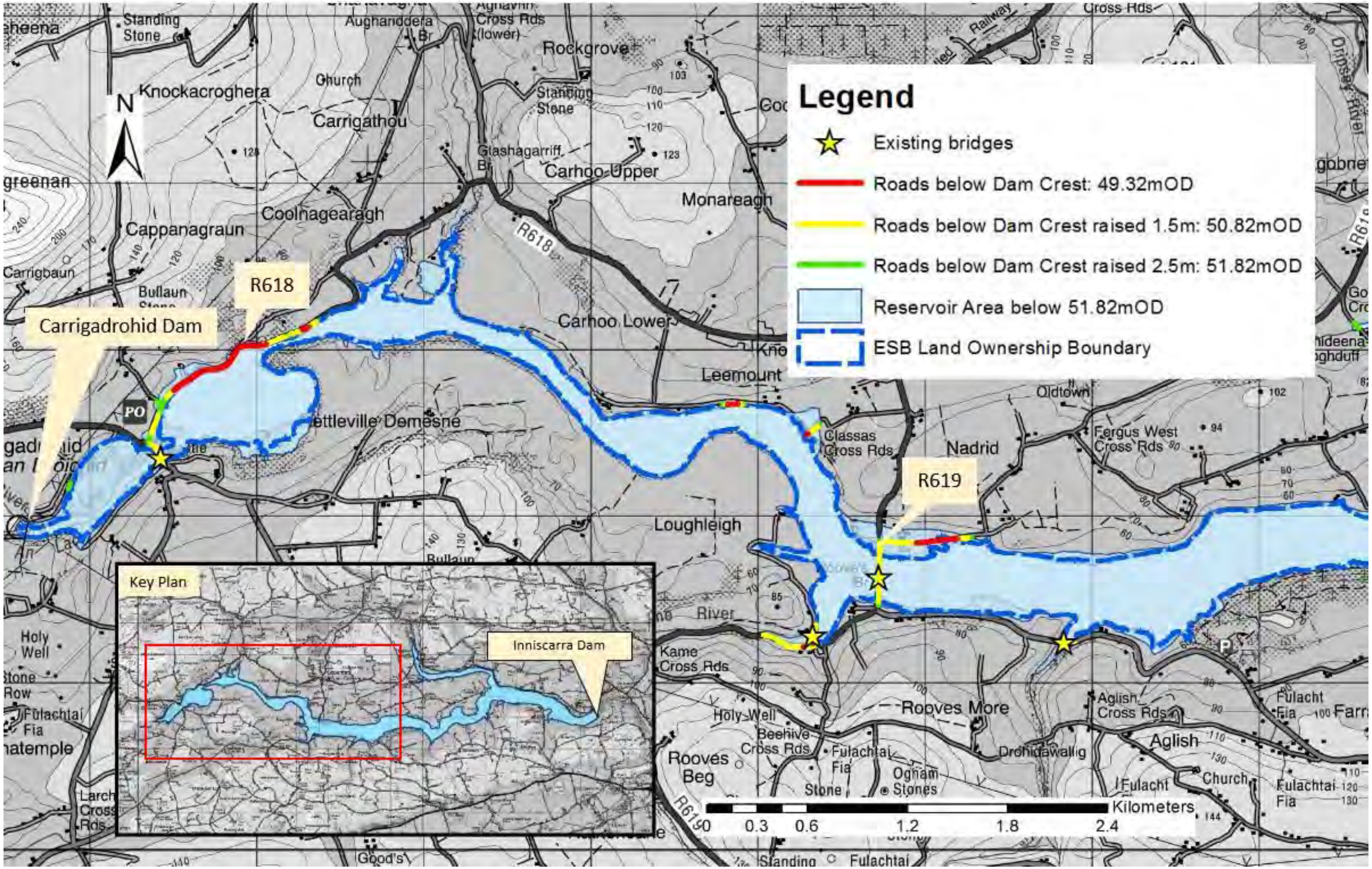


Figure 36: Infrastructure impact – Coachford area



6.3.3.1 Indirect Impact

The comments contained in Section 6.2.3.2 are equally relevant to Inniscarra reservoir.

6.3.4 Environmental Impacts

Unlike Carrigadrohid reservoir, the Inniscarra reservoir does not contain any designated sites under the EU Habitats Directive or EU Birds Directive. Notwithstanding this, a project involving raising of the Inniscarra reservoir could still have significant environmental impacts, which would need to be assessed in accordance with the relevant environmental legislation. It is likely that considerable environmental mitigation measures would be required.

Note that a dam raising project would also have a significant human and socio-economic impact due to the increased reservoir. These impacts are significant and can be inferred from the physical impact on land, property and infrastructure as outlined in Section 6.2. It is likely that the impacts would result in local opposition to such a scheme, which could cause extended delay to the project, during which time Cork City would remain at risk.

7 Preliminary Cost Estimate

7.1 Cost Estimation Methodology

Cost estimation can generally be undertaken in two main fashions as follows:

1. A top-down approach where international examples of similar projects are used to generate unit costs or relationships which can then be applied to estimate the cost of this project.
2. A bottom-up buildup prepared by developing a detailed schedule of specific elements, quantities and rates for the constituent elements of the proposed works.

Both approaches have been used in the preparation of this report to provide a potential range of costs.

7.2 Initial Top-Down Capital Cost Estimate

A review of publically available costs for international dam raising projects was carried out.

It was found that while there are many examples of dam raising projects internationally, the majority of these dams have significant differences to the Lee dams, which could greatly affect the cost. These differences can be summarised as follows:

- Many examples of raised dams are dams which were originally designed to be subsequently raised, which the Lee dams are not.
- Many available project examples are water supply dams which do not have a hydroelectric function. This significantly reduces the cost associated with the modification or replacement of electrical/mechanical elements.
- Many examples of raised dams do not have active spillway controls (i.e. they only have a passive overflow spillway), which greatly simplifies the construction of the dam raising.

Therefore, when selecting appropriate projects to use in a top-down estimate, the following types of projects were favoured:

- Concrete gravity dams, with
- A hydroelectric function, and with
- Active spillway controls

It was found that the publically available cost data typically does not include detailed breakdowns and therefore is of limited accuracy individually. The costs quoted in the source data are generally project costs (i.e. inclusive of construction costs, employer's costs etc.). Where it was felt that the quality of the information for individual projects was unacceptably low, they were screened out of the analysis.

Where the project cost breakdowns itemised upstream measures such as major new roads and bridges etc., these were removed from the total to ensure consistency insofar as possible. However, the costs quoted are still believed to include some element of mitigation works around the reservoir rim. The prices quoted were converted from the source currency to euro, and were inflated to 2017 prices using CPI.

Table 13 summarises the collated data which meets the above criteria:

Table 13: Estimated International Dam Raising Project Costs

Project name/Dam name	**Discharge Control**	**Length (m)**	**Original Height (m)**	**Raising (m)**	**Approximate Project Cost (€) (2017)**
Shasta dam option CP4A[13]	Active	1050	183	5.6	€273,403,200
Shasta dam option CP2	Active	1050	183	3.8	€259,560,000
Shasta dam option CP1	Active	1050	183	2	€242,256,000
Clanwilliam dam[14]	Active	240	43	13	€143,000,000
Roseires Dam[15]	Active	24,000m (main dam 1,100m)	68	10	€398,778,360*
Gross Reservoir Expansion[16]	Active	320	103	40	€319,200,000

* An estimated allowance for the earthen wing dams of €30m was subtracted from the project cost to give an approximate cost of the dam wall only

To convert the above data into useable unit rates, the total costs were graphed in terms of unit length, height of raising and percentage height of raising, as shown in Figure 37 and Figure 38 below.

[13] Department of the Interior 2015, *Shasta Lake Water Resources Investigation Feasibility Report*, accessed 8 August 2017, https://www.usbr.gov/mp/slwri/
[14] Frankson, L. *Raising of Clanwilliam Dam project well underway*, accessed 8 August 2017, http://www.infrastructurene.ws/2016/03/24/raising-of-clanwilliam-dam-project-well-underway/
[15] *Roseires Dam, Sudan, North Africa*, accessed 8 August 2017, http://www.arcoplate.net/wp-content/uploads/2014/11/RoseiresDam.pdf
[16] *Gross Reservoir Expansion Project*, accessed 8 August 2017, https://grossreservoir.org/about-the-project/dollars-and-cents/

Figure 37: Top-down cost analysis: cost/length vs height of raising

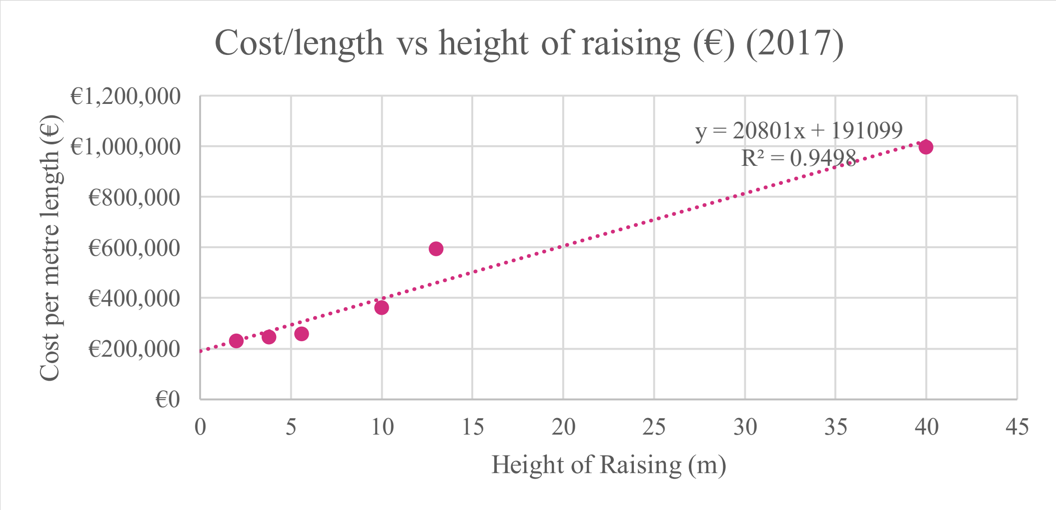


Figure 38: Top-down cost analysis: cost/length vs % height of raising

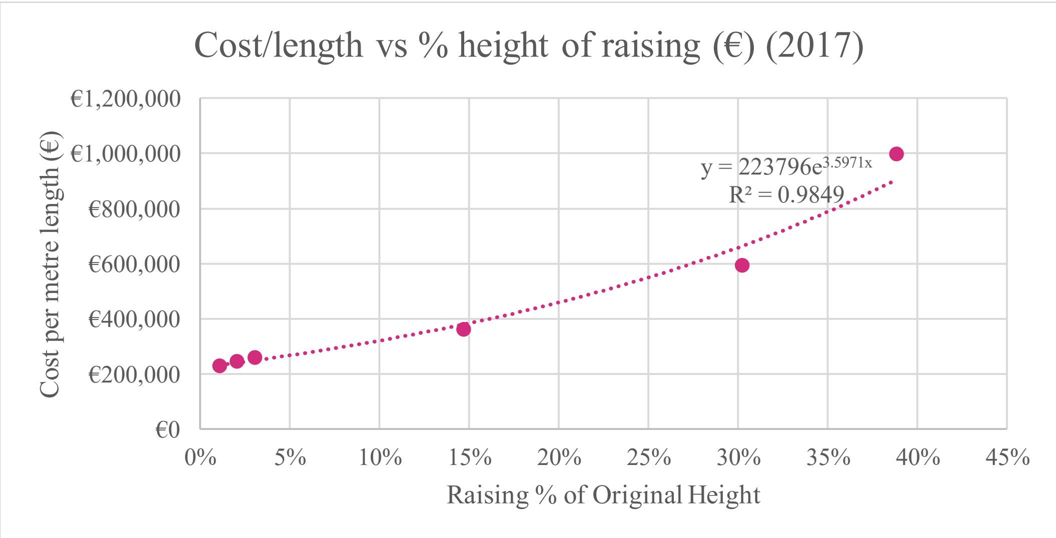


Table 14 summarises the estimated costs of raising Inniscarra and Carrigadrohid dams based on the above.

Table 14: Initial Top-Down Cost Estimate Summary (excluding reservoir impact costs, washlands defences and tidal defences)

Option	Estimated Top-Down Project Cost (Upper Bound) (€)	Estimated Top-Down Project Cost (Lower Bound) (€)
Option B (raise Carrigadrohid by 2.5m)	€ 43,784,307	€ 31,603,195
Option C (raise Carrigadrohid by 3.75m)	€ 53,713,058	€ 34,983,358
Option G (raise Carrigadrohid by 1.5m and Inniscarra by 2.5m)	€ 112,348,402	€ 89,674,440
Option H (raise Carrigadrohid by 2.5m and Inniscarra by 1.5m)	€ 107,047,950	€ 87,178,320
Option I (raise Carrigadrohid and Inniscarra by 2.5m)	€ 118,952,711	€ 92,378,570

Comparing the options that are likely to achieve the objective, it appears that "Option B" (raise Carrigadrohid by 2.5m) would be the most economical. However, the above estimate should be treated with caution, due to the small project sample size and limitations of the source data.

7.3 Preliminary Bottom-Up Capital Cost Estimate (Dam-Raising Element)

7.3.1 Limitations

The difficulty with a bottom up approach is as follows:

- It requires significant detailed design to be undertaken and requires significant definition of aspects of the project. This is particularly difficult to achieve at prefeasibility stage, where there is insufficient study to propose a definitive scheme design.
- There would be great uncertainty in terms of appropriate rates in the Irish context, given the absence of comparable projects.
- It is very sensitive to too many assumptions which cannot be made accurately at this level of study.

In addition to the costs of the dam raising, the cost of residual tidal defences which would still be required in Cork to address the tidal flood risk have also been costed to allow a direct comparison of the exhibited scheme (which addresses both tidal and fluvial risk) against an alternative solution incorporating dam raising.

Other costs such as design and supervision, environmental mitigation costs, optimism bias and contingency have also been added as percentage costs to allow direct comparison against the exhibited scheme.

7.3.2 Main Dam Works Costs

Approximate base costs for the main civil structural elements of the dam-raising scheme were built up using estimated unit rates for similar works. Table 15 below summarises the cost of each feasible option. A detailed buildup is included in Appendix B.

Table 15: Dam Raising Civil/Structural Works Cost Summary

Option	Description	Construction Cost Estimate including Risk Items
B	Carrigadrohid +2.5m	€10,513,618
C	Carrigadrohid +3.75m	€14,627,728
G	Carrigadrohid +1.5m, Inniscarra +2.5m	€34,526,838
H	Carrigadrohid +2.5m, Inniscarra +1.5m	€32,534,848
I	Carrigadrohid +2.5m, Inniscarra +2.5m	€37,039,348

7.3.3 Site Investigation and other Surveys

While extensive site investigation was carried out as part of the original dam construction project, it is envisaged that some additional site investigation will be required as part of the dam raising project, particularly underneath the footprints of the new wing dams. An approximate allowance of €150,000 per dam for these surveys has been included in the cost estimate.

7.3.4 Design and Site Supervision Costs

An allowance of 10% of the construction cost has been made for design and site supervision costs, reflecting the best estimate of the likely duration of the construction contract and required size of site supervision teams.

7.3.5 Land Purchase and Compensation

It is assumed that land purchase and compensation is covered under "reservoir impacts" (Section 7.6).

7.3.6 Operation and Maintenance Cost

The whole life cycle cost should be considered in the development of any major project. These costs will include operation and maintenance (O&M) costs. While the actual O&M costs for the Lee dams were unavailable, international large scale hydroelectric projects have O&M costs in the range of 2% to 2.5% of the scheme capital cost[17]. When this is estimated based on the original construction cost of the

[17] International Renewable Energy Agency *Renewable Power Generation Costs in 2014*, accessed 11 September 2017,

dams (refer to Section 7.9), this suggests that the annual O&M cost for the existing dams is in the range of €1.8m to €3.25m.

7.3.7 Impact on Hydroelectric Generation Income

The average wholesale price of electricity on the Irish market varies continuously, however the average price over the financial years 2014/2015 and 2015/2016 has been €48.75 per MWh[18]. The annual average output from the Lee stations is in the order of 80 x 10^6 kWh[19]. Therefore the average annual generation income is approximately €3.9m.

Added to the generation income is the "Capacity Payment", which is a fixed revenue system of payment for suppliers offering generation capacity to the market. The mechanism features at its core, a fixed "pot" of money that is calculated on an annual basis by the Regulatory Authority. ESB has advised that their Capacity Payment is approximately 20% of the annual generation income.

Over an economic life of 50 years, at a discount rate of 4%, the total hydroelectric generation income in net present value terms would be approximately €104m.

It has generally been assumed that operation and maintenance costs would be offset by continuation of hydroelectric generation activities at the dams post-construction of the dam-raising works. If the hydroelectric function were proposed to be permanently removed as part of the project, then this cost would need to be added to the total cost of the scheme.

It has however been assumed that due to the impact of the construction works on the dams, hydroloectric generation will need to temporarily cease during the construction period. It is considered reasonable to assume that generation would cease for a period of at least one year. This has been included in the capital costs of the options, as shown in Table 16.

Table 16: Estimated ESB Lee Dams Hydroelectric Generation Income

Dam	Average Annual Output	Approximate Annual Generation Income
Carrigadrohid	$22x10^6$ kWh	€1.07m
Inniscarra	$58x10^6$ kWh	€2.83m
Total excl capacity payment	-	€3.9m
Total incl capacity payment	**-**	**€4.7m**

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http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf
[18] SEMO *Regulatory Authority Annual Report 2016*, http://www.sem-o.com/MarketOperatorPerformance/MarketOperatorPerformance/SEMO%20Annual%20Report%202016.pdf , accessed 8 September 2017
[19] ESB, *The River Lee Hydro-Electric Scheme*, https://ruralelectric.files.wordpress.com/2016/02/river-lee-hydro-electric-scheme-pr-pamphlet.pdf, accessed 10 October 2017

7.3.8 Contingency/Optimism Bias

There can be a tendency for budget cost estimates for major civil engineering schemes to be overly optimistic. In a project of this nature where access for labour, plant and materials will be difficult, including a robust contingency in the cost estimate is essential.

A contingency/optimism bias of 40% of the construction cost has been included in the whole project cost. This is considered to be an appropriate allowance, given the pre-feasibility level of design in this report.

7.3.9 Allowance for Art

The "per cent for art" scheme is compulsory for all major public works contracts. For this size of project, the required allowance for art is 1% of the capital cost up to a maximum of €64,000. Therefore the maximum allowance of €64,000 has been included in the cost estimate.

7.4 Residual Washlands Defences

The cost buildup for the washlands defences was taken from the Lower Lee Options report. Refer to Appendix B for a cost buildup for the washlands defences. The project cost total for these measures is €12,687,908.

7.5 Residual Tidal Defences

The cost buildup for the defences in the city centre was taken from the Lower Lee Options report. However, recognising that the height of tidal-only defences would be significantly lower than the equivalent tidal-fluvial defences towards the western end, the cost in these areas was reduced proportionately. Refer to Appendix B for a cost buildup for the tidal-only defences. The project cost total for these measures is €78,383,211.

7.6 Reservoir Impact Costs

The following table summarises the cost for the different components of reservoir impact costs. In order to avoid an over-estimate of the reservoir impact costs, the following general approach has been adopted:

- The land and buildings in the zone between the existing ESB landownership line and the new peak level of the reservoir during the circa 100 year flood would be frequently flooded under the new regime and therefore would need to be purchased. National and regional roads in this zone would need to be raised/diverted. It has been assumed that local roads in this zone would remain unchanged.
- Land and properties between the 100 year contour and the dam crest would be flooded very infrequently. Therefore it may be reasonable to maintain existing ownership and compensate the landowners for loss incurred due to inundation

in events greater than the 100 year. This compensation mechanism could take one of the following forms:

- Single payment at reservoir construction
- Payment for individual flood events
- Annuity payments

As the occurrence of events greater than the 100 year are so rare, this compensation cost is expected to be relatively small over the design life of the scheme.

- An allowance of 10% of the reservoir impact cost has been made for works associated with environmental/archaeological impacts.

Table 17 presents a summary of the reservoir impact costs for each option. A detailed buildup is included in Appendix C.

Table 17: Reservoir Impact Costs.

Option	Description	Reservoir Impact Cost Estimate	Comment
B	Carrigadrohid +2.5m	€60,122,853	Cost includes land purchase and infrastructure mitigation up to 1.5m above existing dam crest level
C	Carrigadrohid +3.75m	€84,981,453	Cost includes land purchase and infrastructure mitigation up to 2.5m above existing dam crest level
G	Carrigadrohid +1.5m, Inniscarra +2.5m	€ 40,102,071	**Carrigadrohid**: Cost includes land purchase and infrastructure mitigation up to existing dam crest level **Inniscarra**: Cost includes land purchase and infrastructure mitigation up to 1.5m above existing dam crest level
H	Carrigadrohid +2.5m, Inniscarra +1.5m	€64,237,163	**Carrigadrohid**: Cost includes land purchase and infrastructure mitigation up to 1.5m above existing dam crest level **Inniscarra**: Cost includes land purchase and infrastructure mitigation up to existing dam crest level
I	Carrigadrohid +2.5m, Inniscarra +2.5m	€83,900,452	**Carrigadrohid**: Cost includes land purchase and infrastructure mitigation up to 1.5m above existing dam crest level **Inniscarra**: Cost includes land purchase and infrastructure mitigation up to 1.5m above existing dam crest level

7.7 Bottom-Up Cost Estimate Summary

Table 18 below summarises the bottom-up cost buildup for the various dam raising options. It can be seen that Option B (raise Carrigadrohid by 2.5m) is the least expensive of the options assessed.

Table 18: Bottom-up Cost Estimate Summary

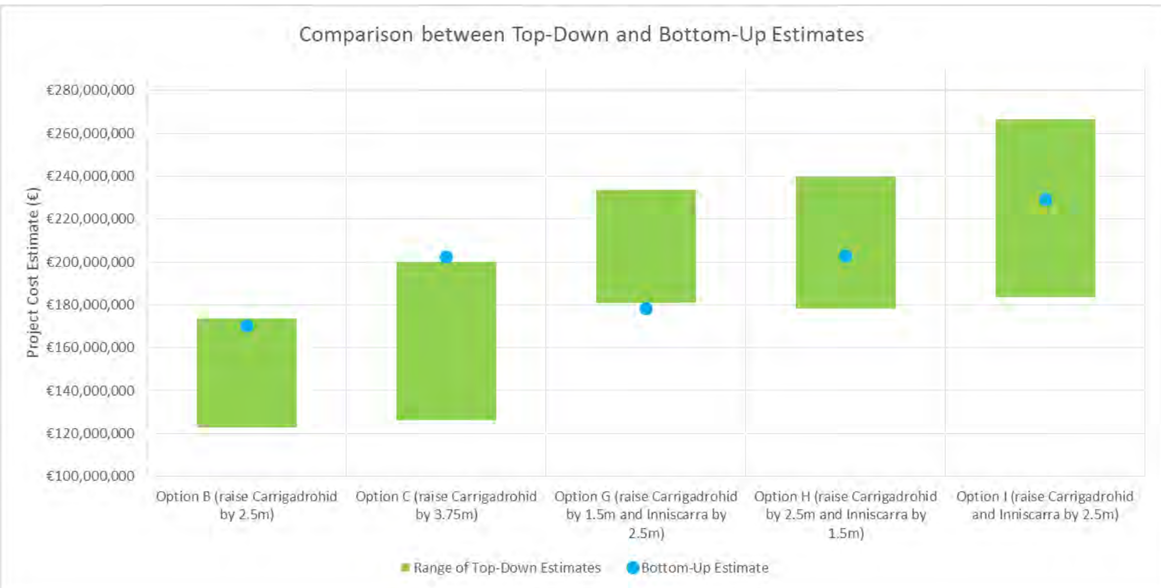
	Option B (raise Carrigadrohid by 2.5m)	**Option C (Raise Carrigadrohid by 3.75m)**	**Option G (raise Carrigadrohid by 1.5m and Inniscarra by 2.5m)**	**Option H (raise Carrigadrohid by 2.5m and Inniscarra by 1.5m)**	**Option I (Raise Carrigadrohid and Inniscarra by 2.5m)**	**Option K (Raise Carrigadrohid by 2.5m, plus new reservoir at Dromcarra)**
Construction Cost (Carrigadrohid dam)	€ 10,513,619	€ 14,627,729	€ 8,001,109	€ 10,513,619	€ 10,513,619	€ 10,513,619
Construction Cost (Inniscarra dam)	€ -	€ -	€ 26,525,730	€ 22,021,230	€ 26,525,730	€ -
Construction Cost Subtotal	€ 10,513,619	€ 14,627,729	€ 34,526,839	€ 32,534,849	€ 37,039,349	€ 10,513,619
Add fees and supervision @ 10%	€ 1,051,362	€ 1,462,773	€ 3,452,684	€ 3,253,485	€ 3,703,935	€ 1,051,362
Construction Cost & fees Total	€ 11,564,980	€ 16,090,501	€ 37,979,522	€ 35,788,333	€ 40,743,283	€ 1,564,980
Site investigation	€ 150,000	€ 150,000	€ 300,000	€ 300,000	€ 300,000	€ 150,000
Temporary loss of hydroelectric generation income	€ 1,284,000	€ 1,284,000	€ 4,680,000	€ 4,680,000	€ 4,680,000	€ 1,284,000
Art	€ 64,000	€ 64,000	€ 64,000	€ 64,000	€ 64,000	€ 64,000
Dam Raising Subtotal	€ 13,062,980	€ 17,588,501	€ 43,023,522	€ 40,832,333	€ 45,787,283	€ 13,062,980
Reservoir Impacts	€ 60,122,853	€ 84,981,452.55	€ 40,102,070.57	€ 64,237,163	€ 83,900,452	€ 60,122,853
Archaeology & environmental @10%	€ 6,012,285	€ 8,498,145	€ 4,010,207	€ 6,423,716	€ 8,390,045	€ 6,012,285
Dam-Raising Project Cost Total	€ 79,198,118	€ 111,068,099	€ 87,135,800	€ 111,493,213	€ 138,077,781	€ 79,198,118
New Reservoir at Dromcarra Project Cost Total	€ -	€ -	€ -	€ -	€ -	€15,000,000 to €20,000,000 (assume €17.5m)
Residual Washlands Defences	€ 12,687,908	€ 12,687,908	€ 12,687,908	€ 12,687,908	€ 12,687,908	€12,687,908
Residual Tidal-only Defences	€78,383,211	€78,383,211	€78,383,211	€78,383,211	€78,383,211	€78,383,211
Total Project Cost	**€170,269,237**	**€202,139,218**	**€178,206,919**	**€202,564,332**	**€229,148,900**	**€187,769,237**

7.8 Comparison of Top-Down Cost Estimate with Bottom-Up Estimate

In order to carry out a sense-check, a comparison was carried out of the cost estimates obtained from the different methods. Figure 39 compares the bottom-up cost estimate against the range of costs indicated by the top-down analysis. Both sets of estimates contain the same allowances for tidal defences and washlands defences. An element of reservoir impact cost was added to the top-down upper bound cost to mitigate the uncertainty regarding its inclusion in the source data (refer to Appendix C1.3 for a breakdown of this allowance).

It is noted that the bottom-up estimate for Option B and Option C (Carrigadrohid raising) appears to be close to the upper bound of the top-down estimates. This is believed to be a result of an inherent under-estimate in the top-down cost, related to the small size of Carrigadrohid dam relative to the sample projects making up the top-down estimate. The economies of scale achieved with raising a larger dam would not be achieved with a smaller dam.

Figure 39: Comparison between top-down and bottom-up estimates



7.9 Comparison with Reconstruction Cost

A potentially feasible alternative option to achieve the required additional storage may be to construct a new larger hydroelectric dam a short distance downstream of the existing Carrigadrohid dam. This new dam would have more/larger sluice gates than the existing dam, which would allow greater control of discharges up to the 10,000 year event. With larger gates in a new dam, in theory the required magnitude of dam height increase should be less than in the case of raising the existing dam. This option is explored further in this section.

The cost of the original Lee Hydroelectric Scheme is contained in the Ministerial approval order amendment[20]. This suggests that the outturn cost for the scheme was approximately £4.5m in 1957. This includes costs of compensation for lands, fisheries, reconstruction of roads and bridges etc. Converting this to 2017 prices using CPI suggests a cost of circa €130m. Apportioning this cost between the two dams on a "per megawatt (MW)" basis can give an estimate of the cost of the individual dams.
See Table 19 below. Note that that the cost breakdown is likely to be skewed, since the quantity of landowner compensation and infrastructure mitigation works associated with Carrigadrohid dam are expected to have been higher than Inniscarra dam.

The above was compared with the costs of other international hydroelectric projects, as outlined by IRENA[21], which would suggest that the average total installed cost for small schemes in the European Union ranges from approximately $750/kW to $7,500/kW, with a capacity weighted average of approximately $4,500 USD per kW. The weighted average equates to approximately €3.36m per MW when converted on the basis of purchasing power parities and inflated to 2017 prices.

Note that the weighted average above suggests a lower construction cost than appears to have occurred in reality. This is expected to be due to site-specific conditions which cannot be well represented in the weighted average. Notwithstanding this, it may be useful to view the weighted average cost as a lower-bound.

Table 19 gives the construction cost for each dam when estimated on this basis.

Table 19: Approximate Original Construction Cost of ESB dams

Dam	Output	Approximate Project Cost (Estimated from International weighted averages) (€, 2017)	Approximate Project Cost (Estimated from Ministerial Order) (€, 2017)
Carrigadrohid	8MW	€26.9m	€38.5m
Inniscarra	19MW	€63.8m	€91.5m
	Total	**€90.7m**	**€130m**

The cost of reconstructing Carrigadrohid dam would be significantly higher than the original cost due to the proposed increase in crest level, and the likely increase in dam width due to the widening of the valley immediately downstream of the existing dam. On the basis of the above unit rate per MW, it is estimated that base cost of reconstructing Carrigadrohid dam, say 1.5m higher than existing would be in the order of €30m to €43m excluding the majority of costs associated with

[20] River Lee Hydro-Electric Scheme Approval Order, 1949 (Amendment) Order, 1957 (S.I. No. 71/1957)
[21] International Renewable Energy Agency *Renewable Power Generation Costs in 2014*, accessed 11 September 2017, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

increased reservoir impact. While the original project cost in the table above included compensation for lands etc., it should be noted that the land within the existing reservoir areas was predominantly agricultural, with relatively little major infrastructure. If the level of the reservoir were now to be raised, it would impact a far greater proportion of designated sites, structures and infrastructure, including national primary roads, regional roads, domestic properties, Macroom wastewater treatment plant, etc. Therefore, it would be appropriate to add an extra-over cost to account for this increased impact.

It is also considered unlikely that generation activities could continue at the existing dam while the new dam is under construction. Therefore, this loss of income should be included in the project cost.

The cost of decommissioning and demolition of the existing dam should also not be underestimated. Estimates based on project examples in the US suggest that removal costs for projects post-1999 ranged from 20% to 40% of construction costs[22]. As the estimate of this cost is highly site-specific, it is proposed to allow 30% of the lower bound base cost as a conservatively low estimate so as not to overestimate the potential cost.

A further issue which would arise with this option is the resilience of Inniscarra dam during extreme events, particularly the 10,000 year event. The current sluice gates at Inniscarra dam do not have capacity for any increase in peak discharge beyond the current 10,000 year event inflow. Since the peak discharge capacity of the reconstructed Carrigadrohid dam would increase, the potential peak pass-on flow to Inniscarra may also increase and thus increase the residual risk. It is acknowledged that any increase in pass-on flow from Carrigadrohid to Inniscarra could be mitigated by utilising some of the additional storage created at Carrigadrohid. However, it is still considered appropriate to make some allowance for enhancement of Inniscarra dam to facilitate passage of greater inflows through the spillway gates. It is proposed to make a tentative allowance of €10m for carrying out such works. This cost is considered to be conservatively low, but reasonable when considered on a risk/contingency basis. This issue would need to be studied in further detail as part of a feasibility study for a scheme such as this.

Table 20: Option L - Carrigadrohid Dam Reconstruction – Preliminary Cost Estimate

Description	**Cost Estimate (€)**
Carrigadrohid dam - Base reconstruction cost	€30m to €43m
Temporary loss of generation income at existing Carrigadrohid dam (3 years assumed)	€4m
Decommissioning and demolition of existing dam	€9m
Modifications to Inniscarra to facilitate increased 10,000 year discharge	€10m
Extra-over cost for reservoir impacts[23]	€16.2m

[22] *Decommissioning dams - costs and trends*, accessed 11 September 2017, http://www.waterpowermagazine.com/features/featuredecommissioning-dams-costs-and-trends/

[23] Assume that land purchase/infrastructure mitigation up to existing dam crest level would be required

Subtotal	**€69.2m to €82.2m**
Cost of Residual Washlands defences	€12.7m
Cost of Residual Tidal-only defences	€78.4m
Project Cost Total	**€160.3m to €173.3m**

Based on the above, it can be seen that a reconstruction project cost could be reasonably close to the lowest feasible dam-raising option. However, such a scheme would still not be more cost-beneficial than the exhibited scheme.

7.10 Summary and Comparison with Exhibited Scheme

Table 21 below presents a comparison between the various options developed in this report and the exhibited scheme. The benefit cost ratios for each option are also shown.

Table 21: Comparison between Emergent Options and Exhibited Scheme

Option	Description	Project Cost Estimate	Present Value Benefit (PVb)[24]	Benefit Cost ratio	Sensitivity Test - Discount Rate 5%
B	Raise Carrigadrohid by 2.5m, Washlands Defences & Tidal Defences	€170,269,237	€185.45m	1.09	0.92
C	Raise Carrigadrohid by 3.75m, Washlands Defences & Tidal Defences	€202,139,218	€185.45m	0.92	0.77
G	Raise Carrigadrohid by 1.5m and Inniscarra by 2.5m, Washlands Defences & Tidal Defences	€178,206,919	€185.45m	1.04	0.87
H	Raise Carrigadrohid by 2.5m and Inniscarra by 1.5m, Washlands Defences & Tidal Defences	€202,564,332	€185.45m	0.92	0.77
I	Raise Carrigadrohid and Inniscarra by 2.5m, Washlands Defences & Tidal Defences	€229,148,900	€185.45m	0.81	0.68
K	Raise Carrigadrohid by 2.5m, plus new reservoir at Dromcarra, Washlands Defences & Tidal Defences	€182,035,536	€185.45m	1.02	0.86
L	Carrigadrohid Dam Reconstruction, Washlands Defences & Tidal Defences	€160.3m to €173.3m	€185.45m	1.07 to 1.16	0.9 to 0.97
-	Exhibited Scheme - Flow Reduction in South Channel and Direct Defences	€128.45m	€185.45m	1.44	1.21

[24] From Lower Lee Options Report

It can be seen that all of the above options have significantly weaker cost benefit ratios compared to the exhibited scheme.

Also, when subjected to a sensitivity analysis which considers a 5% discount rate, all options except the exhibited scheme would fall below the minimum required break even benefit cost ratio of 1. Given the highlighted uncertainty with the cost estimates themselves, it is not clear whether a robust business case exists for any of the options developed in this report.

8 Multicriteria Analysis

A high level multi-criteria analysis was carried out, comparing the relative merits of the exhibited scheme versus the various options developed in this report. Each scheme is ranked in terms of its relative merit. A traffic light system is used to differentiate the relative merits of each scheme.

Table 22: Multicriteria Comparison

Criteria	Option B-J (Dam Raising)	Option K (Dam Raising plus Dromcarra)	Option L (Carrigadrohid Reconstruction)	Exhibited Scheme
Constructability	These options would be difficult to construct, particularly considering issues such as difficult access, reservoir water management, proximity of the power houses to the dam walls, difficulty connecting new concrete to old concrete, etc.	The dam-raising element would have similar constructability issues as Options B-J. Construction of a new dam at Dromcarra would not be expected to present exceptional difficulties.	Dam construction techniques are well established	Direct defences are generally simple structures with well established methods of construction
Dam safety	Raising of Inniscarra dam would present significant dam safety issues at Carrigadrohid due to the backwater effect reducing the discharge capacity of the deep sluices. This is likely to rule out options biased towards raising of Inniscarra dam. Apart from the above issue, the scheme would need to preserve dam safety by design, i.e. compliance with existing dam safety criteria should be maintained	Dam safety should be preserved by design i.e. compliance with existing dam safety criteria should be maintained	Dam safety should be preserved by design i.e. compliance with existing dam safety criteria should be maintained	Maintains existing dam safety regime which is in line with international best practice
Residual flood risk downstream	Meets design standard of 1 in 100 year fluvial / 1 in 200 year tidal protection	Meets design standard of 1 in 100 year fluvial / 1 in 200 year tidal protection	Meets design standard of 1 in 100 year fluvial / 1 in 200 year tidal protection	Meets design standard of 1 in 100 year fluvial / 1 in 200 year tidal protection
Environmental impacts	Significant alterations to the natural regime of the Gearagh SPA/SAC. May not gain statutory consent when alternatives exist which do not impact on Natura 2000 sites.	Significant alterations to the natural regime of the Gearagh SPA/SAC. May not gain statutory consent when alternatives exist which do not impact on Natura 2000 sites.	Possibly some impact on the natural regime of the Gearagh SPA/SAC. May not gain statutory consent when alternatives exist which do not impact on Natura 2000 sites.	No impact on Natura 2000 sites
Property impact	80+ residential properties would need to be purchased and residents displaced due to the increased reservoir area	80+ residential properties would need to be purchased and residents displaced due to the increased reservoir area	A small number of residential properties would need to be purchased and residents displaced due to the increased reservoir area	No properties / residents displaced

Criteria	Option B-J (Dam Raising)	Option K (Dam Raising plus Dromcarra)	Option L (Carrigadrohid Reconstruction)	Exhibited Scheme
Infrastructure impacts	8km+ of existing roads and bridges would need to be raised/relocated. Several bridges would need to be raised / reconstructed.	8km+ of existing roads and bridges would need to be raised/relocated. Several bridges would need to be raised / reconstructed.	Circa 3km+ of existing roads and bridges would need to be raised/relocated.	Impact on existing roads and bridges will be orders of magnitude less than Options A-L
Land-use impacts	Purchase of 5km^2+ of productive land required. This land would be incorporated into the “live” reservoir area and as such would be permanently sterilised	Purchase of 7km^2+ of productive land required. This land would be incorporated into the “live” reservoir area and as such would be permanently sterilised	Purchase of 1km^2+ of productive land required. This land would be incorporated into the “live” reservoir area and as such would be permanently sterilised	No long-term alterations to existing land use
Hydroelectric power generation (HP) impact	Temporary interruption to HP generation	Temporary interruption to HP generation	Temporary interruption to HP generation	No interruption to HP generation
Cost	All options fall below a benefit cost ratio of 1 when subjected to sensitivity testing	Unlikely to be cost-beneficial	Option falls below a benefit cost ratio of 1 when subjected to sensitivity testing	Strong benefit cost ratio

9 Responses to Key Questions raised through Statutory Exhibition Process

Suggestions that Inniscarra dam should be utilised to control flood water from the Lee catchment area including a monitoring system to observe tides, rainfall and wind forecasts.

A key element of the proposed scheme is to utilise Inniscarra and Carrigadrohid dams to control flood water within the physical limitations of the existing dams, whilst maintaining an acceptable dam safety regime. A set of revised operational procedures (supported by a new flood warning system) is proposed as part of the scheme for operation of the dams during times of flood. The new flood forecasting system will be using forecast rainfall and forecast tide levels.

Suggestion that Carrigadrohid reservoir should be drained and used as a flood reservoir only.

Under the proposed scheme, the existing reservoirs will be drawn down to low levels in advance of a forecasted flood. This maximises the storage available to attenuate floods, while maintaining the existing hydroelectric generation function of the dam. Due to the shape of the Lee valley, the incremental gain in flood storage capacity diminishes rapidly as the reservoir level reduces. Currently the minimum levels at Carrigadrohid are limited by water supply offtakes upstream and environmental considerations at the Gearagh. Working within these constraints would only deliver less than 10 million m^3 of additional storage compared with the proposed revised operational procedures. This would fall well short of the estimated 37 million m^3 required to eliminate fluvial defence in Cork City.

There would be significant environmental issues associated with draining of Carrigadrohid reservoir. The reservoir is of notable ecological value, particularly the vicinity of the Gearagh, which is designated as a Special Protection Area (SPA) and a Special Area of Conservation (SAC). A project which would impact on the existing regime in these designated sites would encounter significant obstacles under environmental legislation, since a viable alternative exists which does not impact the SPA/SAC.

Furthermore, the operation and maintenance costs of the existing Carrigadrohid dam are offset by the income derived from generation of hydroelectricity. If the reservoir were to be maintained in an empty state, this source of income would be removed and the operation and maintenance of the dam would become a project cost. As measures to defend against tidal flooding would still be required to meet the design standard of the scheme, this option would not be cost-beneficial.

Suggestion that releases from Inniscarra dam should be harmonized with the state of the tide.

The proposed revised dam operational procedures will take account of the tidal conditions in Cork Harbour where possible.

Could the water level be kept low in Inniscarra reservoir if ESBs control was discontinued?

Under the proposed scheme, the existing reservoirs will be drawn down to low levels in advance of a forecasted flood. This maximises the storage available to attenuate floods, while maintaining the existing hydroelectric generation function of the dams. At Inniscarra dam, there is a practical limit to how low water can be maintained in the existing arrangement, due to the fact that the sluice gates are located at the top of the dam. There is a major water off take upstream of Inniscarra Dam which is a constraint on how low the water levels can be reduced to. This constraint would not change if the ownership of the dam were to be transferred to another body.

Suggestion that the past fluvial flooding was only due to human error, meaning the proposed scheme is not necessary.

The Lee catchment has a long history of fluvial flooding prior to construction of the Lee dams. Several recorded flood events in the 19th century and early 20th century were of a similar magnitude to November 2009. The existing reservoirs are currently very effective in attenuating small flood events. However, they have limited capacity to manage extreme flood events within the current limitations of flood forecasting and advance discharges. Notwithstanding this, the Lee dams still reduced the peak flow downstream of Inniscarra in November 2009 from 809m^3/s to 546m^3/s (a reduction of over 30%) and therefore significantly reduced downstream flooding.

Under the proposed scheme, the existing reservoirs will be drawn down to low levels in advance of a forecasted flood. This maximises the storage available to attenuate floods, while maintaining the existing hydroelectric generation function of the dams. This will reduce the peak discharge in the design event by circa 40% compared with the existing scenario. However, detailed hydrological analysis and hydraulic analysis has shown that even with this significant reduction, fluvial defence measures will still be necessary to achieve the design standard of protection in Cork.

Lifting of the existing constraints of the dam operating rules should be considered in the immediate term.

The proposed revised dam operation procedures cannot be put in place until the proposed direct defence measures are constructed and the flood forecasting system is operational. This is because there would not be sufficient foresight of a developing flood event to draw down the reservoirs sufficiently, in the absence of the flood forecasting system. Furthermore, the proposed advance discharges would flood properties located in the washlands areas.

Request to demonstrate the cost/benefit analysis of keeping the extreme event discharges to the current operating limits in combination with providing additional storage within the dam or by flow reduction measures through optimised catchment flow management.

This request has been substantially addressed in this report. Some other aspects of the request (e.g. flow reduction measures such as natural flood management) are assessed in separate technical reports prepared in response to those individual issues.

What is the opportunity cost of the state purchasing the dams for predominate use as flood defence purposes?

Accurately defining the cost of purchasing and operating the existing ESB dams as solely flood control and water supply assets is difficult to achieve at this level of study. However, an order of magnitude estimate for the "project cost" is as follows.

The preliminary estimate of the hydroelectric generation income from the existing dams may be a good measure for the loss of income and ongoing O&M cost which would need to be included in the total "project cost". The analysis presented in Section 7.3.7 suggests that the net present value of the above costs (over the next 50 years) for both dams would be in the order of €104m. Added to this would be legal costs, decommissioning of the existing hydroelectric equipment, environmental mitigation measures upstream, purchase of the existing ESB landholding over the footprint of the reservoirs, purchase of fisheries rights, etc. It is considered likely therefore that the total "project cost" of purchasing the dams and operating solely as flood control and water supply assets would be upwards of €120m.

In terms of opportunity cost, it is considered that only the defences within the fluvially-dominated reach between the Kingsley Hotel and the Tyndall Institute could be significantly reduced or removed. These defences have a value (in total project cost terms) of approximately €37m. Therefore, this option is not attractive in terms of opportunity cost.

Has consideration been taken of the effect of the decommissioning of the dams in the future on the FRS?

ESB has recently completed a major capital investment programme in overhauling the hydroelectric generation equipment at both dams and has confirmed that there are no plans to decommission the existing dams in the short to medium term. Therefore it is not appropriate for this issues to influence the decision to use the dams as part of the Scheme.

Suggestions that the dam at Carrigadrohid should be removed.

Removal of the dam at Carrigadrohid would reduce the quantity of flood storage currently available in the catchment, and would therefore increase fluvial flood risk, which would run counter to the aims of the scheme.

Suggestion that the proposed revised operational procedures will increase flows downstream and therefore increase flood risk.

In the context of the major flood for which the scheme is designed, it should be noted that the net effect of the proposed advance discharges is that the peak flow during the design flood event will be reduced by circa 40% compared with the existing scenario. Therefore flood risk will be reduced by the proposed scheme.

For lesser floods and advance discharges under the proposed scheme, the existing reservoirs will be drawn down to low levels in advance of a forecasted flood in order to maximise the storage available to attenuate floods. This will require staged increases in discharges up to 300m^3/s in advance of the onset of the flood event. In the current situation, this discharge rate would cause flooding to some properties located on the floodplain between Inniscarra dam and the western end of the city island. However, the proposed direct defences will mitigate this risk. Hydraulic modelling has shown that the proposed advance discharges are not large enough to cause flooding to properties in the city centre and therefore does not increase flood risk.

Suggestion that options for physical alterations to the existing dams to increase storage capacity should be explored.

This suggestion has been assessed in detail in this report. The options which would be technically viable have generally been found to have significant shortcomings compared with the proposed scheme. The options would have significantly greater environmental impacts, will displace a large number of residential properties, will impact many kilometres of existing national and regional roads, and will sterilise a large area of productive agricultural land. Also, the options for provision of additional upstream storage will only effect defence heights in the western part of Cork City. Independent measures to defend against tidal flooding would still be required. Such options are also significantly more expensive than the exhibited scheme and do not have a positive BCR.

Description of the current discharge regulations as 'business-as-usual-with-panic'.

The top priority in managing the dams is to ensure dam safety at all times, as this is key for the safety of people downstream of the dams. After that, outside of flood periods electricity generation is the priority and during flood periods flood alleviation takes priority over electricity generation.

Reduction of flood risk in Cork is at present therefore a by-product of the dam operation. The dams were not constructed for the purpose of flood risk, but by virtue of the storage available they have served to attenuate many of the major flood events of the last 60 years.

The ESB Regulations have been developed based on the hierarchy described above, i.e. ensuring dam safety is prioritised. The regulations have been developed to ensure that the 10,000 year event can safely be passed. This means retaining storage in the upper part of the reservoirs until later in a flood event on the basis that it may be a 10,000 year event. The magnitude of an event cannot be established with certainty beforehand given the uncertainties with rainfall forecasting and therefore a precautionary approach can only be adopted.

ESB's operation of the dams during the 2009 event attenuated the peak flood by circa 30% and therefore significantly reduced downstream flooding. The proposed Flood Relief Scheme aims to further improve the attenuation capacity by developing a revised set of dam operating rules by introducing new elements and tools not previously available, as follows:

- More sophisticated flood forecasting system based upon the most up to date and highest resolution rainfall data to facilitate more informed early decision making.
- Additional gauging and live data feed on downstream tributary flows to allow discharges be managed dynamically around downstream inflows (and tides).
- Downstream defences to increase the rate at which releases can be safely made in advance of a flood, to maximise storage capacity in the dam around the peak of the flood.
- Statutory powers under the Arterial Drainage Act to facilitate these pre-releases and compensate downstream landowners.

Assertion that the Lee Dams could have saved Cork entirely from flooding in the 2009 event, supported by volume balance calculations.

The calculations received are all undertaken on the premise that reservoir levels can be allowed to reach what is described in the submission as ESB's 'Maximum flood water levels', which is not a defined term in the ESB Regulations. The levels quoted in the submission are 300mm below the ESB landownership level at each reservoir.

The premise of the submitted volume balance calculations appears to be that water levels in the reservoirs can and should be allowed to rise to within 300mm of the landownership level for all major flood events like 2009, for the purposes of maximising the storage and minimising the average discharge to circa 250m3/s or lower.

The volume balance analysis of the 2009 event has been undertaken with the benefit of perfect hindsight, i.e. knowing the total volumes that arose and the timescales for same. However, to implement a robust solution on this basis would require perfect foresight which unfortunately is not a possibility in the real world scenario.

Furthermore, the submission ignores the prescribed dam safety discharges contained in the Regulations which are designed and have been developed to ensure that the 10,000 year event can be safely passed. Under the suggested approach, during the 2009 event, levels in both dams would have risen to within 300mm of the ESB landownership level. For between 50% and 70% of the 2 day period during the 2009 event, the suggested proposal would recommend discharges less than required by the Regulations, thus removing attenuation volume needed to ensure dam safety in the worst flood scenario (and indeed lesser floods).

By allowing levels rise so high (on an assumption about the scale of flood that would transpire), dam safety would have been seriously compromised, as the volume of a 2009 type event is less than that of the design 1 in 100 year event and significantly less than the 1 in 1,000 year and 1 in 10,000 event.

Adopting this approach, water levels would be allowed to rise (to limit discharge to 250m^3/s), when there could not be certainty that that event was only for example a 1 in 50 year event and not the 1 in 1,000 year or even the 1 in 10,000 event. If it were the larger flood event, having used the majority of the storage early, insufficient storage and/or discharge capacity would have been available later in the event and therefore the risk of dam overtopping would arise. For this reason, the suggested approach is incompatible with the ESB's dam safety mandate and requirement and therefore cannot form the basis for a robust flood relief scheme required to deliver downstream protection against the 1 in 100 year flood event in parallel with ensuring that the 1 in 10,000 year event can be passed without compromising dam safety.

In addition, the submission assumes that the contribution of the downstream catchment is limited to 100m^3/s. The estimated peak flow on the Shournagh alone during the 2009 event is between 100m^3/s and 130m^3/s. The flow recorded on the Bride was circa 70m^3/s. During the 2009 event, the peak flow on the Shournagh and Bride had passed before the peak discharge from Inniscarra. However, under the submitted proposal, averaging the Inniscarra discharge over the 2 day window would have meant larger discharges earlier, ensuring that the 250m^3/s discharge from the dam would coincide with the natural peak on the Shournagh/Bride, resulting in the peak in the city occurring shortly after the peak on the Shournagh which would likely have been closer to 400m^3/s rather than 350m^3/s as suggested, and thus would still have caused flooding.

Furthermore, the 1 in 100 year flow on the Shournagh is estimated at 180m^3/s and on the Bride at circa 80m^3/s. Allowing for joint probability, the contribution of the downstream catchment during the design event (which is larger than the 2009 event) would likely be closer to 200m^3/s, meaning that discharges from the dam would need to be limited to 150m^3/s to achieve a maximum flow of circa 350m^3/s at Waterworks Weir. The analysis in the submission confirms that raising of the dams would be required for such a scenario for the 2009 event. Considering that the 1 in 100 year design event has a greater volume than the 2009 event, dam raising would certainly be required to sufficiently reduce fluvial flood risk downstream.

Assertion that flood walls are not required to save Cork from a reoccurrence of a 2009 event, and inference that walls are not required to protect against the design 100 year event.

It has been asserted that flood walls are not required to defend the city against a reoccurrence of the 2009 event. There are a number of difficulties with this statement as follows:

- The 2009 event was of smaller magnitude than the design event, so protecting only for this event would not achieve the required standard of protection. Considering a scheme solely to protect against a reoccurrence of a singular event of smaller magnitude is not correct or appropriate, and in fact could be misleading to the public. It is not a proxy for the design event.
- Notwithstanding the above, the analysis undertaken by OPW and its consultants confirms that defences are required for events similar to the 2009 event and up to and including the design event.

- The required defences are not high and include an appropriate mix of embankments, walls and flood gates suitably incorporated into the city's public realm space.

Assertion that the proposed scheme is not based on comparative simulation of the operation of the Lee reservoirs under different release rules and that the potential of precisely managing large flows through the use of the large sluice gates has been ignored.

Refer to the Lower Lee FRS Hydrology Report and Appendices which are available on the project website. The proposed scheme has optimised the use of the dams by developing revised rules for dam discharges in the lead up to and during major flood events. It addresses in detail the human agency aspect of reservoir control as does Chapter 6 of the Lower Lee FRS Options Report.

10 Conclusion

This report has assessed the options for providing additional upstream flood storage by raising one or both of the existing ESB dams. It has been prepared in response to submissions received through the statutory exhibition process for the Lower Lee (Cork City) Drainage Scheme (flood relief scheme).

The report builds on the assessment of ancillary storage potential on the Lee tributaries carried out as part of the scheme options report. That assessment found that even with the implementation of flood forecasting, revised operational rules and downstream washlands, the flood storage available at the reservoirs would need to be doubled to eliminate the need for fluvial defences in Cork.

The main constraints within which a dam raising solution must work are outlined in Section 4.2. The main issues with the solutions proposed by others is that they do not appropriately take account of dam safety rules, and inadequately address the residual risks associated with events greater than the 1 in 100 year return period. Dam safety must be prioritised and it must be ensured that events up to the 10,000 year event can be safely passed at all times. The magnitude of a developing flood event cannot be established with enough certainty beforehand to warrant an approach that completely fills the reservoirs during the 100 year event. Therefore it is more appropriate to adopt a precautionary approach. The approach in the ESB Regulations retains storage in the upper part of the reservoirs until later in a flood event on the basis that it may become a 10,000 year event. This is particularly important at Carrigadrohid, where the maximum discharge capacity is significantly less than the 1 in 10,000 year design peak inflow.

The Lower Lee FRS (as exhibited) proposes optimised rules working within these real-world constraints, and any option for raising the dams would need to do likewise.

In order to allow the reservoirs to fully mitigate the existing fluvial flood risk in Cork City, additional storage would be required. A number of options to achieve this have been developed in this report, all of which may be technically viable.

However, all of the options developed have significant shortcomings compared with the exhibited scheme:

- There would be significant alterations to the natural regime of the Gearagh Special Protection Area. Dam-raising schemes may be unlikely to gain statutory consent when alternatives exist which do not impact on Natura 2000 sites.
- A minimum of 80 residential properties would need to be purchased and residents displaced due to the increased reservoir area. This could critically damage communities such as Toonsbridge, which is situated relatively close to the existing reservoir levels
- A minimum of 8km of existing roads and bridges would need to be raised/relocated. Several bridges would need to be raised/reconstructed.

- Purchase of a minimum of 5km^2 of substantially productive land would be required. This land would be incorporated into the "live" reservoir area and as such would be permanently sterilised
- Only a relatively modest proportion of the proposed direct defences would be reduced/eliminated if a dam-raising scheme were to be advanced. Defences would still be required in the washlands area and independent measures to protect against tidal flooding would still be required.
- All options developed in this report fall below a benefit cost ratio of 1 when subjected to sensitivity testing. As such the business case for such options is significantly weaker than the exhibited scheme.

Appendix A

Typical Cross Sections

A1 Carrigadrohid Typical Sections

Figure 40: Carrigadrohid Intake Block Section

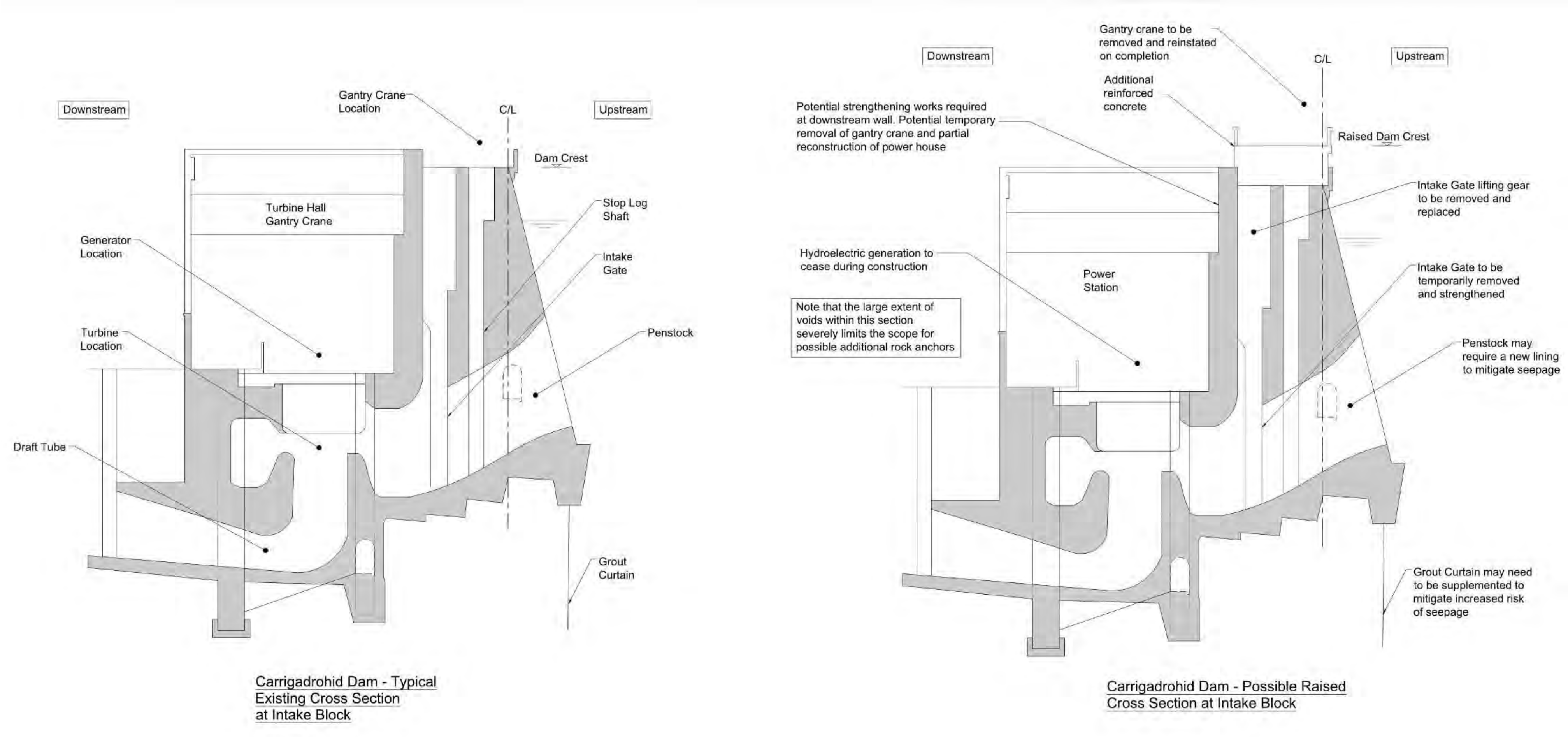


Figure 41: Carrigadrohid Deep Sluice Block Section

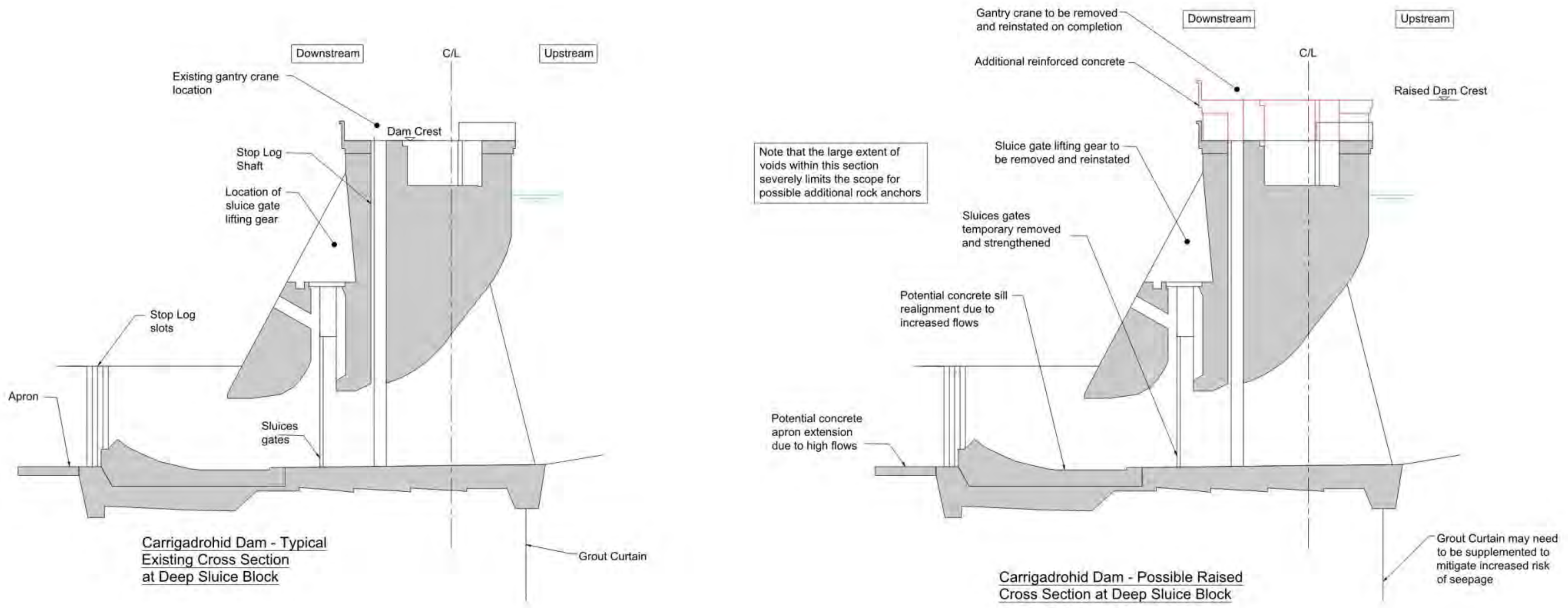


Figure 42: Carrigadrohid Wing Block Section

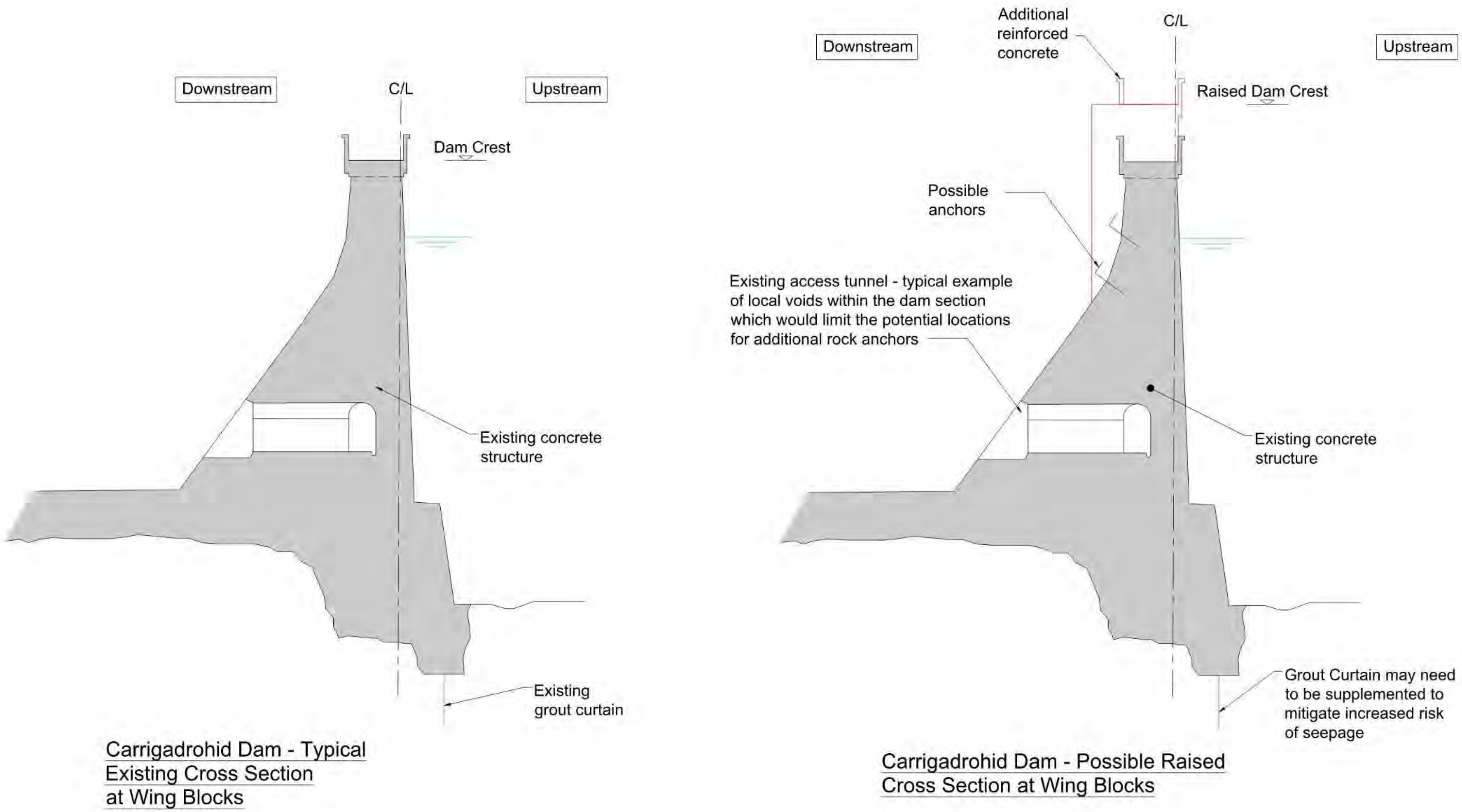
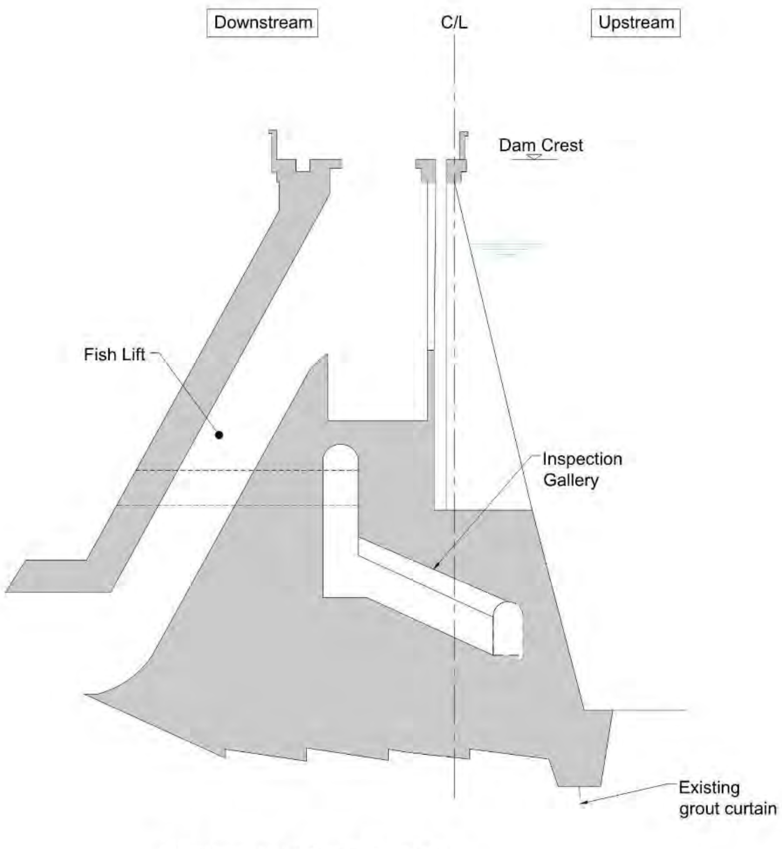
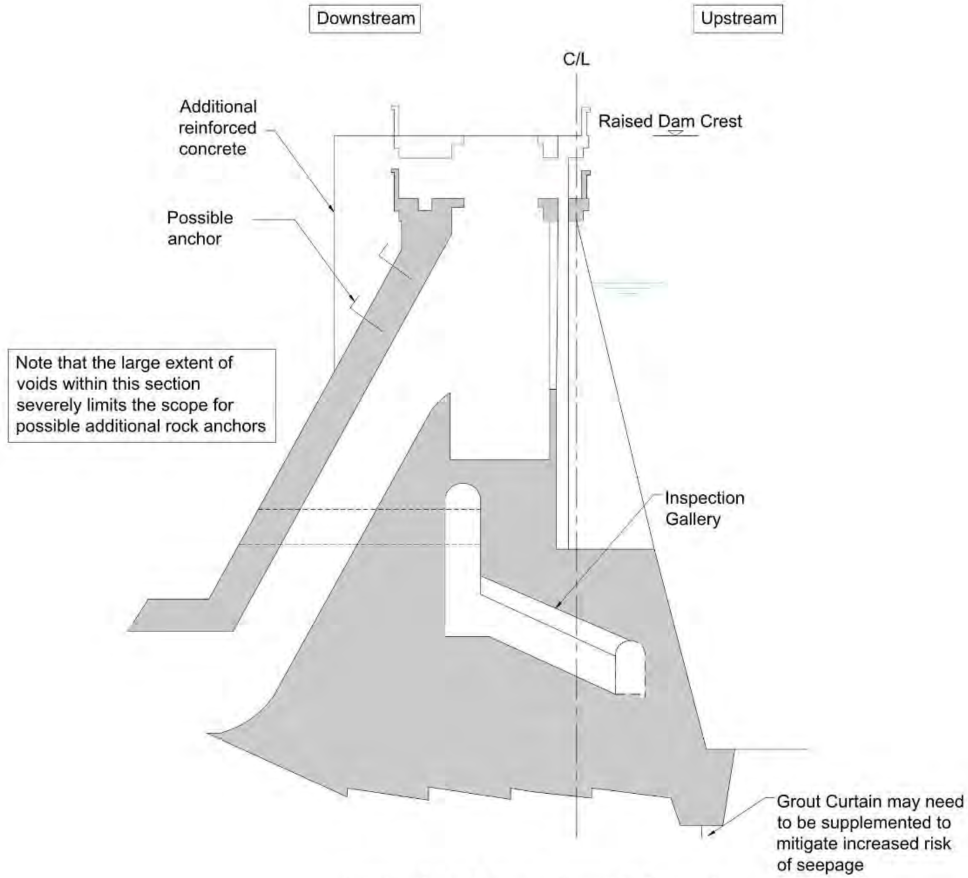


Figure 43: Carrigadrohid Fish Pass Block Section



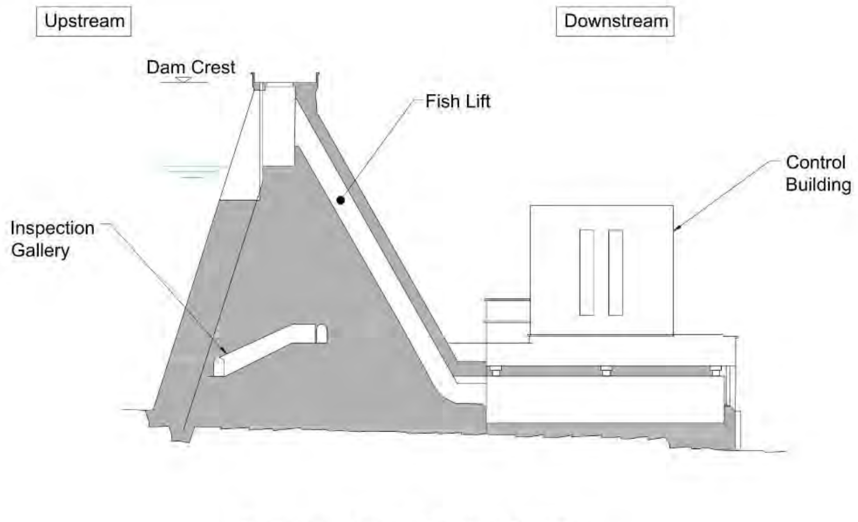
Carrigadrohid Dam - Typical Existing Cross Section at Fish Pass



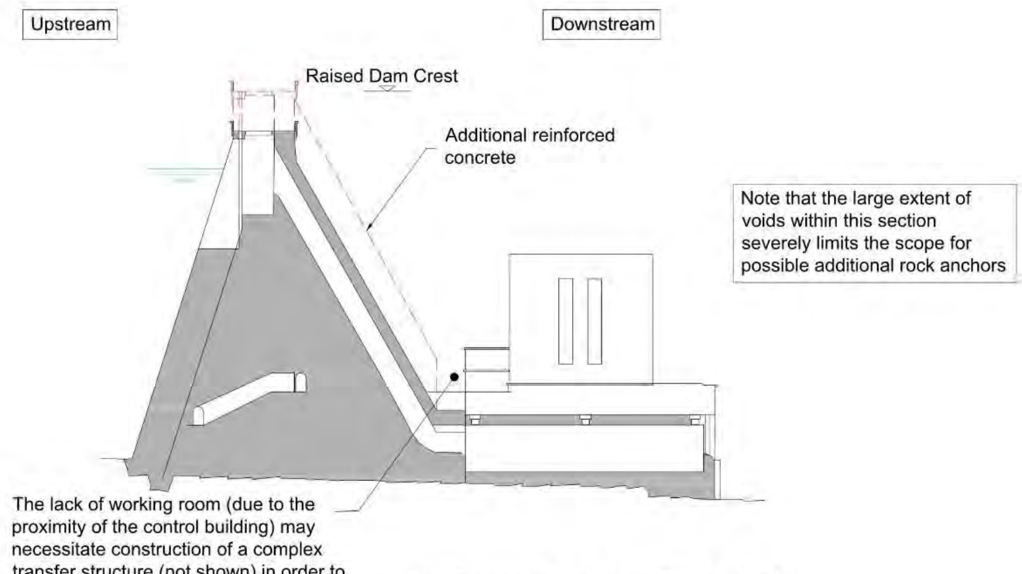
Carrigadrohid Dam - Possible Raised Cross Section at Fish Pass Block

A2 Inniscarra Typical Sections

Figure 44: Inniscarra Fish Pass Block Section



Inniscarra Dam - Typical Existing Cross Section at Fish Pass Block



Inniscarra Dam - Possible Raised Cross Section at Fish Pass Block

Figure 45: Inniscarra Intake Block Section

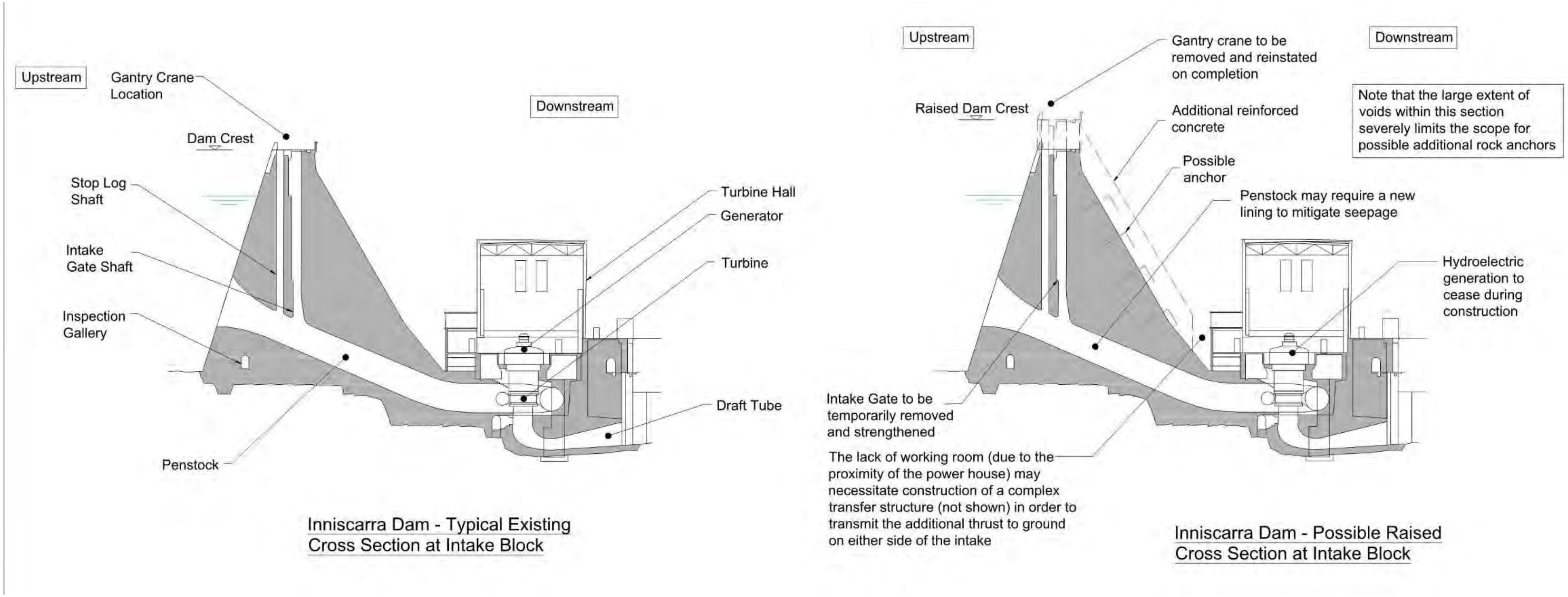


Figure 46: Inniscarra Spillway Block Section

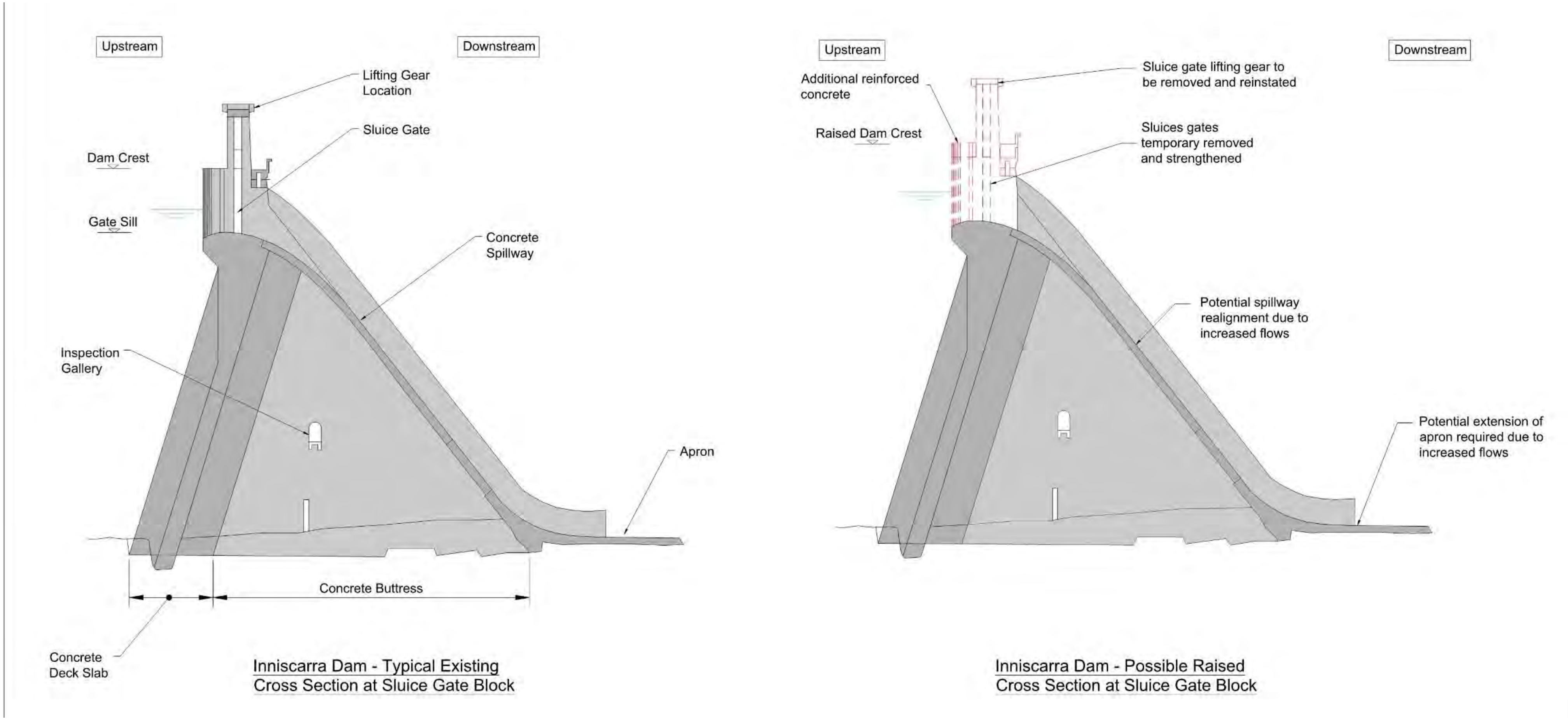
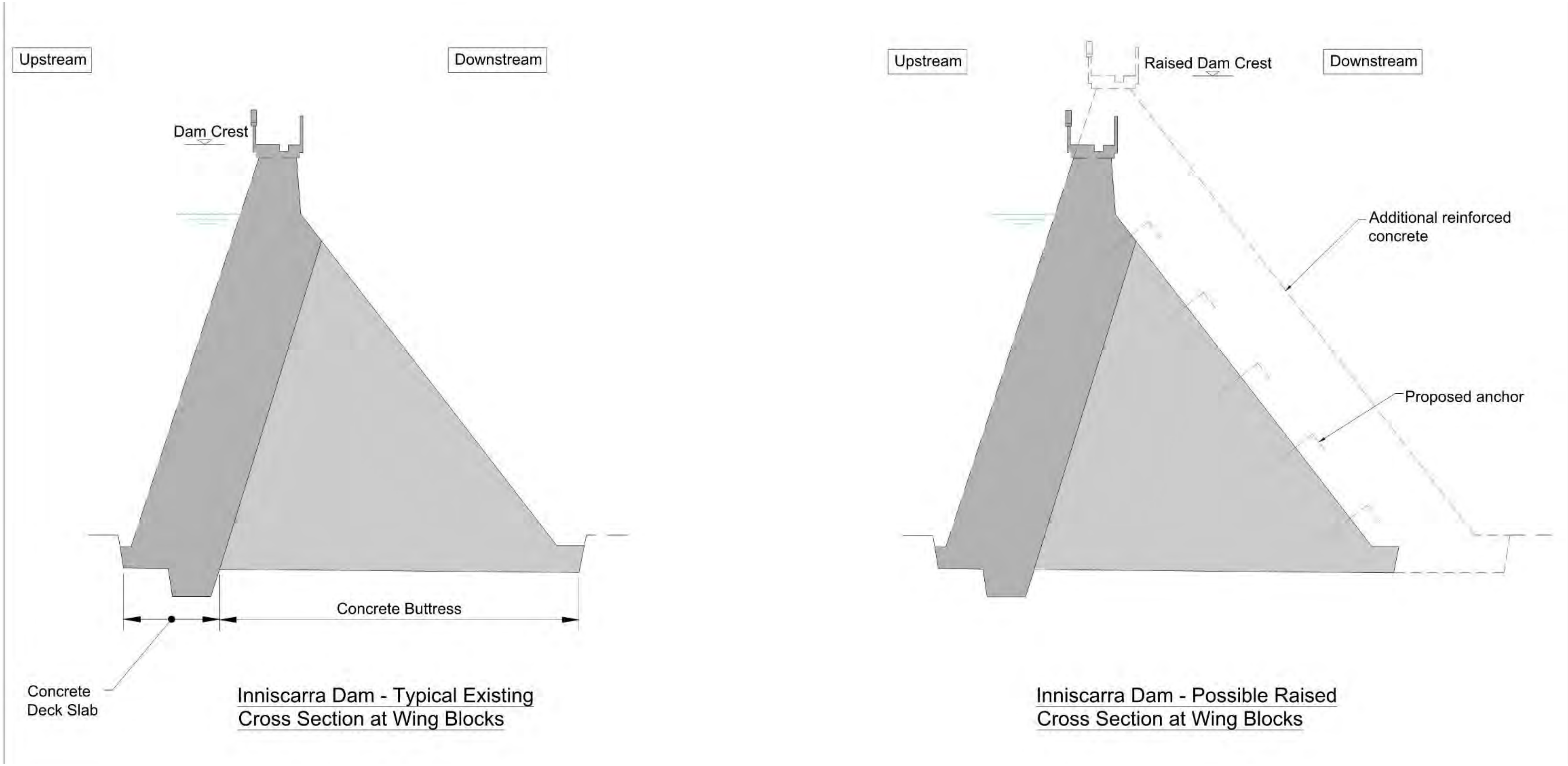


Figure 47: Inniscarra Wing Block Section



Appendix B

Preliminary Construction Cost Estimates

B1.1 Carrigadrohid dam

Table 23: Carrigadrohid 1.5m Raising Base Cost Buildup

Works	Unit	Quantities	Unit prices(€)	Cost(€)
Remove crest concrete/clearance	m^3	300	200	€60,000
Removal, refurbishment and reinstatement of gantry cranes	item	2	50000	€100,000
Remedial works to deep sluice gates and intake gate	item	4	50000	€200,000
Preparation of surfaces to receive concrete	m^2	5070	20	€101,400
New Concrete on dam wall	m^3	1400	400	€560,000
Reinforcement steel dam body	tn	112	4000	€448,000
Dam's Formwork	m^2	1000	200	€200,000
Concrete C25/30 Spillway	m^3	300	400	€120,000
Spillways Formwork	m^2	500	200	€100,000
Reinforcement steel spillway	tn	45	4000	€180,000
Road Ashpalt	m^2	120	100	€12,000
Rock excavation	m^3	200	60	€12,000
Additional downstream scour protection	sum			€100,000
Grout curtain				€100,000
Base cost				€2,293,400
Add unmeasured items @ 30%				€688,020.00
Add risk items				€1,175,000
Subtotal				**€4,156,420.00**
Add preliminaries @ 17.5%				€727,373.50
Add temporary works @ 20%				€831,284.00
Base Construction Cost Total				**€5,715,077.50**
Contingency/ Optimism Bias				€2,286,031.00
Construction Cost Subtotal				**€8,001,108.50**

Table 24: Carrigadrohid 2.5m Raising Base Cost Buildup

Works	**Unit**	**Quantities**	**Unit prices(€)**	**Cost(€)**
Remove crest concrete/clearance	m^3	300	200	€60,000
Removal, refurbishment and reinstatement of 2no gantry cranes	item	2	50000	€100,000
Remedial works to deep sluice gates and intake gates	item	4	50000	€200,000
Preparation of surfaces to receive concrete	m^2	5070	20	€101,400
New Concrete on dam wall	m^3	2150	400	€860,000
Reinforcement steel dam body	tn	215	4000	€860,000
Dam's Formwork	m^2	1200	200	€240,000
Concrete C25/30 Spillway	m^3	520	400	€208,000
Spillways Formwork	m^2	580	200	€116,000
Reinforcement steel spillway	tn	80	4000	€320,000
Road Ashpalt	m^2	200	100	€20,000
Rock excavation	m^3	200	60	€12,000
Additional downstream scour protection	sum			€100,000
Grout curtain				€100,000
Base cost				€3,297,400
Add unmeasured items @ 30%				€989,220.00
Add risk items				€1,175,000
Subtotal				**€5,461,620.00**
Add preliminaries @ 17.5%				€955,783.50
Add temporary works @ 20%				€1,092,324.00
Base Construction Cost Total				**€7,509,727.50**
Contingency/ Optimism Bias				€3,003,891.00
Construction Cost Subtotal				**€10,513,618.50**

Table 25: Carrigadrohid 3.75m Raising Base Cost Buildup

Works	Unit	Quantities	Unit prices(€)	Cost(€)
Remove crest concrete/clearance	m^3	300	200	€60,000
Removal, refurbishment and reinstatement of 2no gantry cranes	item	2	50000	€100,000
Remedial works to deep sluice gates and intake gates	item	4	50000	€200,000
Preparation of surfaces to receive concrete	m^2	5070	20	€101,400
New Concrete on dam wall	m^3	3310	400	€1,324,000
Reinforcement steel dam body	tn	413	4000	€1,652,000
Dam's Formwork	m^2	1400	200	€280,000
Concrete C25/30 Spillway	m^3	900	400	€360,000
Spillways Formwork	m^2	660	200	€132,000
Reinforcement steel spillway	tn	125	4000	€500,000
Road Ashpalt	m^2	200	100	€20,000
Rock excavation	m^3	200	60	€12,000
Additional downstream scour protection	sum			€100,000
Grout curtain	€100,000			€100,000
Base cost				€4,941,400
Add unmeasured items @ 30%				€1,482,420.00
Add risk items				€1,175,000
Subtotal				**€7,598,820.00**
Add preliminaries @ 17.5%				€1,329,793.50
Add temporary works @ 20%				€1,519,764.00
Base Construction Cost Total				**€10,448,377.50**
Contingency/ Optimism Bias				€4,179,351.00
Construction Cost Subtotal				**€14,627,728.50**

B1.2 Inniscarra Dam

Table 26: Inniscarra 1.5m Raising Construction Cost Buildup

Works	Unit	Quantities	Unit prices(€)	Cost(€)
Remove crest concrete/clearance	m^3	300	200	€60,000.00
Removal, refurbishment and reinstatement of gantry crane	item	1	50000	€50,000.00
Crest gates (remove and replacement)	item	3	400000	€1,200,000.00
Remedial works to intake gates	item	3	50000	€150,000.00
Preparation of surfaces to receive concrete	m^2	7950	20	€159,000
Concrete C25/30	m^3	6500	400	€2,600,000.00
Reinforcement steel	tn	650	4000	€2,600,000.00
Dam's Formwork	m^2	2600	200	€520,000.00
Road Ashpalt	m^2	110	100	€11,000.00
Rock excavation	m^3	3200	60	€192,000.00
Additional downstream scour protection	sum			€100,000.00
Grout curtain				€100,000.00
Subtotal				€7,742,000.00
Add unmeasured items @ 30%				€2,322,600.00
Add risk items				€1,375,000
Subtotal				**€11,439,600.00**
Add preliminaries @ 17.5%				€2,001,930.00
Add temporary works @ 20%				€2,287,920.00
Base Construction Cost Total				**€15,729,450.00**
Contingency/ Optimism Bias				€6,291,780.00
Construction Cost Subtotal				**€22,021,230.00**

Table 27: Inniscarra 2.5m Raising Construction Cost Buildup

Works	Unit	Quantities	Unit prices(€)	Cost(€)
Remove crest concrete/clearance	m3	300	200	€60,000.00
Removal, refurbishment and reinstatement of gantry crane	item	1	50000	€50,000.00
Crest gates (remove and replacement)	item	3	400000	€1,200,000.00
Remedial works to intake gates	item	3	50000	€150,000.00
Preparation of surfaces to receive concrete	m^2	7950	20	€159,000.00
Concrete C25/30	m^3	8700	400	€3,480,000.00
Reinforcement steel	tn	870	4000	€3,480,000.00
Dam's Formwork	m^2	2800	200	€560,000.00
Road Ashpalt	m^2	110	100	€11,000.00
Rock excavation	m^3	3200	60	€192,000.00
Additional downstream scour protection	sum			€100,000.00
Grout curtain				€100,000.00
Subtotal				€9,542,000.00
Add unmeasured items @ 30%				€2,862,600.00
Add risk items				€1,375,000
Subtotal				**€13,779,600.00**
Add preliminaries @ 17.5%				€2,411,430.00
Add temporary works @ 20%				€2,755,920.00
Base Construction Cost Total				**€18,946,950.00**
Contingency/ Optimism Bias				€7,578,780.00
Construction Cost Subtotal				**€26,525,730.00**

B1.3 Risk Items

As outlined in Section 5.4, there are a number of risk items which were highlighted during the course of this study. Since it cannot be determined with confidence at this level of study whether these items would be required, it is proposed to include these in the cost on the basis of a risk analysis. Table 28 presents the analysis.

Table 28: Carrigadrohid Construction Cost Risk Items Table

Risk Description	Estimated Probability of Risk Item Being Required	Estimated Cost (€)	Cost to be Allowed in Buildup (€)
Local Flood Protection to Control Building	50%	€50,000	€25,000
Lining Intake Penstock	50%	€1,000,000	€500,000
Additional Rock Anchors	75%	€200,000	€150,000
Reconstruction of Power House & control building	50%	€1,000,000	€500,000
		Total	€1,175,000

Table 29: Inniscarra Construction Cost Risk Items Table

Risk Description	Probability of Occurrence	Estimated Cost (€)	Cost to be Allowed in Buildup (€)
Local Flood Protection to Control Building	50%	€50,000	€25,000
Lining 2no. Penstocks	50%	€2,000,000	€1,000,000
New rock anchors	75%	€200,000	€150,000
Reconstruction of Power House & control building	20%	€1,000,000	€200,000
		Total	€1,375,000

B1.4 Cost of Residual Tidal Defences

The table below shows a buildup of the cost estimate for tidal-only defences in Cork city centre.

Table 30: Tidal-Only Defences Cost Buildup

Description	Cost (€)
Measured Items	30,671,000
Prelims 17.5%	5,367,454
Unmeasured Items 20%	6,134,233
Subtotal	**42,172,853**
Archaeology & Environmental	4,217,285
Baseline Construction Cost Total	**46,390,139**
Contingency/ Optimism Bias	9,278,028

Description	Cost (€)
Construction Cost Subtotal	**55,668,166**
Fees and Supervision	5,010,135
Construction + Fees Subtotal	60,678,301
Land Acquisition	5,566,817
Art	9,143
Site Investigation & Surveys	171,429
Capital Cost Total	**66,425,689**
NPV Maintenance	11,957,522
Project Cost Total	**78,383,211**

B1.5 Cost of Residual Washlands Defences

The table below shows a buildup of the cost estimate for the residual washlands defences.

Table 31: (Residual) Fluvial Only Defences Cost Buildup

Description	Cost (€)
Measured Items	€4,905,392
Prelims 17.5%	858,444
Unmeasured Items 20%	981,078
Subtotal	6,744,914
Archaeology & Environmental	674,491
Baseline Construction Cost Total	7,419,405
Contingency/ Optimism Bias	1,483,881
Construction Cost Subtotal	8,903,286
Fees and Supervision	801,296
Construction + Fees Subtotal	**9,704,582**
Land Acquisition	890,329
Art	9,143
Site Investigation & Surveys	171,429
Capital Cost Total	10,775,482
NPV Maintenance	1,912,426
Project Cost Total	12,687,908

Appendix C

Reservoir Impact Cost Estimates

C1 Reservoir Impact Costs

The following tables summarize the estimated costs for the different components associated with the main physical impacts associated with dam/reservoir raising.

C1.1 Carrigadrohid Reservoir

C1.1.1 Land Purchase Costs

According to CSO data, the median purchase price of permanent grassland in the south-west region in 2015 was €17,500 per hectare. As agriculture is the predominant land use type in this area, it was assumed that this rate would be representative as an average land purchase rate. An allowance of 5% of the cost was added to allow for legal fees.

Table 32: Estimated Land Purchase Cost - Carrigadrohid

Level Description	Area above existing ESB Landownership Line (km^2)	Estimated Land Purchase Cost (above existing ESB landownership line)	Legal Fees (€)	Total (€)
Current dam crest	1.34	€2,345,000	€117,250	€2,462,250
Current crest + 1.5m	4.42	€7,735,000	€386,750	€8,121,750
Current crest + 2.5m	6.44	€11,270,000	€563,500	€11,833,500
Current crest + 3.75m	8.66	€15,155,000	€757,750	€15,912,750

C1.1.2 Property Impact Costs

According to CSO data, the average purchase price for second hand houses in County Cork in the first three quarters of 2016 was €237,911. Assuming that this costs includes an element of land purchase (which is separately itemised above), it appears reasonably conservative to allow €200,000 for the purchase and demolition of each affected property. An allowance of 5% of the cost was added to allow for legal fees.

Table 33: Carrigadrohid – Cost of Property Impact

Scenario	Buildings within reservoir area	Purchase Price (€)	Legal Fees (€)	Total (€)
Current crest	5	€1m	€50,000	€1.05m

Scenario	Buildings within reservoir area	Purchase Price (€)	Legal Fees (€)	Total (€)
Current crest + 1.5m	62	€12.4m	€620,000	€13.02m
Current crest + 2.5m	84	€16.8m	€840,000	€17.64m
Current crest +3.75m	117	€23.4m	€1,170,000	€24.57m

C1.1.3 Road Impact Costs

Based on typical rates of €200/m^2 for road construction and €20/m^3 for imported fill. Add-ons consisted of preliminaries at 17.5%, temporary works at 5% and contingency/optimism bias at 20%.

Table 34: Carrigadrohid – Cost of Infrastructure Impact - Roads

Scenario	Roads to be diverted/elevated			Subtotal Cost	Construction Cost Total (including add-ons)
	National (km)	Regional (km)	Local (km)		
Current crest	0.39	2.74	N/A	€8,609,353	€12,655,749
Current crest + 1.5m	2.75	6.21	N/A	€24,145,025	€35,493,187
Current crest + 2.5m	3.95	7.41	N/A	€35,372,765	€51,997,965
Current crest +3.75m	4.91	8.68	N/A	€54,153,793	€79,606,076

C1.1.4 Bridge Impact Costs

The cost of bridge reconstruction has been estimated at €2000 per m^2 based on past experience of such projects. Add-ons consisted of preliminaries at 17.5%, temporary works at 5% and contingency/optimism bias at 20%.

Table 35: Carrigadrohid – Cost of Infrastructure Impact - Bridges

Scenario	Bridge Inundated	Plan Dimensions (length x width)	Subtotal Reconstruction Cost(€)	Reconstruction Cost Total (including add-ons)
Current crest	None	N/A	N/A	N/A
Current crest + 1.5m	Coolcower Bridge N22	115m x 8m	€1,840,000	€2,704,800

Scenario	Bridge Inundated	Plan Dimensions (length x width)	Subtotal Reconstruction Cost(€)	Reconstruction Cost Total (including add-ons)
	Toons Bridge R584	30m x 8m	€480,000	€705,600
Current crest + 2.5m	Coolcower Bridge N22	115m x 8m	€1,840,000	€2,704,800
	Toons Bridge R584	30m x 8m	€480,000	€705,600

C1.1.5 Compensation Costs

The compensation costs for property between the peak 100 year flood level and dam crest has been estimated on the following basis:

- A single payment made at the time of construction
- The amount of flood damage was calculated using methods contained in the Multicoloured Manual[25].
- Payment for agricultural losses made on the assumption that a single flood event would occur within the economic life of the scheme (50 years). Agricultural damage was taken as being equal to the "Adjusted Net Margin" (refer to Table 9.5 of the Multicoloured Manual). Converting to Euro and 2017 prices, damage to agricultural land would be compensated at a rate of approximately €206/ha.
- Residential damage was calculated using the Weighted Annual Average Damage method contained in the Multicoloured Manual. Payment for residential damage made on the assumption of a 100 year threshold of flooding for each property. The net present value of damage over a 50 year period was taken as being equal to the compensation to be paid. Converting to Euro and 2017 prices, damage to residential property would be compensated at a rate of approximately €1,632/property.

Table 36: Assessment of Compensation Costs – Carrigadrohid Reservoir

Band (relative to Existing Dam Crest Level)	Quantities		Damage for Single Flood Event	
	Agricultural Land (ha)	Residential Property (no.)	Agricultural Land (amount)	Residential Property (amount)
0m to +1.5m	308	57	€ 63,448.00	€ 93,049
+1.5m to +2.5m	202	22	€ 41,612.00	€ 35,914
+2.5m to +3.75m	222	33	€ 45,732.00	€ 53,871

[25] Flood Hazard Research Centre (2014), *Flood and Coastal Erosion Risk Management Handbook for Economic Appraisal*

C1.2 Inniscarra Reservoir

C1.2.1 Land Purchase Costs

Table 37: Estimated Land Purchase Cost - Inniscarra

Level Description	Area above existing ESB Landownership Line (km^2)	Estimated Land Purchase Cost (above existing ESB landownership line)	Legal Fees (€)	Total (€)
Current dam crest	0.27	€472,500	€23,625	€496,125
Current crest + 1.5m	0.79	€1,382,500	€69,125	€1,451,625
Current crest + 2.5m	1.08	€1,890,000	€94,500	€1,984,500

C1.2.2 Property Impact Costs

Table 38: Inniscarra – Cost of Property Impact

Scenario	Crest Level	Buildings within reservoir area	Total Cost of Purchase (€)	Legal Fees (€)	Total (€)
Current crest	49.32mOD	4	€0.8m	€40,000	€840,000
Current crest + 1.5m	50.82mOD	23	€4.6m	€230,000	€4,830,000
Current crest + 2.5m	51.82mOD	31	€6.2m	€310,000	€6,510,000

C1.2.3 Road Impact Costs

Based on typical rates of €200/m^2 for road construction and €20/m^3 for imported fill. Add-ons consisted of preliminaries at 17.5%, temporary works at 5% and contingency/optimism bias at 20%.

Table 29: Inniscarra – Cost of Infrastructure Impact - Roads

Scenario	Roads to be diverted/elevated			Subtotal Cost	Construction Cost Total (including add-ons)
	National (km)	Regional (km)	Local (km)		
Current crest	0.00	0.7	N/A	€1,861,541	€2,736,465
Current crest + 1.5m	0.00	2.35	N/A	€6,929,078	€10,185,745

Scenario	Roads to be diverted/elevated			Subtotal Cost	Construction Cost Total (including add-ons)
	National (km)	Regional (km)	Local (km)		
Current crest + 2.5m	0.00	2.80	N/A	€10,127,443	€14,887,341

C1.2.4 Bridge Impact Costs

The cost of bridge reconstruction has been estimated at €2000 per m^2 based on past experience of such projects. Add-ons consisted of preliminaries at 17.5%, temporary works at 5% and contingency/optimism bias at 20%.

Table 29: Inniscarra – Cost of Infrastructure Impact - Bridges

Scenario	Bridge Inundated	Plan Dimensions (length x width)	Subtotal Reconstruction Cost(€)	Reconstruction Cost Total (including add-ons)
Current crest	None	N/A	N/A	N/A
Current crest + 1.5m	Rooves Bridge R619	280m x 8m	€4,480,000	€6,585,600
	Dripsey bridge R618	30m x 8m	€480,000	€705,600
Current crest + 2.5m	Rooves Bridge R619	280m x 8m	€4,480,000	€6,585,600
	Dripsey bridge R618	30m x 8m	€480,000	€705,600

C1.2.5 Compensation Costs

The compensation costs for property between the peak 100 year flood level and dam crest has been estimated on the following basis:

- A single payment made at the time of construction
- The amount of flood damage was calculated using methods contained in the Multicoloured Manual[26].
- Payment for agricultural losses made on the assumption that a single flood event would occur within the economic life of the scheme (50 years). Agricultural damage was taken as being equal to the “Adjusted Net Margin” (refer to Table 9.5 of the Multicoloured Manual). Converting to Euro and 2017 prices, damage to agricultural land would be compensated at a rate of approximately €206/ha.
- Residential damage was calculated using the Weighted Annual Average Damage method contained in the Multicoloured Manual.

[26] Flood Hazard Research Centre (2014), *Flood and Coastal Erosion Risk Management Handbook for Economic Appraisal*

Payment for residential damage made on the assumption of a 100 year threshold of flooding for each property. The net present value of damage over a 50 year period was taken as being equal to the compensation to be paid. Converting to Euro and 2017 prices, damage to residential property would be compensated at a rate of approximately €1,632/property.

Table 39: Assessment of Compensation Costs – Inniscarra Reservoir

Band (relative to Existing Dam Crest Level)	**Quantities**		**Damage for Single Flood Event**	
	Agricultural Land (ha)	**Residential Property (no.)**	**Agricultural Land (amount)**	**Residential Property (amount)**
0m to +1.5m	52	19	€ 10,712	€ 31,016
+1.5m to +2.5m	29	8	€ 5,974	€ 13,060

C1.3 Summary

Table 40 and Table 41 summarise the assessment of reservoir impact costs.

Table 40: Reservoir Impact Cost Summary – To be included in Bottom Up Buildup

Category	Option B (raise Carrigadrohid by 2.5m)	Option C (Raise Carrigadrohid by 3.75m)	Option G (raise Carrigadrohid by 1.5m and Inniscarra by 2.5m)	Option H (raise Carrigadrohid by 2.5m and Inniscarra by 1.5m)	Option I (Raise Carrigadrohid and Inniscarra by 2.5m)	Option K (Raise Carrigadrohid by 2.5m, plus new reservoir at Dromcarra)
Land Purchase	€ 8,121,750	€ 11,833,500	€ 3,913,875	€ 8,617,875	€ 9,573,375	€ 8,121,750
Land Compensation	€ 41,612	€ 45,732	€ 69,422	€ 52,324	€ 47,586	€ 41,612
Property Purchase	€ 13,020,000	€ 17,640,000	€ 5,880,000	€ 13,860,000	€ 17,850,000	€ 13,020,000
Property Compensation	€ 35,904	€ 53,856	€ 106,080	€ 66,912	€ 48,960	€ 35,904
Roads	€ 38,390,590	€ 56,242,696	€ 24,706,105	€ 41,350,440	€ 49,407,824	€ 38,390,590
Bridges	€ 3,688,800	€ 3,688,800	€ 7,886,400	€ 3,688,800	€ 11,575,200	€ 3,688,800
Total	**€ 63,298,656**	**€ 89,504,584**	**€ 42,561,882**	**€ 67,636,351**	**€ 88,502,945**	**€ 63,298,656**

Table 41: Reservoir Impact Cost Summary – To be added to Top-Down Estimate

Category	Option B (raise Carrigadrohid by 2.5m)	Option C (Raise Carrigadrohid by 3.75m)	Option G (raise Carrigadrohid by 1.5m and Inniscarra by 2.5m)	Option H (raise Carrigadrohid by 2.5m and Inniscarra by 1.5m)	Option I (Raise Carrigadrohid and Inniscarra by 2.5m)	Option K (Raise Carrigadrohid by 2.5m, plus new reservoir at Dromcarra)
Roads	€ 38,390,590	€ 56,242,696	€ 24,706,105	€ 41,350,440	€ 49,407,824	€ 38,390,590
Bridges	€ 3,688,800	€ 3,688,800	€ 7,886,400	€ 3,688,800	€ 11,575,200	€ 3,688,800
Total	**€ 42,079,390**	**€ 59,931,496**	**€ 32,592,505**	**€ 45,039,240**	**€ 60,983,024**	**€ 42,079,390**

Appendix D

Ecological Assessment

OIFIG na nOIBREACHA POIBLÍ
OFFICE OF PUBLIC WORKS

Lower Lee (Cork City) Drainage Scheme

Ecological Assessment of Options: Dam Raising

November 2017

CONSULTING ENGINEERS
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Introduction

The Gearagh SAC is an area of woodland, river and reservoir in a wide, flat valley of the River Lee. It is noted for its alluvial and wet woodland within an anastomosing channel and is the only such site remaining in Ireland. As the Gearagh represent the only extensive alluvial woodland in Ireland, Britain or west of the Rhine in Europe the site is also designed as a Statutory Nature Reserve. The international importance of the Gearagh is recognised by its designation both as a Ramsar site and a Biogenetic Reserve. The reservoir is also a Wildfowl Sanctuary and designated as a Special Protection Area (SPA).

The Gearagh SAC

The SAC is designated for the following habitats and species listed on the EU Habitats Directive

- Alluvial Woodland (Priority habitat)
- Old Oak Woodland
- Water course of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation
- Rivers with muddy banks with Chenopodion rubric pp and Bidention pp vegetation
- Otter (*Lutra lutra*)

Alluvial Woodland

The River Lee at the Gearagh breaks into a complex network of streams and channels (anantomosing channel) though a series of wooded island. This alluvial woodland qualifies as a priority habitat under Annex I of the EU Habitats Directive. The wooded element of the Gearagh is likely to be post-glacial and frequent flooding served to enhance its character. The area is a unique feature and has a wild character where many fallen trees block the channels so that access by foot and boat is difficult. The woodland of the Gearagh is approximately 40% of that which was present prior to felling and the commencement of the Hydrological Schemes at Carrigadrohid and Inniscarra. In order to maintain alluvial woodland habitat, periodic flooding is essential for the woodland along the river flood plains but not for woodland around springs / seepage areas. A target of the conservation objectives for this habitat is to provide an appropriate hydrological regime necessary for maintenance of alluvial vegetation. See Figure 1.1 for distribution of Alluvial Woodland within the Gearagh SAC.

Old Oak Woodland

North of Toon Bridge an oakwood occurs which supports oak along with silver birch, holly, hazel, ash and Rowan. The ground flora is typical of an oakwood but is relatively species rich. The habitat has not been surveyed in detail but has been mapped as an area of 10.4ha. Figure 1.1 identified Old Oak woodland habitat within the Gearagh SAC.

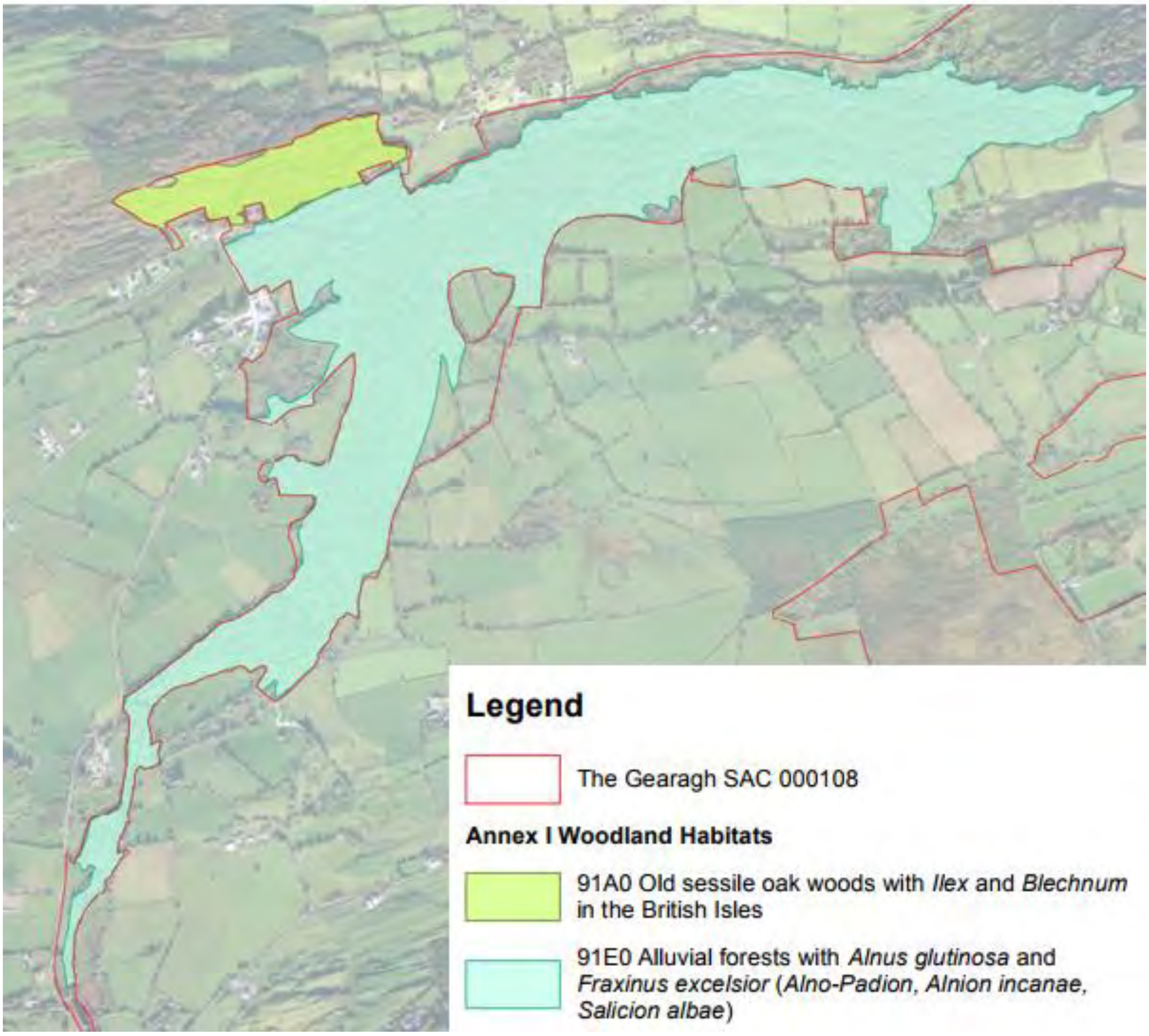


Figure 1.1 The Gearagh SAC Woodland Habitats (NPWS, Conservation Objectives, 2016)

Water course of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation

Floating River Vegetation habitat is a broad habitat covering both upland and lowland rivers and form various subtypes/communities. Within the Gearagh SAC, information is limited and the distribution and sub-type communities are unknown. **Figure 1.2** below identifies the potential distribution of this habitat type at the Gearagh SAC (NPWS 2016) Hydrology is the key ecological drive for this habitat which is generally linked to naturally functioning river systems. It is considered that the influence of the hydroelectric scheme is less so in woodland to the west of the SAC where high conservation value examples of FRV are expected to occur. The habitat type is dependent on a regime more representative of the natural hydrology of the system. River flow is often the most important hydrological attribute for this habitat type, which is required for both plant communities and channel geomorphology, for many sub-types of this habitat high flows are required to maintain the substratum necessary for the characteristic species. Flow variation is particular important with high flow and flood being critical to the hydromorphology. Conservation Targets for this habitat type include maintenance of appropriate hydrological regime necessary to support typical species and vegetation composition of the habitat.

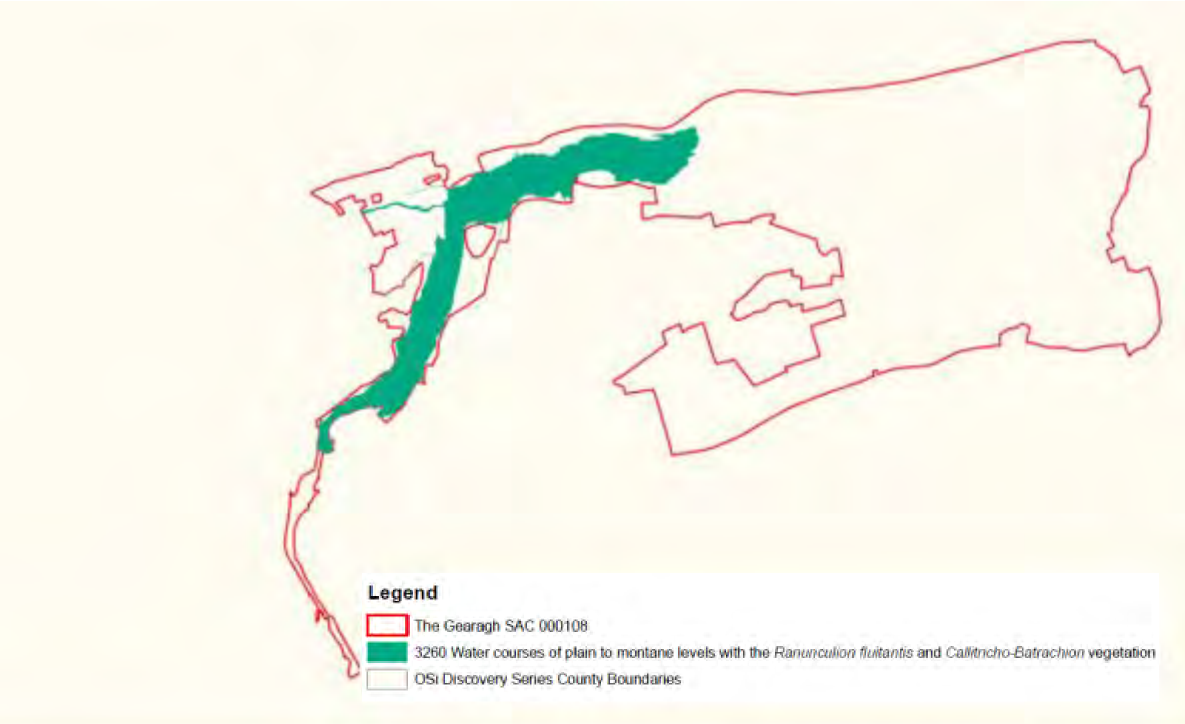


Figure 1.2 Potential distribution of Water courses of plain to montane levels with the Ranunculion fluitantis and CallitrichoBatrachion vegetation (3260) at The Gearagh SAC (NPWS, 2016)

River with muddy banks with Chenopodion rubric pp and Bidention pp vegetation

The Gearagh SAC is the only known Irish example of River with muddy banks with Chenopodion rubric pp and Bidention pp vegetation occurring in the floodplain of a surface river (normally a habitat of Turloughs in Ireland). It is a dynamic habitat found on damp, fine, mineral soils (typically alluvial muds). Typical species are small, short-lived, fast growing annuals that are poor competitors. River with muddy banks with Chenopodion rubric pp and Bidention pp vegetation is flooded for an extended period each year, becoming exposed in summer and this allows the annual, short lived species that typify the habitat to grow, while preventing perennial species from completing their lifecycles. The habitat does not need to dry out every year to survive nor does it require flood duration and timing to be consistent among years. The habitat at this location is known to experience year-round flooding every few years which may prevent the establishment of perennials. The area of flooding and the extent of the mud exposed by the draw-down determine the area of habitat provided. The depth of water level fluctuations (likely to be from 2m up to 6m plus) and average water depth during flooding may be significant factors in limiting the colonisation of the habitat by perennial species. Both the area of mud exposed in summer and the flood depth in other seasons are likely to vary among years at The Gearagh SAC, with the operation of the hydro-electric scheme. The habitat found within this SAC is assumed to be strongly associated with the reservoir and a significantly modified hydrological regime. See **Figure 1.3** for potential location of this habitat with the Gearagh SAC.

A number of conservation targets for this habitat type is related to the management of the Hydroelectric scheme and maintenance of an appropriate hydrological regime necessary to support the typical species and vegetation composition of the habitat.

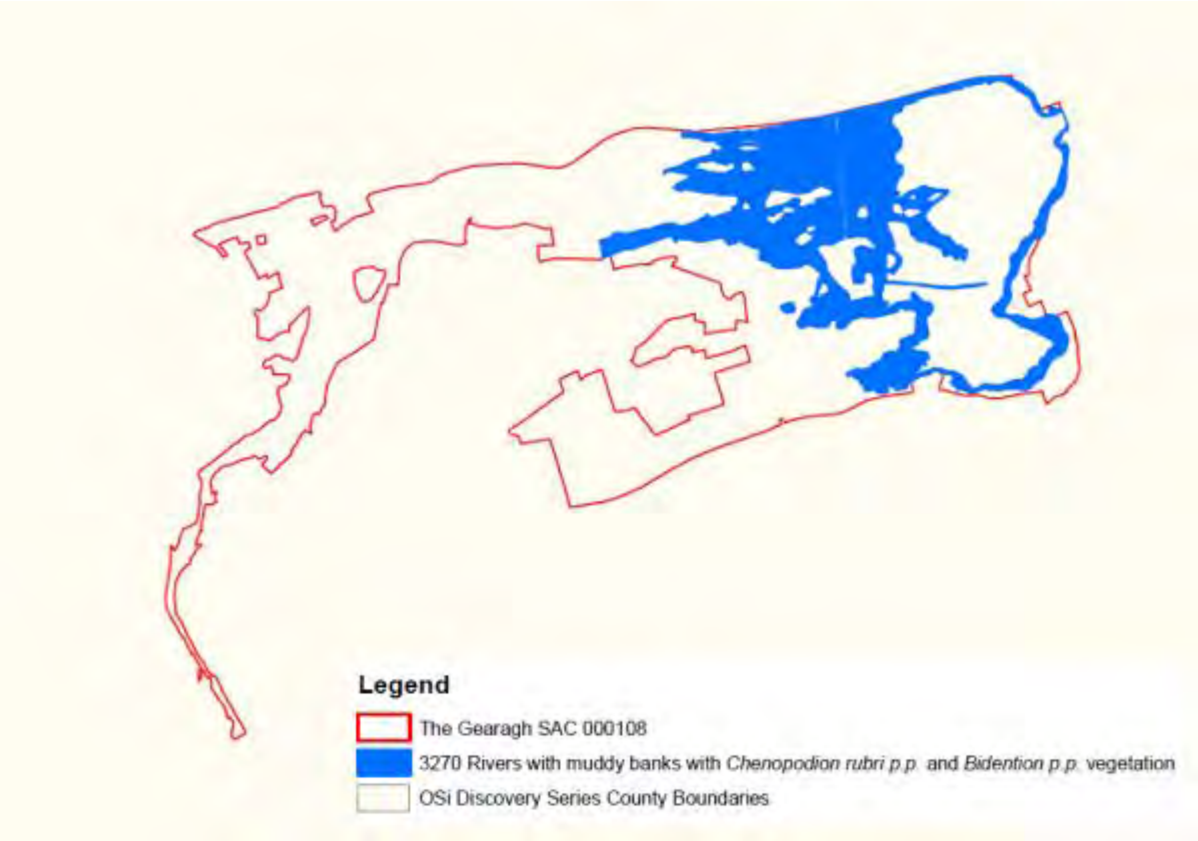


Figure 1.3 Potential distribution of Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation (3270) at The Gearagh SAC

Otter (Lutra lutra)

Otter are protected under Annex II & V of the EU Habitats Directive (92/43/EEC). Article 17 Reports on the status of otters nationally were considered to be in 'Favourable or Good Conservation Status'. Otters are a riparian species with a basic requirement or aquatic prey and refuge from predators. In general, where aquatic prey is abundant and the adjacent habitat offers plenty of cover, healthy otter populations can be expected.

An otter usually maintains numerous couches and holts within its territory among rocks, in caves, excavated tunnels in peat banks, within root systems of mature bank-side trees and man-made structures, such as drainage pipes and rock-armouring. Cubs are born in natal holts. These tend to be especially well hidden, usually far from other otter traffic. Natal holts are difficult to locate and easily overlooked. Above-ground couches are often on islands, or hidden in extensive reed beds, or in dense scrub, brambles or nettles. Holts and couches may be found some distance from freshwater, but most are within the immediate area of riparian vegetation. Natal holts may also be sited some distance from the normal areas of activity. In general, however, otters exploit a narrow strip of habitat at the aquatic – terrestrial interface. In addition to the width of the rivers, lakes and streams, a 10m riparian buffer (both banks) is considered to comprise part of the otter habitat along with the entire area of wet woodland that occurs on the islands where the River Lee main channel breaks into a complex and dynamic network of channels. Otter is considered to be frequent throughout the Gearagh, given the suitability of habitat for otters and its inaccessibility in many parts by humans.

Gearagh SPA

The SPA extends from Annahala bridge westwards to Toon bridge. The principal habitat is a shallow lake or reservoir which is fringed by wet woodland, scrub and grassland that is prone to flooding.

The Gearagh supports part of an important wintering bird population. The area most utilised by birds extends also east of the site, towards Cork city (Carrigadroighid). The site is designated for nationally important populations of the following species

- Wigeon
- Teal
- Mallard
- Coot

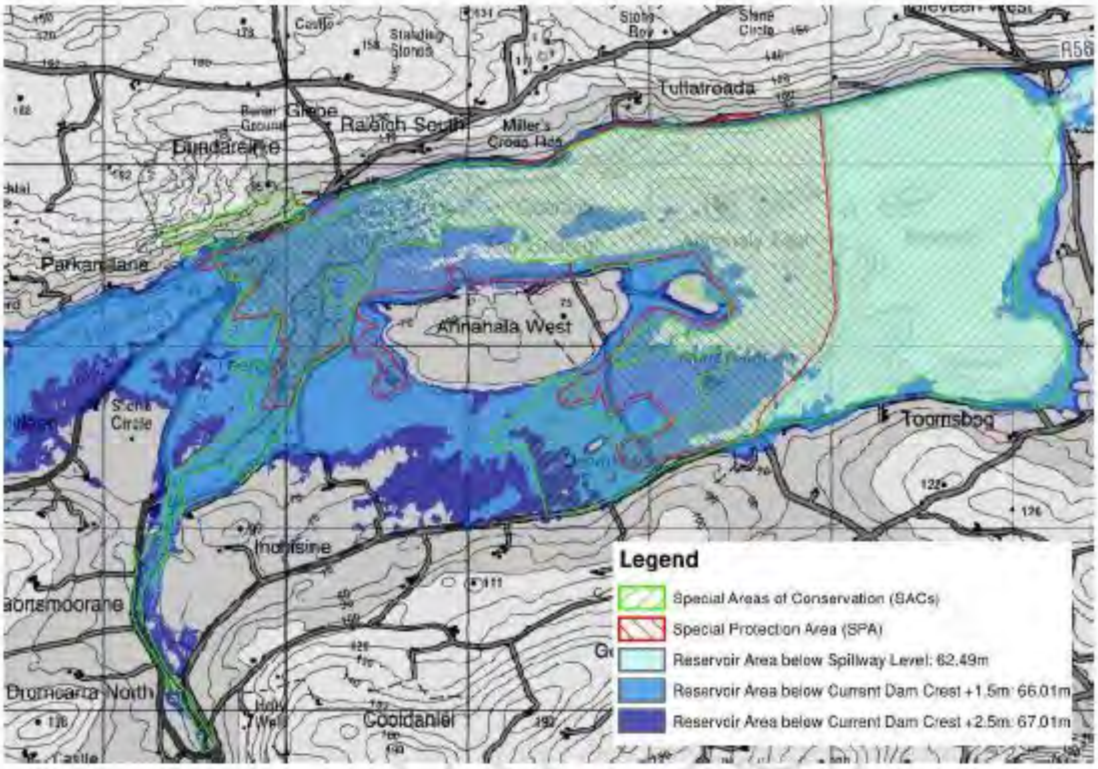
In addition, Whooper Swans, Tufted Duck use the area. Golden Plover utilise the site on occasions while there is a regular flock of Dunlin, a species unusual at inland sites. A late summering flock of Mute Swan is regular. Great Crested Grebe breed in small numbers, while there is a feral flock of Greylag Goose.

Potential impact on the Gearagh SAC and SPA as a result of change to the management of Hydroelectric schemes (dam raising).

The Gearagh SAC

As identified within this report increasing the level of Carrigadrohid would lead to a significant increase in the Surface Area of the reservoir. While inundation is not permenant, it is likely to be transition and occur on a semi-regular basis. All options discussed will result in increased frequency of induration of some the land designated as Natura 2000 sites which were previously not subject to this activity. See Figure 2.2 below.

Figure 22: Existing SPA/SAC at the Gearagh



Alluvial woodland

The majority of existing alluvial woodland designated and mapped by NPWS Conservation Objectives (See Figure 1.1) for the site is currently not under significant influence of the dam at present. This system is a priority designated habitat and is considered unique in Ireland and Great Britain. Any changes to the hydrology of the system has the potential to impact on alluvial woodland throughout most of its range in the Gearagh and would require detailed impact assessment in the form of a Natura Impact Statement. If it cannot be demonstrated that there will be no significant impact on the integrity of Alluvial woodland habitat within the Gearagh SAC, Stage 3 Assessment of Alternatives would be required.

Old Oak Woodland

Old Oak Woodland is present north of Toon Bridge. The area is outside that predicted to be impacted by any of the options outlined in this report. It is therefore determined that there is no likely impact on Old Oak Woodlands as a result of changes to dam raising and subsequent management.

Water course of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation

Floating river vegetation habitat is identified to the west of the SAC and will be potentially directly affected by the proposed works. Floating vegetation is dependant on the natural regime of the river system at the Gearagh and changes to this may result to changes in community structure and distribution. As for Alluvial woodlands a NIS would be required in order to fully assess the potential impacts on this habitat type.

River with muddy banks with Chenopodion rubric pp and Bidention pp vegetation

This habitat type is under the influence of the Hydroelectric scheme, impacts from more frequent flood events over a larger area may have the potential to impact negatively on perrinnial plants species and provide competitive opportunity for this habitat type resulting in an increased range of Rivers with muddy banks with Chenopodion rubric pp and Bidention pp vegetation. Should the ESB management regime not change significantly for dry weather conditions there will be no potential for impact on the habitat during this time and conditions in the Gearagh are therefore not negatively impacted on the habitats success.

Otters (Lutra lutra)

Potential impact on otters is a result of direct impact on resting and breeding habitat. In general, the impact would be very much dependant on the season and duration along with any other environmental factors (for example are other environmental constraints apparent in that particular year / season that would exacerbate the impact on already compromised habitats and species).
It can be considered that the increased floodplains results in a risk to mammal habitat and breeding success. Given that the impact is long term, it is possible that the newly flooded areas would no longer suitable for breeding holts and therefore a significant loss of habitat and range would be consequent. A NIS would be required to fully assess the impact of the project on otter populations.

The Gearagh SPA

Annex I Birds

The site is protected for overwintering birds, nesting bird's area not considered potentially impacted by the proposal. There would be changes to the habitat type and make up, some impact may be considered positive by increasing the range of the reservoir while there would be some loss of grassland habitat that is also used by many of the over wintering species. Impact is likely to be neutral overall on overwintering birds.