River Liffey WFD III Barrier Assessment
Obstacles to Fish Passage and Mitigation Options

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NATIONAL BARRIERS PROGRAMME

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Table of Contents

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Summary

The Liffey, *An Lifé*, has a long history of anthropogenic use and its associated river modifications including dams, weirs, sluices, and diversion channels. Now, many of the industrial and historical uses requiring this infrastructure are defunct, but the instream structures remain. Consequentially, the lower 65km of the River Liffey, from Athgravan to the Liffey Estuary, contains 13 historic weirs, almost all of which are rated as impassable for multiple fish species. These large structures prevent diadromous species such Atlantic salmon and European eel from reaching and/or utilising substantial swathes of the River Liffey habitat.

Although the river is subject to various anthropogenic pressures, the Liffey still supports several resident and migratory fish species and retains considerable ecological potential. Unfortunately, most Water Framework Directive (WFD) fish survey sites in the Liffey catchment are only realising a status of "Moderate" or below and are therefore failing the WFD requirement of achieving at least "Good" status. The River Liffey is significantly fragmented. The lack of longitudinal connectivity impacts on its WFD status and its ecological health. The absence of salmon from fish communities in the middle and lower catchment is the primary reason for its WFD non-compliance in fish ecological status.

The thirteen major weirs on the middle and lower reaches of the Liffey were surveyed in autumn 2021 using the WFD III or SNIFFER barrier assessment protocol. Fish passage at Leixlip reservoir was not assessed, as fish passage options at this structure are outside the scope of the SNIFFER barrier assessment protocol. Of the 13 weirs, 10 have fish passage options designed to facilitate fish migration. Five of the 10 fish passes are complete barriers to all fish species. These fish passage options were designed for and are accessible primarily to adult salmonids. However, none score better than a high impact partial barrier (score 0.3) for adult salmonid upstream passage. If these fishways were repaired, adult salmonid migration in the Liffey would improve. However, the restored fish passage options would still insufficiently service other important native fish, such as the Annex II listed lamprey species or juvenile salmonids.

Individually, the barriers were generally found to be major impediments to fish passage. This sequence of barriers presents a challenge for species movement, which becomes cumulatively harder as biota move through the system. Considered together as a complex, they completely block migratory fish species from accessing most of the river and degrade/impound the habitat they need to complete their life cycles. Interventions are now required to improve the Liffey's fish community. The easing of fish passage at the structures outlined in this report will help migratory species such as salmon, sea trout, eel, and lamprey spp. to freely utilize upstream environments. Consequently, this will improve the fish community status as required under the WFD and return iconic fish species to places where they have become absent.

Background

Fish and European Union Directives

A range of structures in rivers can interfere with fish migration. These structures include bridge floors, culverts, sluices, and weirs. The structures may span the full width of the channel or a portion of the channel. Structures that span the full width are the most likely to provide difficulties for fish movement. Some fish species, known as diadromous species, spend part of their life cycle at sea and part in freshwater. It is vital that these species are able to migrate between freshwater and marine habitats to complete their life cycle. The migratory fish species in Ireland– Atlantic salmon, sea trout, sea lamprey, river lamprey, twaite shad, allis shad, and the European eel, have been native to the island since the last Ice Age. A range of other fish species, such as pike, brown trout, and bream, live entirely in freshwater but are known to travel extensively for feeding or spawning. Impediments to passage can lead to fish suffering from physiological stress, predation, loss of energy, and physical damage. Any delays to fish migrations may have negative consequences for their reproductive capacity and could lead to a decline in population.

Several of the fish species noted above are listed in Annex II of the European Union (EU) Habitats Directive (92 / 43 / EEC), including Atlantic salmon, lamprey spp., and shad *sp*. This legislation obligates Ireland to restore or maintain, to a favourable status, both the habitats and populations of wild flora and fauna. Ireland has designated Special Areas of Conservation (SACs) on several of our large river systems where the conservation status of these species is of particular concern.

The EU Biodiversity Strategy for 2030 exceeds the aims of the existing Habitats Directive. It addresses the need for increased resilience to threats such as climate change and contains a programme of measures to reverse biodiversity loss. The strategy's targets include restoring continuity to at least 25,000 km of rivers within the EU. As part of the strategy, the European Commission will develop a proposal for legally binding nature restoration objectives.

The Water Framework Directive (WFD) requires Ireland to protect and improve water quality, with the aim of achieving "Good" ecological status by 2027. Multiple contributing factors, known as quality elements, are considered when assessing the ecological status of a waterbody. One such quality element is fish species composition. This is assessed by comparing the current fish community of a waterbody to the predicted fish community under high quality conditions. Another important quality element is 'hydromorphology'. This term combines the quantity and dynamics of water flow (hydrology) with the quality of the physical habitat (morphology). A third component of hydromorphology is that of 'continuity' or 'connectivity'. This refers to the undisturbed movement of water flow, aquatic wildlife, and sediment within the river.

The EU Eel Regulation (2007) is concerned with the recovery of European eel stocks. The species is critically endangered under The International Union for Conservation of Nature (IUCN) Red List. One of the primary objectives of the regulation is to facilitate the upstream migration of juvenile (glass) eels and the downstream migration of mature (silver) eels by improving river corridor connectivity. As the species is catadromous, adults must migrate towards the Sargasso Sea to spawn. A recent review of the Eel Regulation (European Commission, 2020) recommended an increased focus on making rivers more passable for the species.

River Connectivity and Habitat Fragmentation

In the main, the river systems of Europe have been altered for the economically important purposes of supplying water, generating power, navigation, and flood mitigation. However, there has been little consideration of the environmental consequences. River ecosystems are shaped by, and dependent on, the natural movement of water, sediments, nutrients, and stream biota. Excessive alteration of the magnitudes, duration, frequency, and timing of flows can substantially impair the ecological productivity of these systems. Infrastructure including dams, levees, diversions, and channelization works, reduce the dynamism and diverse characteristics of river systems leading to comparatively fragmented, static, and simplified habitats. Biota must navigate through these homogenised habitats to reach isolated patches of river that are still able to support their life cycle. The discontinuity in habitat quality can diminish stream biota resilience to negative events by limiting species' abundance and dispersal. This has implications for the population structure and species' renewal after disturbance (Mueller *et al.*, 2011).

Artificial structures can also lead to the fragmentation of a river's thermal regime. Impounded waterbodies, constrained behind dams and weirs, thermally perform more like lakes than rivers. Further thermal damage occurs when the confined water is released. The temperature of the discharged water is typically different to that of its free-flowing counterpart leading to thermal pollution. The discharges from thermally stratified reservoirs in particular can be detrimental to downstream aquatic assemblages (Olden and Naiman, 2010). Instream barriers can also indirectly lead to thermal degradation. The artificially altered water volumes of rivers with instream anthropogenic structures impact the rate at which rivers respond to atmospheric changes in temperature. For example, lower water levels caused by a dammed flow heat up faster. Such thermal pressures render rivers more susceptible to the impacts of climate change (Woodward *et al.,* 2010). Additionally, the thermal pollution resulting from artificial barriers can influence life cycle cues and favour invasive species with a wider thermal tolerance (Olden and Naiman, 2010).

Connectivity acts on one temporal and three spatial dimensions. The temporal dimension is the continuity of interactions, usually in a seasonal pattern, that structure a habitat. The spatial dimensions are: longitudinally from headwaters to confluences and the sea, laterally from the main channel to floodplains, and vertically between the riverbed and groundwater in the hyporheic zone. The importance of each dimension changes along the river's course and has led to the development of complimentary concepts in landscape ecology:

- Hydrological connectivity supports the passive downstream transport of material and energy, but also enables a multidimensional dispersal of organisms.
- Ecological connectivity emphasises the connection between different areas of habitat. This is particularly important in linear river ecosystems, where certain species and life stages require diverse habitats along the river continuum to complete their life cycle.

Loss of ecological connectivity can be described as a consequence of habitat reduction, in which large, continuous habitat is broken up into many smaller fragments. The few remnants of quality habitat are separated by an anthropogenically modified matrix of different land use types. The presence of artificial barriers along the river continuum create a challenge for species movement, which becomes cumulatively harder as a species move through the system. Moreover, the sub-optimal habitat between better areas means that biota must expend more energy moving from location to location. Habitat loss and the associated fragmentation has a dual effect. It disrupts the spatial patterning of resource availability and also limits the carrying capacity at each patch i.e. dispersed habitat is harder to reach and can support less organisms. Remediation efforts to improve connectivity should, therefore, take a complimentary approach that aims to mitigate barriers to improve passage and also increase overall habitat quality.

Assessing structures for passability – the WFD111 method

Structures that interfere with continuity can be considered barriers. Regarding fish migration, barriers can present a problem under both the Habitats Directive and the Water Framework Directive. In the course of implementing the WFD, EU member states have developed a range of sampling strategies for quality elements. As part of this process, a barrier assessment was developed by SNIFFER (Scotland and Northern Ireland Forum for Environmental Research). This process is known as the WFD 111 method. It has been used extensively in Northern Ireland and is currently used by Inland Fisheries Ireland to examine structures where some form of remedial work (partial removal, full removal, or modification, etc.) is proposed.

The WFD 111 barrier assessment methodology examines the structure and identifies the number of potential routes that fish species could use to surpass the barrier (travelling upstream or downstream). Each possible route is referred to as a 'transversal section' (TS). A series of criteria are then assessed at each transversal. The criteria include:

- water velocities
- depth of water over the structure's surface
- hydraulic head height
- length of structure's slope
- Slope (hydraulic head / length X 100)
- presence/absence of a plunge pool
- flow type.

A flow meter and engineering level are used in collecting the survey data. The field data gathered from all transversal sections is referenced against tabled values for each fish species present in the catchment. A 'barrier passability' score for individual fish species or life stage is then calculated. Upstream migrants include Atlantic salmon, brown trout, shad, cyprinids, pike, river lamprey, sea lamprey, and juvenile eels. Downstream migrants include salmon smolts, juvenile lamprey, and adult eels. All values generated are specific to the date of survey and the river conditions at the time.

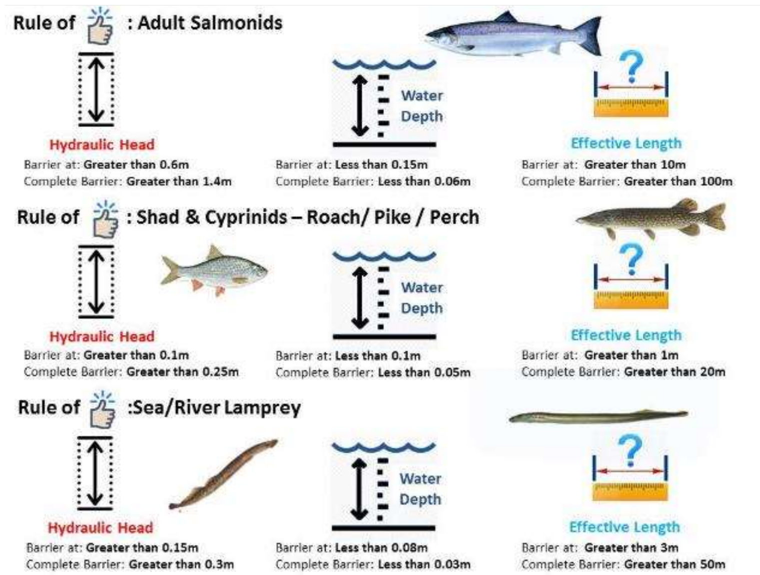

Figure 1. Guideline metrics for assessing barrier risk.

Passability scoring.

There are four scores devised for the WFD 111 assessment (SNIFFER, 2010):

- **Complete barrier (value = 0.0):** Impassable, complete obstacle for the target species/life-stage
- **Partial high impact barrier (value = 0.3):** The structure represents a significant impediment to the target species/life-stage but some of the population (e.g. < one third) will pass eventually
- **Partial low impact barrier (value = 0.6):** The structure represents a significant impediment to the target species/life-stage but most of the population (e.g. > two thirds) will pass eventually
- **Passable barrier (value 1.0):** No obstacle.

The River Liffey

The Liffey catchment encompasses an area of approximately 1250km^2 and is located within the Eastern River Basin District (ERBD). It is the most populated catchment in Ireland, although that population is not dispersed evenly. While the low-lying areas have a high population density, the upland south-easterly sections are relatively sparse in habitation (EPA, 2021). Land use surrounding the river is primarily pastural, although peat bogs encompass the source, and urban environments dominate as the river enters Dublin County. The river itself has a length of approximately 125km, which curves west in a crescent shape from the Liffey Head Bog in Wicklow, north through Kildare, and east into Dublin. After reaching the tidal limit at Island Bridge, the Liffey enters the Irish Sea at Dublin Bay. Multiple tributaries flow into the main stem, including the Brittas, Camac, Dodder, Kings, Morell, Poddle and Rye Water. The geology of the catchment is predominantly limestone, with transitions to sandstone and marine mudstone in the middle reaches, and then granite towards the river's upper extent.

There is a Water Framework Directive surveillance monitoring site on the main channel of River Liffey at Kilcullen Bridge, Co. Kildare (Figure 2). This location is 4.65km upstream from Athgarvan Weir, the furthest upstream barrier detailed in this report. The Kilcullen site was sampled by Inland Fisheries Ireland using single-pass boat-based electrofishing in August 2008, September 2013, and August 2019. In 2008, four fish species were recorded downstream of the bridge (Kelly *et al.*, 2009). Brown trout were the most common, followed by salmon, eel, and stone loach. In 2013, six fish species were captured (Kelly *et al.,* 2014). Again, brown trout were the most abundant, followed by salmon, minnow, stone loach, perch, and eel. In 2019, seven species were found (IFI, 2019). Brown trout once more had the highest abundance, followed by minnow, gudgeon, salmon, eel, perch, and pike. The densities of brown trout, salmon, and eel have varied from 2008 to 2019 (Table 1.). In 2019, 53 locations were surveyed throughout the Liffey catchment in addition to the Kilcullen Br. site (IFI, 2019). Eleven fish species were recorded in total, comprising of brown trout, three-spined stickleback, minnow, stone loach, eel, lamprey, salmon, pike, perch, roach, and gudgeon.

Table 1. Densities (no. of fish/m2) at Kilcullen Bridge (Kelly *et al.,* 2009; Kelly *et al.,* 2014; IFI, 2019)

Common name	Species name	2008	2013	2019
Brown trout	*Salmo trutta*	0.0189	0.0240	0.0048
Salmon	*Salmo salar*	0.0121	0.0210	0.0005
Eel	*Anguilla anguilla*	0.0004	0.0001	0.0002

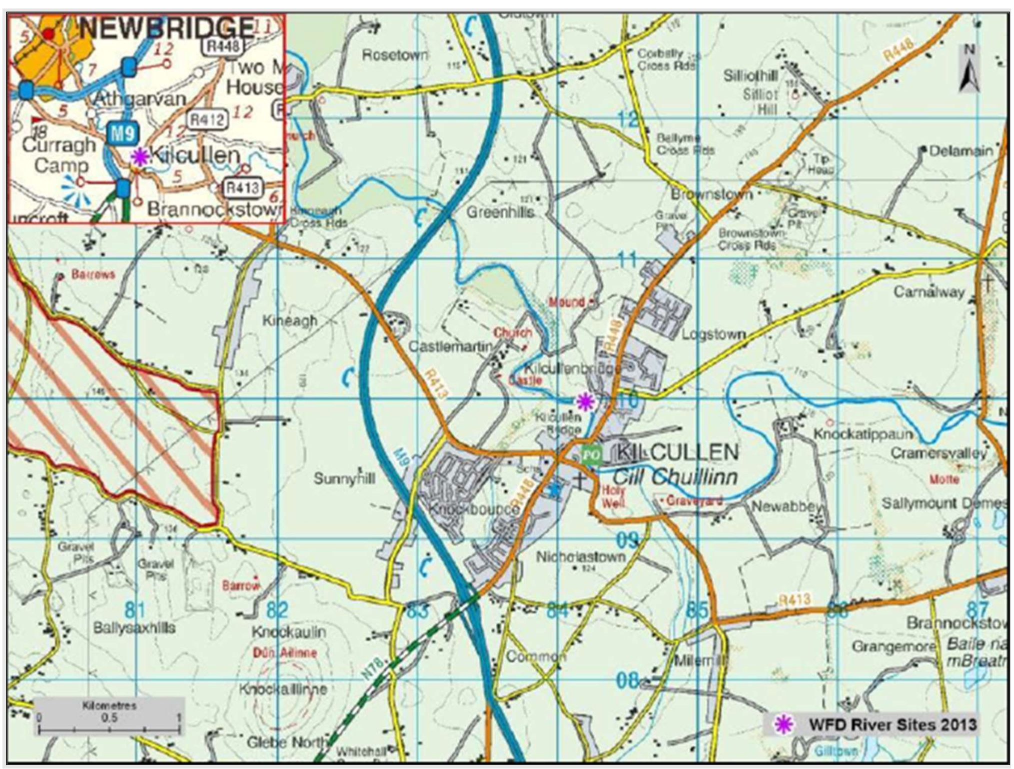

Figure 2. Location of the Kilcullen Br. WFD monitoring site (Kelly *et al.*, 2014).

The WFD fish species composition surveys conducted by IFI contribute to the overall WFD ecological status of the Liffey. The 2013 to 2018 WFD status for the Liffey main channel alternated predominantly between "Good" and "Moderate" (EPA, 2019). This is the most up to date status available based on the latest complete monitoring assessment period. The river status noticeably declines immediately downstream of the Pollaphuca reservoir, Leixlip, and upon entering Dublin County. In particular, the stretch of river by Leixlip deteriorates substantially from "Good" to "Poor" (Figure 3). Of the 81 river waterbodies in the Liffey catchment, 54% are at risk (EPA, 2021). An "at risk" river waterbody is one that is not currently meeting the "Good" or "High" ecological status required by the WFD, or one that is experiencing an increase in nutrients or ammonia that will prevent it from reaching the necessary status by the end of Cycle 3 (EPA, 2021). Significant issues for river waterbodies in the Liffey catchment include nutrient pollution, organic pollution, morphological impacts, sediment (from cattle access), and hydrological impacts (EPA, 2021). The anthropogenic pressures specifically involve wastewater treatment plant discharges, water abstraction for public supply, hydroelectric power schemes, channel modification, agricultural run-off (predominantly phosphorous), urban run-off, and large and small scale in-stream barriers.

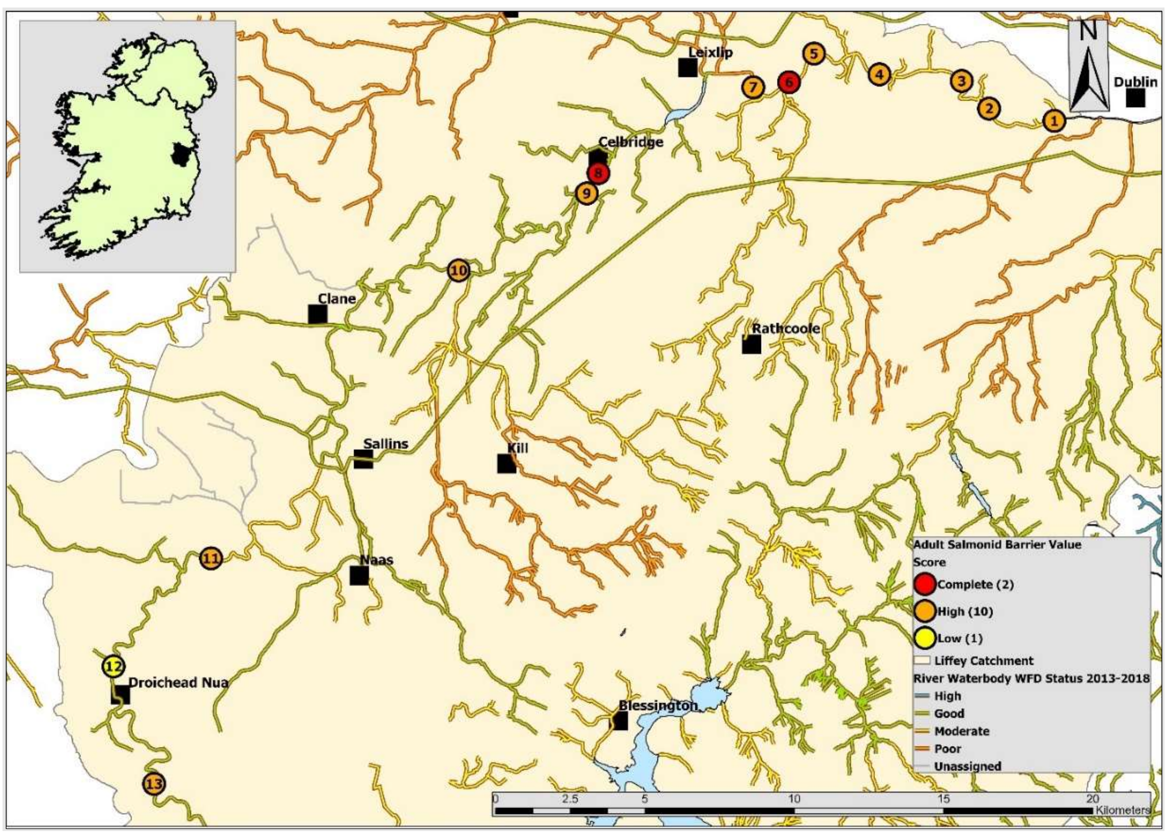

Figure 3. Barrier locations on the Liffey main channel, with the risk rating for upstream migrating adult salmonids denoted by colour. The surrounding waterbodies are colour-coded according to their WFD ecological status, 2013-2018 (EPA, 2019).

The Electricity Supply Board (ESB) owns and operates three hydroelectric power stations in the Liffey catchment, at Pollaphuca, Golden Falls, and Leixlip. These were built in the 1940s and form part of the Liffey Hydroelectric Scheme. Pollaphuca and Golden Falls were constructed above the natural limit for salmon upstream migration, while Leixlip has a fish lift and spillway gates to aid salmon passage (ESB, 2021). In addition to generating electricity, water is abstracted from Pollaphuca and Leixlip for public supply. Due to its instream infrastructure, the ESB can artificially alter the flow of the main channel of the River Liffey to varying degrees, by withholding or discharging the water in the reservoirs. The Liffey also absorbs discharges from treatment plants at Leixlip, Osberstown, and Blessington in the form of wastewater effluent. In June 2022, a fish kill, which caused the mortality of over 500 brown trout, on the River Rye Water in Leixlip exemplified the extreme pressures faced by the inhabitants of the Liffey (IFI, 2022a).

Figure 4. Fish kill on the River Rye Water in Leixlip, Co. Kildare, June 2022 (IFI, 2022).

By June 2022, 306 barriers to fish passage had been identified in the Liffey catchment by the National Barriers Programme at Inland Fisheries Ireland (IFI, 2022b). These include bridge aprons, culverts, and weirs. Although many of these barriers are less consequential than the larger structures assessed for this report, the cumulative impact to fish migration is substantial (Lucas *et al.*, 2009). The river has a long history of industrial use which required weirs, sluices, and diversion channels. In many cases the waterpower is no longer necessary, but the affiliated in-stream structures are still present. Thirteen significant weirs were identified on the Liffey main channel. Figure 3. shows the impact of these weirs on adult salmonid upstream migration. All 13 were barriers to migration, with 2 being complete barriers, 10 being high impact partial barriers, and 1 scoring as a low impact partial barrier.

The Liffey is primarily a game river for angling. Brown trout on the river are fast growing, but short-lived (Delanty *et al.*, 2022). Salmon and sea trout fishing is also available. However, the sea trout run is small and the catches of salmon were regarded as in decline at the start of the 21st century (O'

Reilly, 2002). A Vaki fish counter, located at Island Bridge, recorded 337 salmon (primarily grilse) and 105 sea trout over 365 days in 2020 (IFI, 2021). In 2021, the fish counter logged 181 salmon and 64 sea trout (IFI, 2022c). The counter was operating well, although it was possible for fish to bypass the technology during flood conditions. Unusually amongst the larger Irish river catchments, both brown trout and salmon utilise the main Liffey channel for spawning (Delanty et al., 2022).

Interventions are now required to improve fish status and address the pressures that this waterbody is subject to. This includes barrier mitigation to improve ecological connectivity throughout the system. Atlantic salmon and other migratory species including trout, sea lamprey, river lamprey, and eel are likely to re-colonise upstream stretches in greater numbers provided barriers to passage are addressed. Reconnecting the segmented Liffey is likely to improve fish status and the related overall ecological status. As such, potential barrier mitigation options aimed at improving connectivity are outlined below together with the WFD 111 barrier assessment results.

WFD 111 Barrier Assessment Results:

Thirteen major barriers were surveyed on the main channel of the River Liffey from September 2021 to October 2021 (Figure 5). A structure has been present in each location since at least the mid-19th century. The results of these surveys are described below.

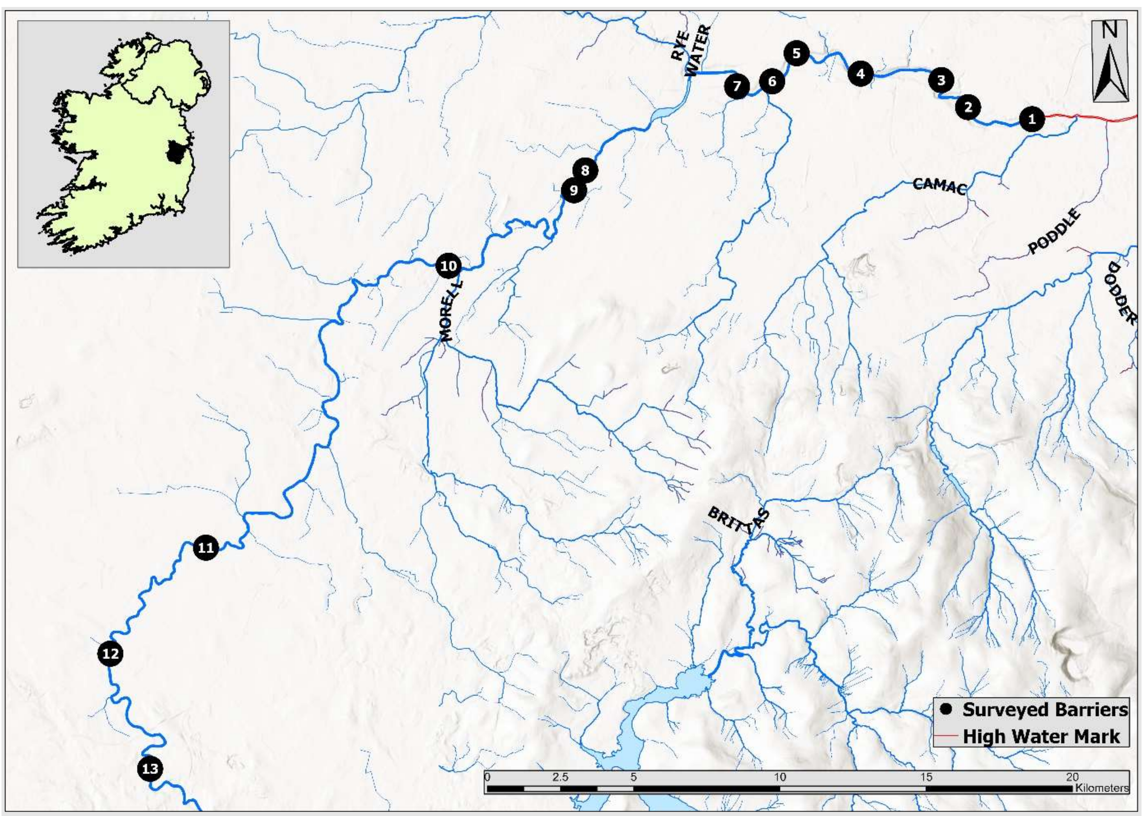

Figure 5. Location of WFD 111 barrier surveys, 2021.

1. Island Bridge Weir

This weir, built circa 1780, marks the tidal limit for the River Liffey and the beginning of the Upper Liffey Estuary. Located beside the Phoenix Park, the weir is constructed predominantly from masonry. Although originally associated with a variety of industrial processes, such as calico production and malting, the weir no longer provides an industrial service (NIAH, 2020). The total hydraulic head height is 2.86m. It is the highest of the thirteen barriers included in this report. The total width of the weir along the crest is 250m, of which 40m were wetted on the date of survey. The river channel width at this point is 45m. Three potential fish passage routes, known as transversal sections (TS), were available to migrating fish. These are described below.

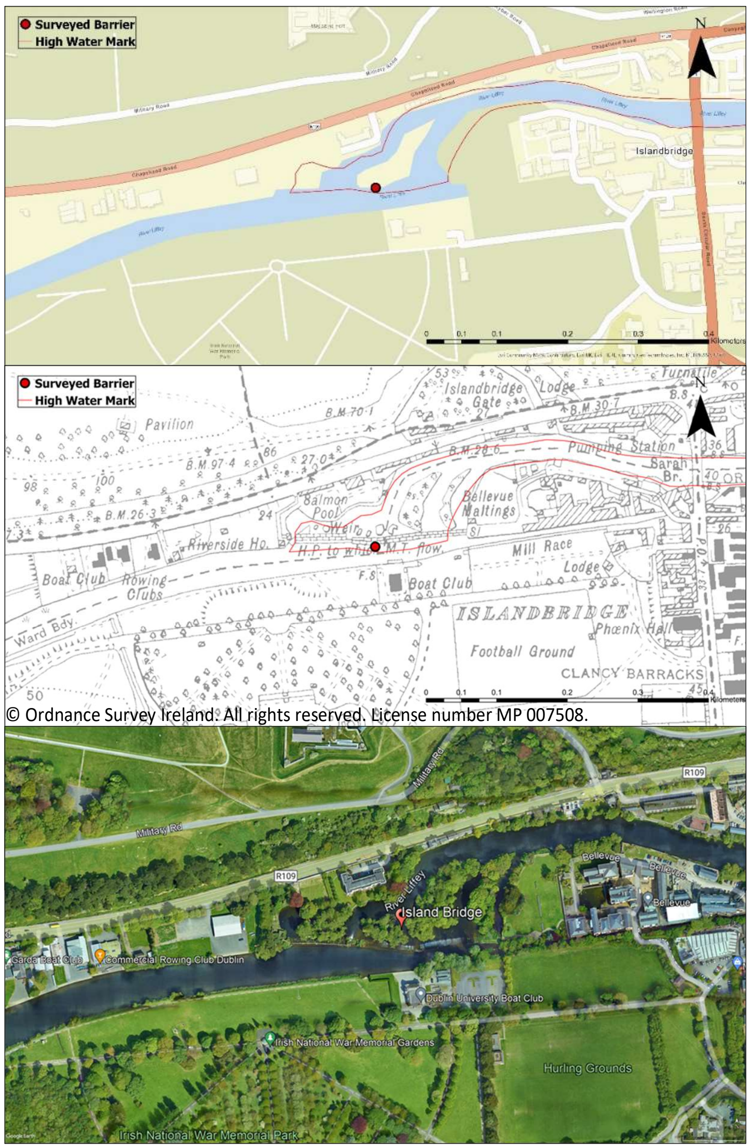

Figure 6. The location of the Island Bridge Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2020).

Transversal 1:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to upstream migration for all species except adult salmonids and juvenile eel. The box step height of 0.47m presented a jump barrier to cyprinids, adult lamprey, and juvenile salmonids. The low step water depth (0.65m) created a high impact partial barrier for adult salmonids (score 0.3). However, this transversal did offer a climbing substrate to juvenile eel, allowing the species complete passability (score 1.0). High flows have the potential to improve passage for adult salmonids due to increased depths. Sufficient water depths and low velocities at the crest, in addition to a lack of damaging structures or debris, mean downstream migrants faced no barrier (score 1.0) at this fish passage option.

Figure 7. Fish passage option (TS1).

Transversal 2:

In prevailing conditions, this sluice was a complete barrier (score 0.0) to upstream migration for all fish. High levels of turbulence created a swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. High velocities at the midpoint and crest (1.01m/s to 3.4m/s) represented an additional swim barrier for non-salmonids. The slope (10.71%), lack of effective resting locations, and high levels of turbulence created a high impact partial barrier (score 0.3) for adult salmonids. With regard to downstream migration, adult trout, juvenile lamprey, and adult eel faced no barrier (score 1.0). However, velocities greater than 1.65m/s at the crest impeded the downstream migration of cyprinids (score 0.3) and both juvenile and adult salmon (score 0.6).

Figure 8. Sluice (TS2).

Transversal 3:

In prevailing conditions, the weir face was a complete barrier (score 0.0) to upstream migration for all species except juvenile eel. The slope (25.32%), high turbulence, and low depths at the midpoint and crest all presented obstacles. Juvenile eel could surmount this transversal utilising the climbing substrate available. Therefore, the structure was no barrier (score 1.0) to their upstream passage. With regard to downstream migration, juvenile salmonids, juvenile lamprey, and adult eel faced no barrier (score 1.0). However, low depths at the weir crest impeded the downstream migration of adult salmon (score 0.3), adult trout (score 0.6), and cyprinids (score 0.6).

Figure 9. Sloping weir face (TS3).

Passability Assessment for Site

On the day of the survey, Island Bridge Weir represented a complete barrier (score 0.0) for the upstream migration of all species except adult salmonids and juvenile eel (Table 2). Adult salmonids could make passage at transversals one or two, however both were high impact partial barriers (score 0.3). The structure presented no barrier (score 1.0) to juvenile eel, as the species could make passage utilising the available climbing substrate at transversals one or three. With regard to downstream migration, transversal one was the best option, presenting no barrier (score 1.0) to any species. Transversal one also offered the best passability overall, despite not facilitating the upstream passage of cyprinids, adult lamprey, or juvenile salmonids. High flows will improve the structure, reducing it to a low impact partial barrier (score 0.6) for adult salmonids. However, for cyprinids, adult lamprey, and juvenile salmonids migrating upstream, it will remain impassable.

Figure 10. Google Earth ortho-imagery of Island Bridge Weir, April 2020. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 2: Final Passability Assessment for Island Bridge Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	**Partial barrier Low impact** 0.6	**Partial barrier High impact** 0.3	**Complete barrier** 0.0	**No barrier** 1	**Partial barrier Low impact** 0.6	**Partial barrier High impact** 0.3	**Complete barrier** 0.0
Adult Salmon (AS)	current conditions			✗		✗			
	high flows		✗			✗			
Adult Trout (AT)	current conditions			✗		✗			
	high flows		✗			✗			
Cyprinids (C)	current conditions				✗	✗			
	high flows				✗	✗			
Adult Lamprey (AL)	current conditions				✗				
	high flows				✗				
Juvenile Eel (JE)	current conditions	✗							
	high flows	✗							
Juvenile Salmonids (JS)	current conditions				✗	✗			
	high flows				✗	✗			
Juvenile Lamprey (JL)	current conditions					✗			
	high flows					✗			
Adult Eel (AE)	current conditions					✗			
	high flows					✗			

2. Chapelizod Weir

This weir is located 2.52km upstream of the Island Bridge Weir and 0.32km upstream of the Anna Livia Bridge in Chapelizod. Dating from circa 1800, the weir is constructed from masonry. The total hydraulic head of the weir is 1.96m and the total width of the weir along its crest is 237m. On the date of survey, 70m of the weir crest was wetted. The width of the river channel at this point is 34m. The weir is comprised of vertical and sloping elements, which offered the four transversal sections described below.

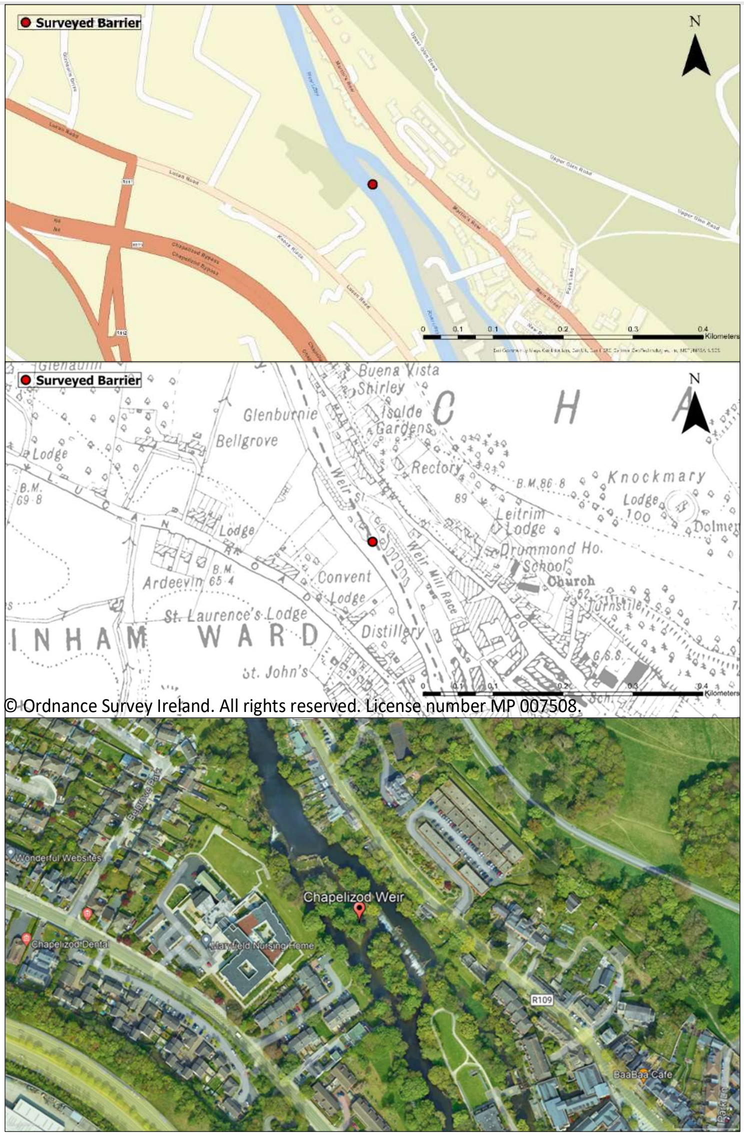

Figure 11. The location of Chapelizod Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2020).

Transversal 1:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to upstream migration for all species except adult salmonids. The high levels of turbulence constituted a complete swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. The high velocities at the midpoint and outlet (>2.25m/s) created an additional complete barrier for non-salmonids. For adult salmonids, the slope (13.24%), standing wave, and high turbulence rendered this transversal a high impact partial barrier (score 0.3). Downstream migrants of all species face no barrier (score 1.0) at this fish passage option.

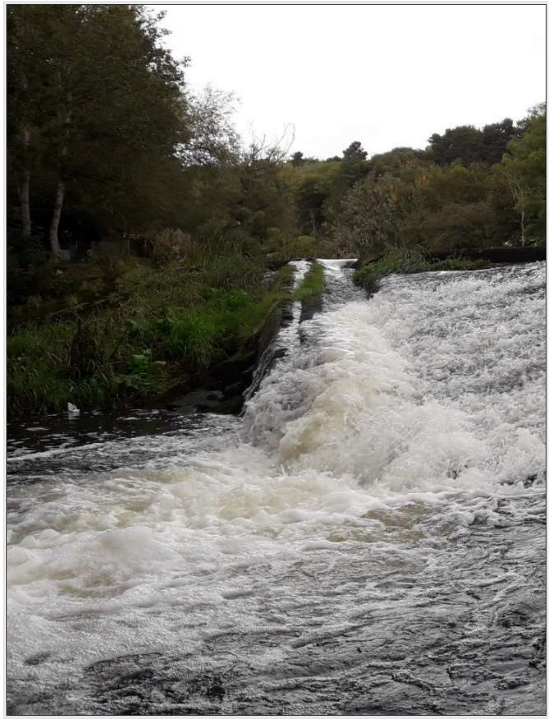

Figure 12. Fish passage option (TS1).

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to upstream migration for all species except adult trout and juvenile eel. The slope (27.22%) and high levels of turbulence at this transversal represented a complete barrier for cyprinids, adult lamprey, and juvenile salmonids. Meanwhile, the low depths (≤0.07m) at the midpoint and outlet created a complete barrier for adult salmon passage. High flows will improve this transversal, reducing it to a high impact partial barrier (score 0.3) for adult salmon, due to increased depths. The low water depths on the face of the weir also presented an issue for adult trout, however not to the same extent. Due to the slope, limited depths, standing wave, and turbulence, this transversal was a high impact partial barrier (score 0.3) for adult trout. Juvenile eels faced no barrier and could make passage on the available climbing substrate. In a downstream direction, the transversal was passable for migrants of all species (score 1.0).

Figure 13. Breach into TS1 by TS2.

Transversal 3:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to upstream migration for all species except juvenile eel. The hydraulic head or vertical drop height, at 1.96m, posed a complete jump barrier. The low water depths at the weir crest (≤0.05m) and launching (plunge) pool (0.12m) were additional complete barriers for adult salmonids. Juvenile eel could make passage on the available climbing substrate. The limited crest depths also created a complete barrier for the downstream migration of adult salmonids and cyprinids. The rocky outcrop and boulders at the outlet of the transversal had the potential to harm downstream migrants. These damaging structures represented a high impact partial barrier (score 0.3) for the species (juvenile salmonids, juvenile lamprey, and adult eel) able to overcome the low crest depths.

Figure 14. Vertical drop (TS3).

Transversal 4:

In prevailing conditions, the weir face was a complete barrier (score 0.0) to upstream migration for all species except juvenile eel. The slope (41.70%) and high levels of turbulence were the primary factors limiting upstream passage. The low water depths (≤0.07m) at the midpoint and crest were an additional complete barrier for adult salmon. Juvenile eel could use the available climbing substrate along the edge of the transversal to make passage. Downstream migration was impeded completely (score 0.0) for adult salmon due to low water levels at the weir crest. Cyprinids and adult trout were also impacted, with the low depths creating a high impact partial barrier (score 0.3) for downstream passage.

Figure 15. Weir face (TS4).

Passability Assessment for Site

On the day of the survey, Chapelizod Weir represented a complete barrier (score 0.0) to upstream migration for all species except adult salmonids and juvenile eel (Table 3). Different routes were better suited to different species. Both transversals one and two offered passage to adult trout. However, only transversal one presented a viable passage option for adult salmon. The transversals suitable for adult salmonid passage were high impact partial barriers (score 0.3), allowing restricted passability. The structure presented no barrier (score 1.0) to juvenile eel, as the species could make passage utilising the available climbing substrates at transversals two, three, or four. Turbulence and slope were the common issues amongst transversals one, two, and four. However, the vertical drop was the major limiting factor at transversal three. Downstream migration for all species was best catered for at transversals one and two.

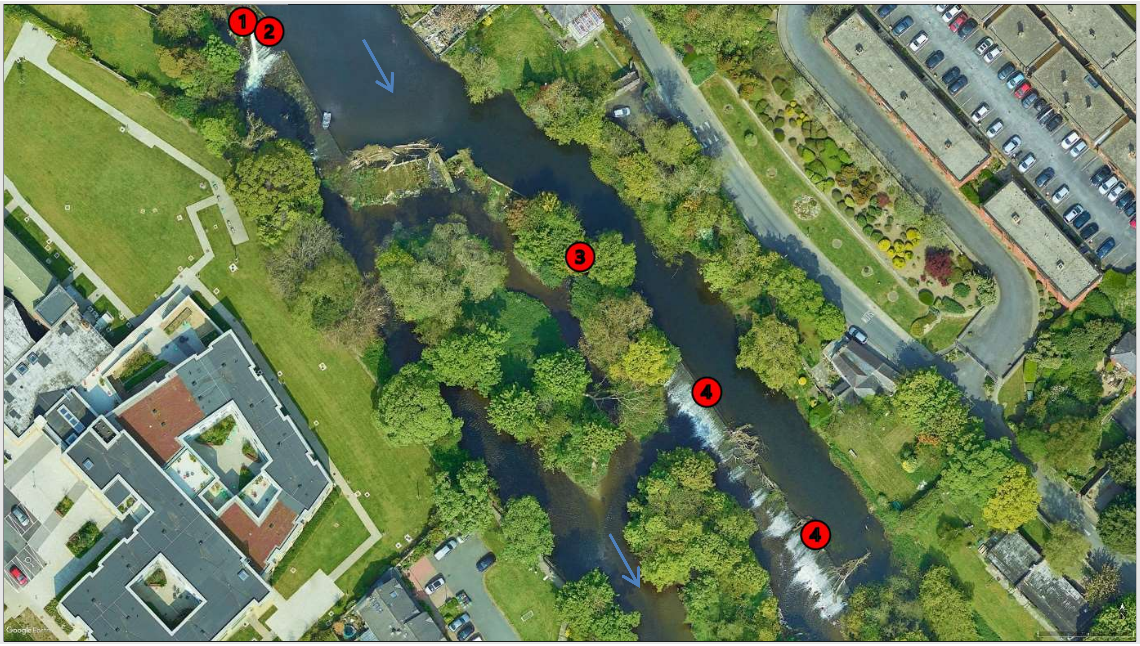

Figure 16. Google Earth ortho-image of Chapelizod Weir, April 2020. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 3: Final Passability Assessment for Chapelizod Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			✗		✗			
	high flows			✗		✗			
Adult Trout (AT)	current conditions			✗		✗			
	high flows			✗		✗			
Cyprinids (C)	current conditions				✗	✗			
	high flows				✗	✗			
Adult Lamprey (AL)	current conditions				✗				
	high flows				✗				
Juvenile Eel (JE)	current conditions	✗							
	high flows	✗							
Juvenile Salmonids (JS)	current conditions				✗	✗			
	high flows				✗	✗			
Juvenile Lamprey (JL)	current conditions					✗			
	high flows					✗			
Adult Eel (AE)	current conditions					✗			
	high flows					✗			

3. Palmerstown Lower Weir

This weir is located 1.88km upstream from the previous barrier and 4.41km from the tidal limit at Island Bridge. Adjacent to the weir is Sun Chemical. The same premises was a Scrutch Mill in the 18th century (NIAH, 2020). Dating from between 1740 and 1790, the V-shaped weir is constructed predominantly from masonry. It has a total hydraulic head height of 1.84m. The total width of the barrier along the crest is 65m, of which 55m were wetted on the date of survey. The channel has a width of 32m at this point of the river. This sloping weir had three transversal sections which are detailed below.

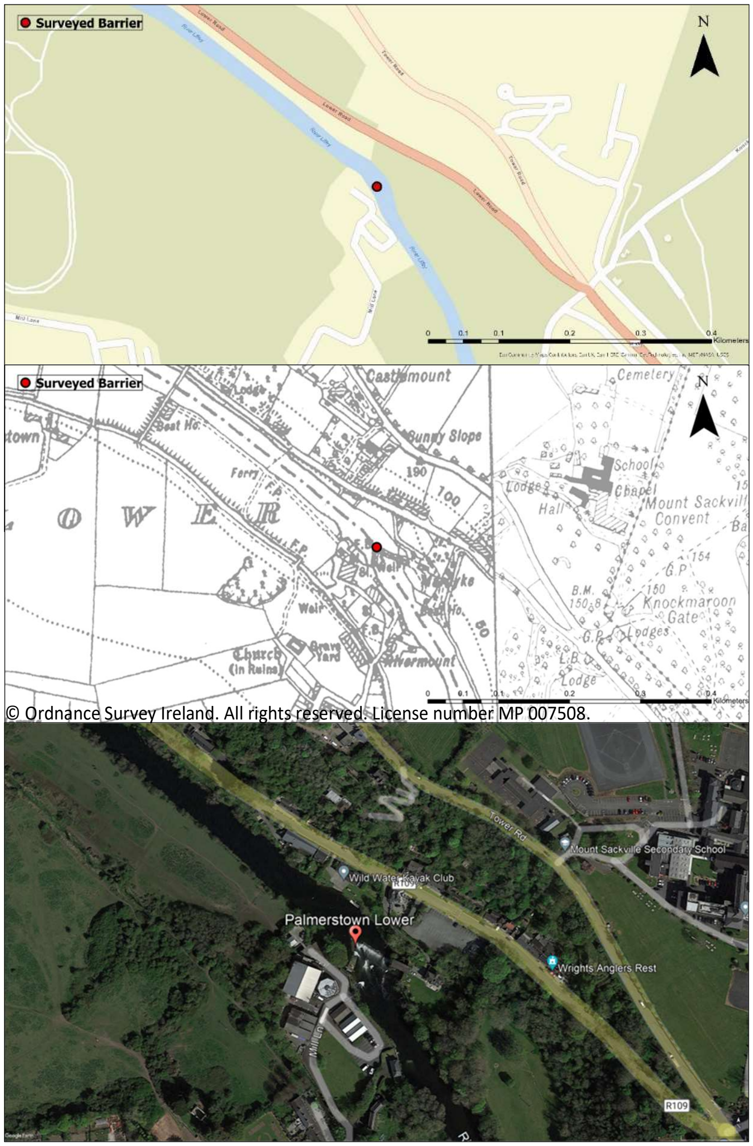

Figure 17. The location of Palmerstown Lower Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species except adult salmonids and juvenile eel. Multiple factors contributed to the negative impact on upstream passage. The slope (26.29%) and high levels of turbulence were complete barriers for cyprinids, adult lamprey and juvenile salmonids. High velocities (1.7m/s to 3.5m/s) at the outlet and midpoint created an additional swim barrier for cyprinids and adult lamprey. The same high velocities, combined with low depths (0.07m to 0.12m), rendered the transversal a high impact partial barrier (score 0.3) for adult salmonids. The slope, lack of effective resting locations and high turbulence also restricted the passage of adult salmonids. Juvenile eel could avail of the climbing substrate to surmount the transversal and therefore experienced no barrier (score 1.0). There was also no barrier (score 1.0) to downstream migration for any species at this segment of the weir face.

Figure 18. Weir face without crest lip (TS1).

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species except adult trout. High levels of turbulence presented a complete swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. Additionally, the slope (26.29%) of the weir face was a complete barrier for cyprinids, adult lamprey, and juvenile eel. Low depths at the midpoint (0.04m to 0.07m) created a complete barrier (score 0.0) for adult salmon. The low depths, in addition to the slope, turbulence, lack of effective resting locations, and lip at the weir crest constituted a high impact partial barrier (score 0.3) for adult trout. Downstream migration was unhindered for almost all species. Only adult salmon were restricted by the low depths at the weir crest (0.06m to 0.12m), which formed a low impact partial barrier (score 0.6) for the remaining species. Elevated flows will improve the passability at this transversal for adult salmon migrating both upstream and downstream.

Figure 19. Weir face with crest lip (TS2).

Transversal 3:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to the upstream migration of all species. In a continuing trend for this weir, turbulence was a major obstructing factor. This transversal was a complete barrier (score 0.0) for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids due to high levels of turbulence. Low depths (0.04m to 0.05m) at the transversal's midpoint created a complete barrier (score 0.0) for all species except juvenile salmonids. The cumulative impact of the depth and swim barriers meant that this transversal was not a functional fish passage option for any species migrating upstream on the day of survey. In high flows, due to increased depth, the transversal will lessen to a high impact partial barrier for adult salmonids. There was no barrier (score 1.0) to downstream migration for any species.

Figure 20. Fish passage option (TS3).

Passability Assessment for Site

On the day of survey, Palmerstown Lower Weir represented a complete barrier (score 0.0) to upstream migration for juvenile salmonids, cyprinids and adult lamprey (Table 4). The structure presented no barrier (score 1.0) to juvenile eel, a species that could negotiate the weir utilising the available climbing substrate on transversal one. For adult salmonids, the structure was a high impact partial barrier (score 0.3). Adult trout could make passage via transversals one or two. However, the only route available to adult salmon was transversal one. In high flows, transversals two and three will also be accessible to adult salmon, but will not improve beyond a high impact partial barrier (score 0.3). High turbulence and limited depths were restricting factors for fish passage across all three transversals. Overall, transversal one offered the best upstream passability, despite providing limited access for adult salmonids, and no passage at all to cyprinids, adult lamprey, or juvenile salmonids. There was no barrier (score 1.0) to downstream migration at the Palmerstown Lower Weir for any species.

Table 4: Final Passability Assessment for Palmerstown Lower Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			✗		✗			
	high flows			✗		✗			
Adult Trout (AT)	current conditions			✗		✗			
	high flows			✗		✗			
Cyprinids (C)	current conditions				✗	✗			
	high flows				✗	✗			
Adult Lamprey (AL)	current conditions				✗				
	high flows				✗				
Juvenile Eel (JE)	current conditions	✗							
	high flows	✗							
Juvenile Salmonids (JS)	current conditions				✗	✗			
	high flows				✗	✗			
Juvenile Lamprey (JL)	current conditions					✗			
	high flows					✗			
Adult Eel (AE)	current conditions					✗			
	high flows					✗			

4. The Wren's Nest Weir

The Wren's Nest Weir is located parallel to the Wren's Nest pub in Astagob, Dublin. It is 2.92km upstream from Palmerstown Lower Weir and 7.32km upstream from the tidal limit at Island Bridge. The weir was built in the mid-19th century (NIAH, 2020). It is constructed from concrete and masonry. The total hydraulic head of the weir is 1.45m, which is the lowest amongst the structures described thus far. The total width across the crest of the weir is 65m, of which 60m were wetted on the date of survey. The river channel has a width of 45m at this point. The barrier presented four transversal sections comprised of both vertical and sloping facets.

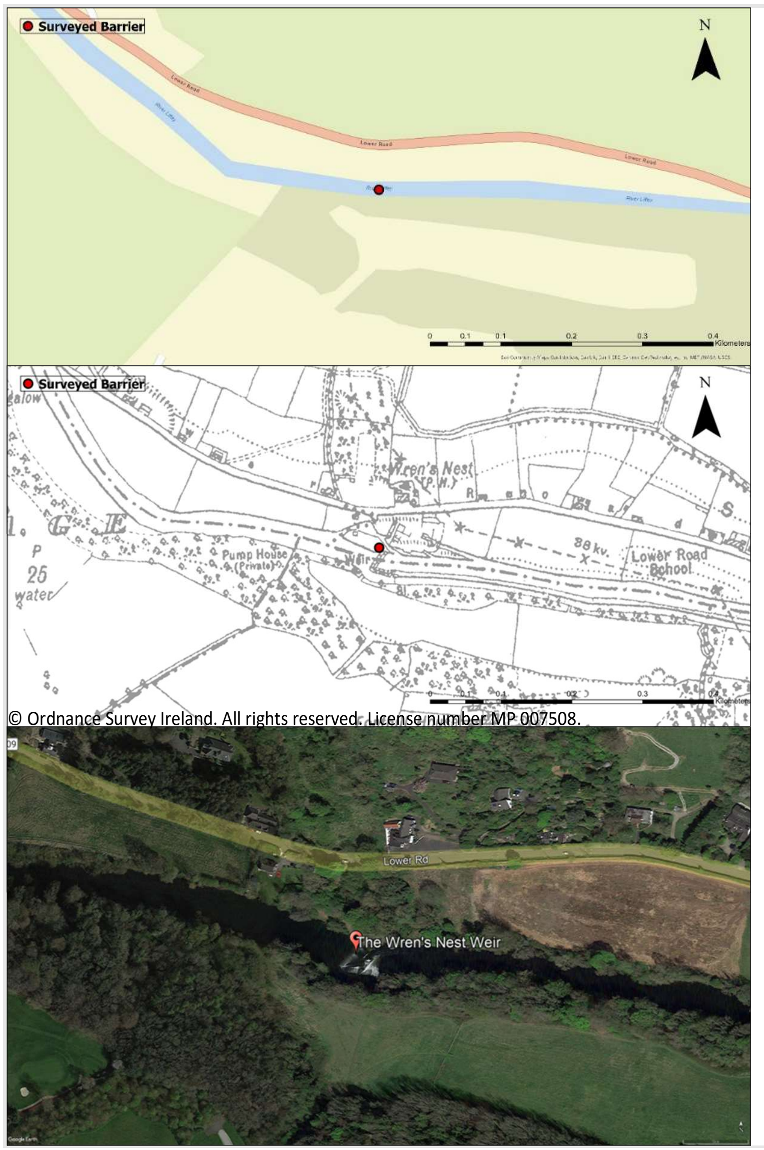

Figure 21. The location of Wren's Nest Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of adult salmonids and cyprinids. Low water depths (0.03m to 0.05m) at the outlet and midpoint of the weir face entirely restricted passage for these species. The limited depths also impacted adult lamprey and juvenile salmonids, creating a high impact partial barrier (score 0.3). Medium levels of turbulence, effective length (9.3m), slope (15.59%), and the presence of a lip at the weir foot were additional high impact partial barriers (score 0.3) for adult lamprey, juvenile salmonids, and cyprinids. Juvenile eel encountered no barrier (score 1.0), as the species could employ the available climbing substrate to surmount the weir face. Downstream migration was unhindered for all species except adult salmon. Low depths at the transversal crest presented a low impact partial barrier (score 0.6) for the species travelling in a downstream direction. High flows will improve the transversal to a high impact partial barrier (score 0.3) for the upstream migration of adult salmonids and cyprinids. The passability of this segment of the weir for downstream migrating adult salmon will also be improved.

Figure 22. Weir face (TS1).

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species except adult salmonids. High levels of turbulence and high velocities (2.14m/s to 3.21m/s) at the outlet created a complete swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. The transversal was rendered a high impact partial barrier (score 0.3) for adult salmonids due to the slope (11.07%) and turbulence. Conditions at the transversal's crest created a swim/depth barrier for cyprinids, juvenile salmonids, and adult salmon migrating downstream. High velocities (1.85m/s to 2.12m/s) impinged on the downstream passage of cyprinids (score 0.3) and juvenile salmonids (score 0.6). Meanwhile, lower water depths (0.1m to 0.11m) established a low impact partial barrier (score 0.6) for downstream migrating adult salmon.

Figure 23. Slope (TS2).

Transversal 3:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to the upstream migration of all species. Elevated velocities at the midpoint and outlet (3.98m/s to 4.8m/s) created an insurmountable swim obstacle. High levels of turbulence were an additional swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. Lesser velocities at the transversal crest (0.92m/s to 1.06m/s) meant fish travelling downstream encountered no barrier (score 1.0).

Figure 24. Fish passage option (TS3).

Transversal 4:

In prevailing conditions, this sluice was a complete barrier (score 0.0) to the upstream migration of all species. The vertical hydraulic head (1.45m) of the transversal was an insurmountable jump obstacle. The shallow effective pool depth (0.35m) downstream of the structure was an additional complete barrier (score 0.0) to adult salmonids. The high levels of turbulence were a further complete swim barrier to cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. Downstream migrants encountered no barrier (score 1.0).

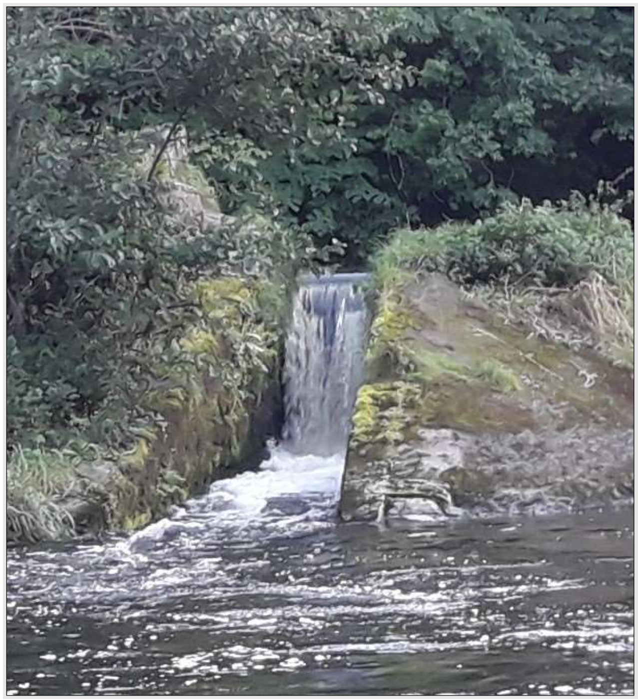

Figure 25. Sluice (TS4).

Passability Assessment for Site

On the day of survey, The Wren's Nest Weir represented a high impact partial barrier (score 0.3) for salmonids and adult lamprey (Table 5). For cyprinids, the structure was a complete barrier (score 0.0). Juvenile eel encountered no barrier (score 1.0), as the species could utilise the available climbing substrate to surmount the weir. Transversal one offered the best upstream route for adult lamprey, juvenile eel, and juvenile salmonids. In high flows, it will also improve to a high impact partial barrier (score 0.3) for cyprinids and adult salmonids. Transversal two was the route most suited to adult salmonid upstream migration in current conditions. Despite transversal three's design as a fish pass, the route was a complete barrier for all species. Downstream migrants could successfully employ any of the four transversals to surpass the weir.

Table 5: Final Passability Assessment for the Wren's Nest Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			✗		✗			
	high flows			✗		✗			
Adult Trout (AT)	current conditions			✗		✗			
	high flows			✗		✗			
Cyprinids (C)	current conditions				✗	✗			
	high flows			✗		✗			
Adult Lamprey (AL)	current conditions			✗					
	high flows			✗					
Juvenile Eel (JE)	current conditions	✗							
	high flows	✗							
Juvenile Salmonids (JS)	current conditions			✗		✗			
	high flows			✗		✗			
Juvenile Lamprey (JL)	current conditions					✗			
	high flows					✗			
Adult Eel (AE)	current conditions					✗			
	high flows					✗			

5. Anna Liffey Weir

This weir is 2.77km upstream from the Wrens Nest weir and 10.09km upstream from the tidal limit at Island Bridge. The Anna Liffey Weir is located at the base of Tinkers Hill and is on the border of the townlands of St. Edmondsbury and Woodlands. The weir was built in the latter half of the 18th century (NIAH, 2020). On the north bank of the weir is the Anna Liffey Flour Mill, also known as the Shackleton Mill, which ceased flour production in 1998. The weir is constructed from concrete and masonry. It has a total hydraulic head height of 1.86m. The total width of the weir along its crest is 140m, of which the full 140 were wetted on the date of survey. The channel width at this point is 37m. The weir has vertical and sloping facets, with five transversal sections available.

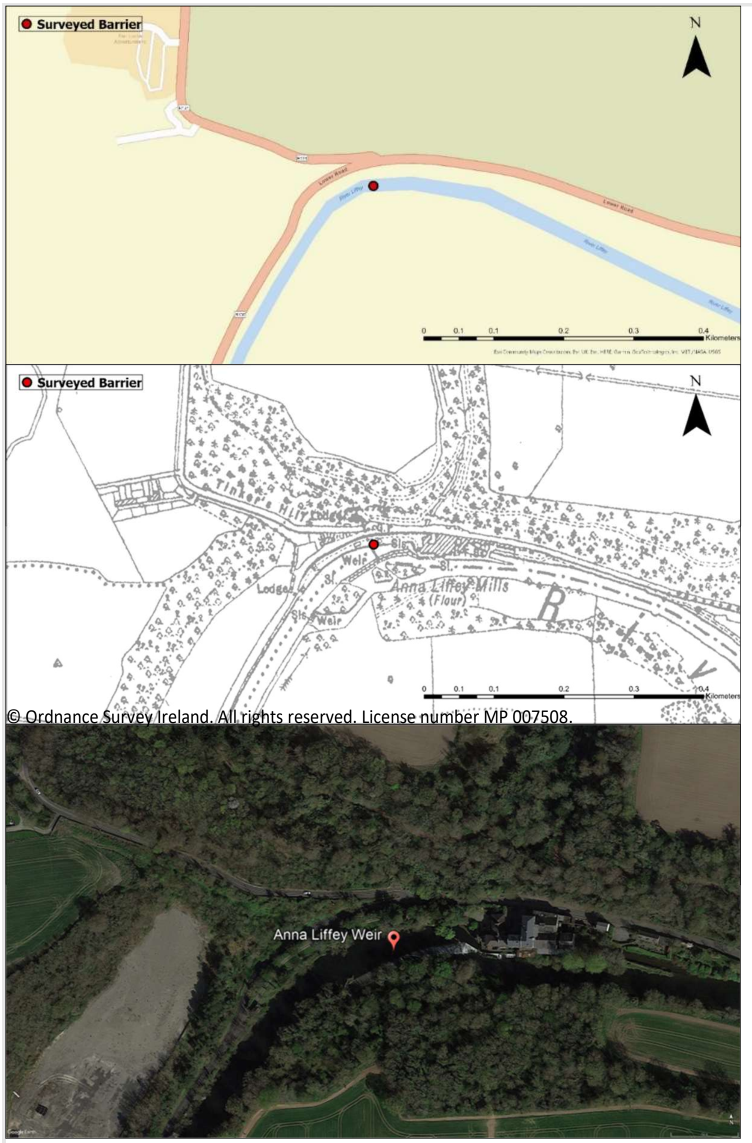

Figure 26. The location of Anna Liffey Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

In prevailing conditions, this vertical drop was a complete barrier (score 0.0) to the upstream migration of all species. The hydraulic head (1.86m) and lack of effective pool depth (0.03m) was a complete barrier to adult salmonids. Meanwhile, high levels of turbulence constituted a complete swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. Downstream migrants were hindered by an exposed rocky sill which could injure individuals attempting to employ this transversal. The presence of a physically damaging element to this structure rendered this transversal a high impact partial barrier (score 0.3) for all species migrating downstream.

Figure 27. Vertical drop (TS1).

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species except juvenile eel. The slope (29.06%) and high levels of turbulence were complete barriers for cyprinids, adult lamprey, and juvenile salmonids. Adult salmonids encountered a complete depth barrier (water depth ≤0.05m) at the outlet of this section of the weir face. The upstream migration of adult salmonids will be aided by increased depths during high flows. However, additional obstructing factors such as high turbulence will ensure that the structure does not improve beyond a high impact partial barrier (score 0.3). Juvenile eel were presented with no barrier (score 1.0) due to the available climbing substrate.

Figure 28. Weir face (TS2).

Transversal 3:

In prevailing conditions, this fish passage option was a high impact partial barrier (score 0.3) to all salmonids. The slope (11.34 %) and crest lip were common factors negating passage. For cyprinids and adult lamprey, the transversal was as a complete barrier (score 0.0). High velocities at the outlet and midpoint (2.39m/s to 4.02m/s) created an effective swim obstacle for these species. For juvenile eel, a climbing substrate was available and therefore no barrier (score 0.0) encountered. Downstream migrants of all species faced no barrier (score 0.0) at this fish passage option.

Figure 29. Fish passage option (TS3).

Transversal 4:

In prevailing conditions, this sluice was a complete barrier (score 0.0) to the upstream migration of all species except adult trout and juvenile eel. Adult salmon were impeded by low depths (≤0.06m) at the crest, while cyprinids, adult lamprey, and juvenile salmonids were unable to surmount the vertical hydraulic head (0.92m). For adult trout's upstream passage, the low crest water depths, hydraulic head, and effective pool depth (0.41m) generated a high impact partial barrier (score 0.3). The transversal was also a high impact partial barrier for juvenile eel due to medium levels of turbulence. All species travelling downstream, excluding juvenile lamprey, were impacted to varying degrees by limited depths at the transversal crest. High flows will render this transversal a viable route for adult salmon migrating upstream, in addition to improving the downstream passage for all species.

Transversal 5:

Due to unsafe conditions on the day of survey, there were no depth or velocity measurements taken at this sluice. However, the combination of high levels of turbulence, a low effective pool depth (0.25m), and the vertical hydraulic head (1m) rendered this transversal a complete barrier (score 0.0) to upstream migration for all species in prevailing conditions. Structures damaging to downstream migrants were present, creating a high impact partial barrier (score 0.3) for all species travelling in that direction.

Figure 30. Sluices at Anna Liffey Weir.

Passability Assessment for Site

On the day of survey, Anna Liffey Weir was a complete barrier (score 0.0) to the upstream migration of cyprinids and adult lamprey (Table 6). For salmonids the weir represented a high impact partial barrier (score 0.3). Adult trout could make passage at transversals three or four. In high flows, the species will also have access to transversal two. Both adult salmon and juvenile salmonids could only surmount the weir at transversal three in current conditions. With elevated flows, adult salmon will also have access to transversals two, four, and five. However, the greater choice of routes does not translate to improved passability. In high flows, the structure will remain a high impact partial barrier for adult salmonids. No barrier (score 0.0) was encountered by juvenile eel as the species could traverse the structure utilising the available climbing substrate at transversals two or three. Downstream migrants faced no barrier (score 1.0) at this structure. Transversal three offers the best passability overall, both upstream and downstream, despite being inadequate for the upstream movement of cyprinids or adult lamprey.

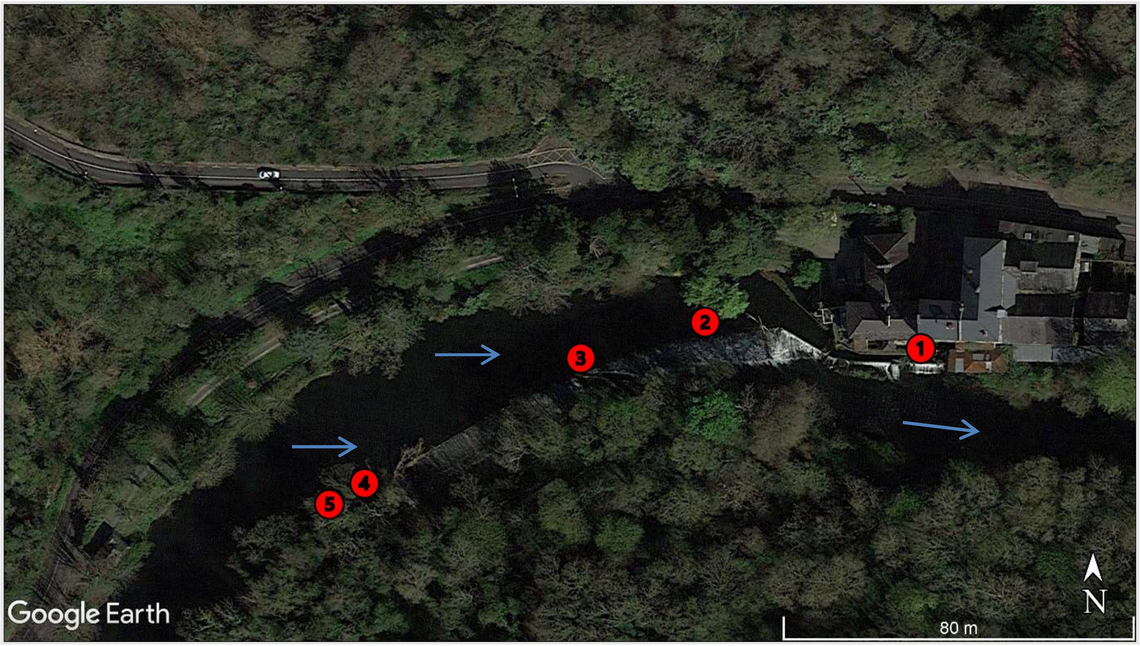

Figure 31. Google Earth ortho-image of Anna Liffey Weir, April 2021. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 6: Final Passability Assessment for Anna Liffey Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			✗		✗			
	high flows			✗		✗			
Adult Trout (AT)	current conditions			✗		✗			
	high flows			✗		✗			
Cyprinids (C)	current conditions				✗	✗			
	high flows				✗	✗			
Adult Lamprey (AL)	current conditions				✗				
	high flows				✗				
Juvenile Eel (JE)	current conditions	✗							
	high flows	✗							
Juvenile Salmonids (JS)	current conditions			✗		✗			
	high flows			✗		✗			
Juvenile Lamprey (JL)	current conditions					✗			
	high flows					✗			
Adult Eel (AE)	current conditions					✗			
	high flows					✗			

6. Lucan Weir

Lucan Weir is 1.38km upstream from Anna Liffey Weir, and 11.47km upstream from the tidal limit at Island Bridge. The weir is located directly upstream of Lucan Bridge on the Lucan border with Laraghcon. Built in the latter half of the 19^{th} century, circa 1870, the weir is constructed form concrete and masonry. It has a total hydraulic head height of 2.69m. The width of the barrier along its crest is 96m, of which 90m were wetted on the date of survey. The channel width at this point is 34m. The sloping structure presented three transversal sections. The fish passage option, transversal two, can also be seen in the historic 6" OSI map (Figure 32).

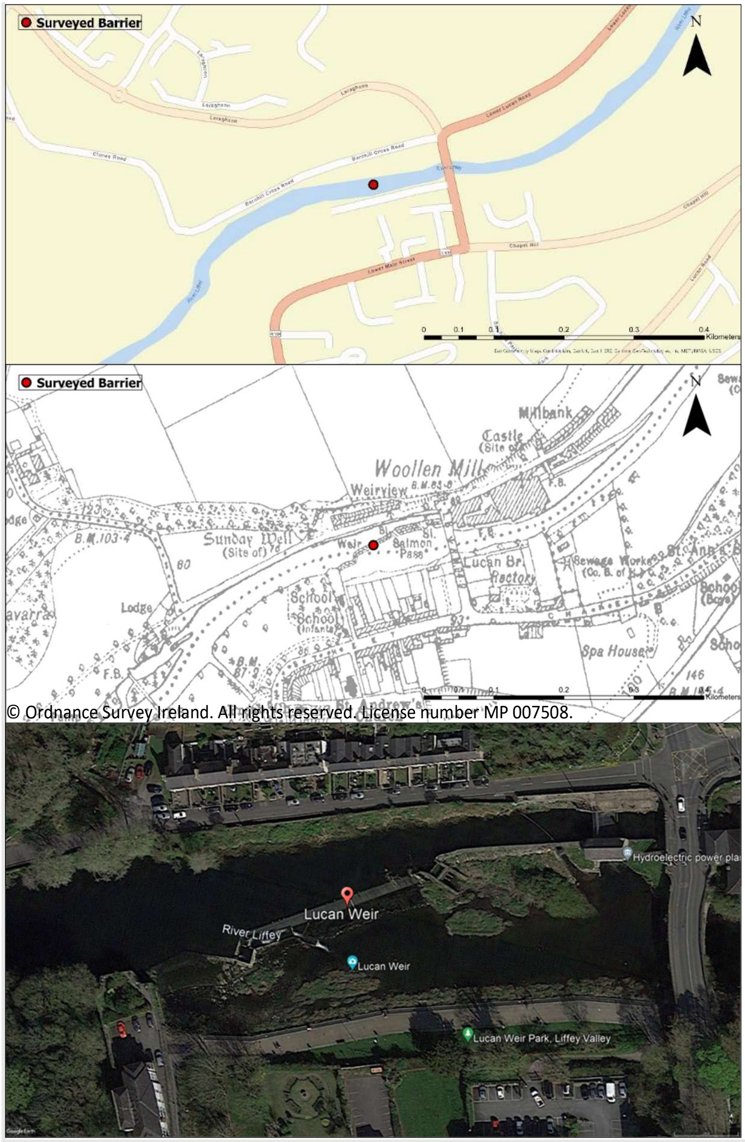

Figure 32. The location of Lucan Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species. Slope (22.42%) was a common prohibitive factor. However, additional swim and depth barriers compounded this impact. High levels of turbulence created a complete swim barrier for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. Low depths (≤ 0.03m) at the midpoint of the weir were a complete depth barrier to all species except juvenile eel. For juvenile eel, it was the midpoint velocities (1.28m/s to 2.75m/s) that were an additional obstruction to passage. Downstream migration was hampered by varying degrees for all species by the low depths (≤ 0.07m) at the crest of the transversal. Adult salmon contended with a complete barrier (score 0.0), while for adult trout and cyprinids the low depths resulted in a high impact partial barrier (score 0.3). Juvenile salmonids and adult eel fared better yet, encountering a low impact partial barrier (score 0.6). Juvenile lamprey were not impeded at all and faced no barrier (score 1.0). In high flows, downstream migration will be better facilitated at this transversal due to increased water depth.

Figure 33. Weir face with rock sill (TS1).

Transversal 2:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to the upstream migration of all species except juvenile eel. For juvenile eel, the available climbing substrate provided a navigable route that resulted in no barrier (score 1.0). For other species, a combination of slope and step features created a range of swim and jump barriers. The slope (52.75%) formed a complete barrier for all species other than juvenile eel. High levels of turbulence and the step height (0.42m) were additional complete barriers for cyprinids, adult lamprey, and juvenile salmonids. High outlet velocities (2.39m/s to 3.11m/s) were yet another complete barrier faced by cyprinids and adult lamprey. Regarding downstream migration, only cyprinids encountered an obstruction. Velocities of 1.49m/s to 1.62m/s created a low impact partial barrier (score 0.6) for the species.

Figure 34. Fish passage option (TS2) from (A) upstream and (B) downstream.

Transversal 3:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species, except juvenile eel. For juvenile eel, a climbing substrate was available and rendered the transversal no barrier (score 1.0). Low depths (≤ 0.04m) at the midpoint and outlet created a complete barrier for all other species attempting to traverse this section of the weir face. Slope (32.02%) was an additional complete barrier for cyprinids, adult lamprey, and juvenile salmonids. With regards to downstream migration, sufficient water depths and low velocities (0.1m/s to 0.42m/s) at the crest, combined with a lack of debris or damaging structures, ensured that this transversal presented no barrier (score 1.0) to any species.

Figure 35. Weir face (TS3).

Passability Assessment for Site

On the day of survey, Lucan Weir was a complete barrier (score 0.0) to the upstream migration of all species except juvenile eel (Table 7). For Juvenile eel, transversals two and three provided climbing substrates that allowed the species to surmount the structure. In high flows, increased depths will ameliorate passage for adult salmonids, creating a high impact partial barrier (score 0.3). Downstream migrants of all species were best catered for by transversal three and faced no barrier (score 1.0) to passage.

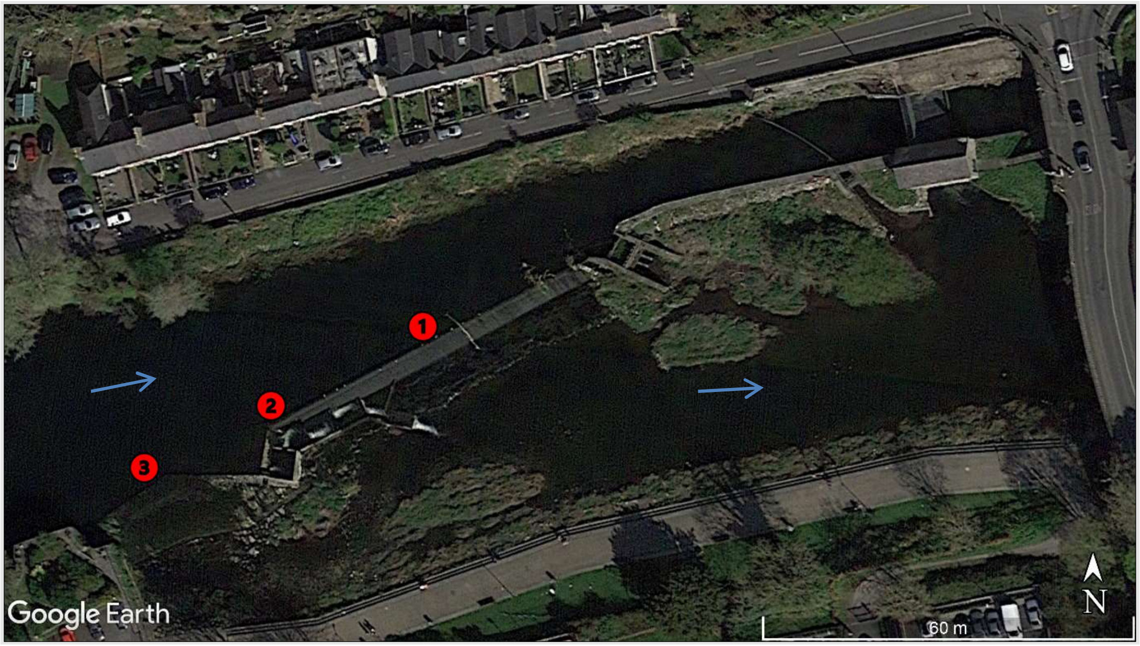

Figure 36. Google Earth ortho-image of Lucan Weir, April 2021. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 7: Final Passability Assessment for Lucan Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon	current conditions				✗	✗			
(AS)	high flows			✗		✗			
Adult Trout	current conditions				✗	✗			
(AT)	high flows			✗		✗			
Cyprinids	current conditions				✗	✗			
(C)	high flows				✗	✗			
Adult Lamprey	current conditions				✗				
(AL)	high flows				✗				
Juvenile Eel	current conditions	✗							
(JE)	high flows	✗							
Juvenile	current conditions				✗	✗			
Salmonids (JS)	high flows				✗	✗			
Juvenile	current conditions					✗			
Lamprey (JL)	high flows					✗			
Adult Eel	current conditions					✗			
(AE)	high flows					✗			

7. Lucan West Weir

This weir is 1.49km upstream from Lucan Weir, and 12.96km upstream from the tidal limit at Island Bridge. It is located just north of the N4, on the border between the townlands of Lucan Demesne and Coldblow. The structure was built in the late 18^{th} century and is constructed from pre-cast concrete and limestone masonry. The height of structure meant that it was unsafe to gather certain measurements at the site. The width of the barrier along the crest was estimated to be 95m. The width of the channel at this point was an estimated 35m. The sloping weir presented a single transversal, a breached sluice on the north side of the river that is currently used for slalom kayaking or canoeing.

Figure 37. The location of Lucan West Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

On the day of assessment, this transversal was unsafe to measure. However, the high levels of turbulence rendered the sluice a complete barrier (score 0.0) to upstream migration for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. The presence of a standing wave, in addition to the high levels of turbulence, created a high impact partial barrier (score 0.3) for adult salmonids. Downstream migrants faced no barrier (score 1.0) from debris or damaging structures, but it was possible that high velocities could cause a swim barrier.

Figure 38. Breached sluice from (A) upstream and (B) downstream (TS1).

Passability Assessment for Site

On the day of survey, Lucan West Weir was a complete barrier (score 0.0) to upstream migration for all species except adult salmonids (Table 8). Only a single fish passage option was present, a breached sluice. For adult salmonids, this transversal represented a high impact partial barrier (score 0.3). For all other species, the high levels of turbulence created a complete swim barrier. Without considering depths and velocities, downstream migrants faced no barrier (score 1.0). However, it was likely that high velocities were causing some impediment to passage.

Table 8: Final Passability Assessment for Lucan West Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon	current conditions			✘		✘			
(AS)	high flows			✘		✘			
Adult Trout	current conditions			✘		✘			
(AT)	high flows			✘		✘			
Cyprinids	current conditions				✘	✘			
(C)	high flows				✘	✘			
Adult Lamprey	current conditions				✘				
(AL)	high flows				✘				
Juvenile Eel	current conditions				✘				
(JE)	high flows				✘				
Juvenile	current conditions				✘	✘			
Salmonids (JS)	high flows				✘	✘			
Juvenile	current conditions					✘			
Lamprey (JL)	high flows					✘			
Adult Eel	current conditions					✘			
(AE)	high flows					✘			

8. Celbridge Abbey Weir

The Celbridge Abbey Weir is 7.28km upstream from the previous barrier and 20.24km upstream from the tidal limit at Island Bridge. Located in Celbridge, Co. Kildare, the barrier is adjacent to Newtown Road and 0.65km upstream from where the R405 crosses the River Liffey. The weir was built circa 1800 and separates the main river channel from a canalised section. The northern canal section originally operated as a mill race or leat for the early 19th century mill located downstream. The two river sections merge at the R405 bridge. The weir itself is constructed from concrete and masonry and has a total hydraulic head height of 2.09m. The total width of the barrier along the crest is 102m, of which 54m were wetted on the date of survey. The total width of the channel at this point is 35m. This sloping weir presented three transversal sections, which are described below.

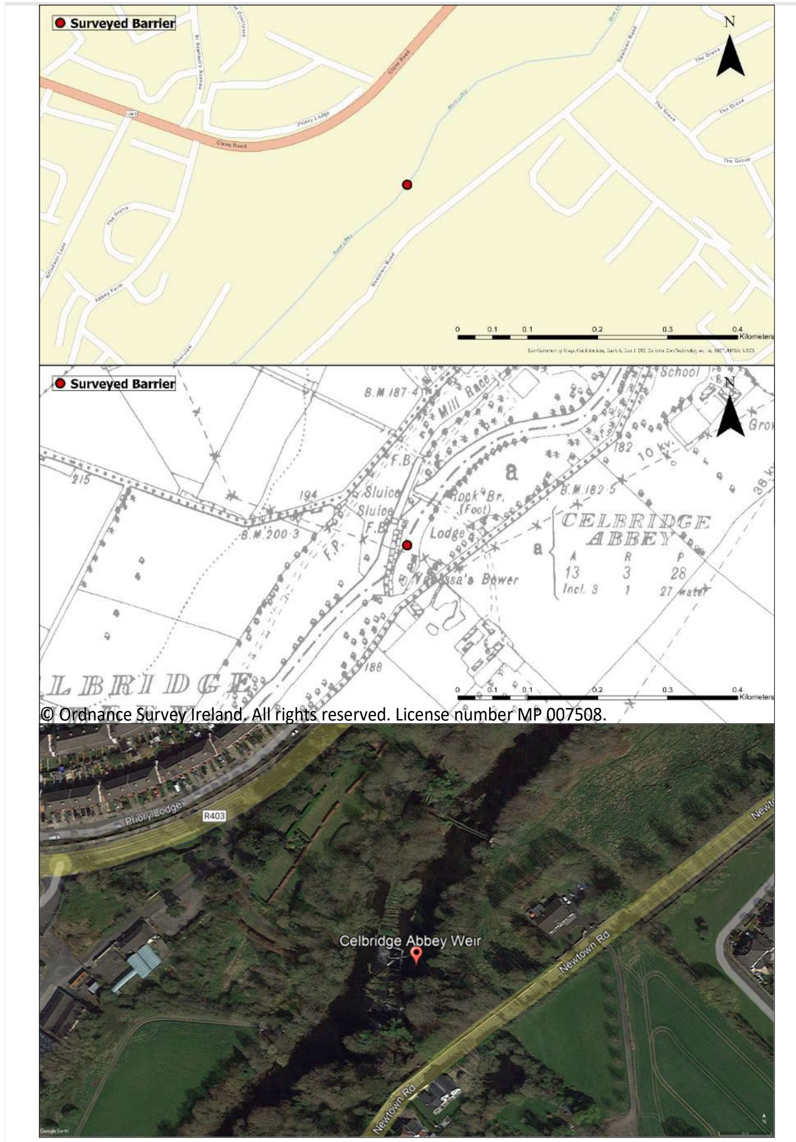

Figure 39. The location of Celbridge Abbey Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to the upstream migration of all species, except juvenile eel. For juvenile eel, the transversal posed no barrier (score 1.0) as a climbing substrate was available. Slope (17.09%) and high midpoint water velocities (≥3m/s) resulted in a complete obstacle for all other species. The step height (0.3m) was an additional prohibiting factor for cyprinids and adult lamprey. Downstream migrants encountered no barrier (score 1.0) at this transversal.

Figure 40. Fish passage option (TS1) from (A) upstream and (B) downstream.

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of adult salmonids and cyprinids. For adult lamprey and juvenile salmonids, the transversal presented a high impact partial barrier (score 0.3). For juvenile eel, the transversal posed no barrier (score 1.0), as climbing substrate was available. Low depths (≤0.06m) at the outlet and midpoint of the weir face were the primary obstacle for all species. During high flows, the passage of adult salmonids and cyprinids will be better facilitated and result in a high impact partial barrier (score 0.3). However, additional hurdles, such as the effective length (17.1m), will prevent any improvement in passage for adult lamprey or juvenile salmonids. With regards to downstream migration, adult salmon were presented with a low impact partial barrier (score 0.6) due to limited crest depths (≤ 0.11). In high flows, this impact will be ameliorated. Downstream migrants of all other species encountered no barrier (score 1.0) at this transversal.

Figure 41. Weir face (TS2).

Transversal 3:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species, except adult lamprey and juvenile salmonids. For adult lamprey and juvenile salmonids, the transversal presented a high impact partial barrier (score 0.3). Low water depths (≤0.05m) at the outlet and midpoint of this weir face section were the primary obstacle for all species, except juvenile eel. For juvenile eel, the outlet velocities (1.18m/s to 1.6m/s) were the main barrier to upstream passage. During high flows, the passage of adult salmonids and cyprinids will be better facilitated and result in a high impact partial barrier (score 0.3). However, the barrier will remain unchanged for other species. With regards to downstream migration, debris blocking the structure created a high impact partial barrier (score 0.3) for all species.

Figure 42. Weir face (TS3).

Passability Assessment for Site

On the day of survey, Celbridge Abbey Weir was a complete barrier (score 0.0) to the upstream migration of adult salmonids and cyprinids (Table 9). For adult lamprey and juvenile salmonids, the weir represented a high impact partial barrier (score 0.3). For juvenile eel, the climbing substrates available at transversals one and two resulted in no barrier (score 0.0) to upstream passage. In high flows, transversals two and three will become viable passage route options for adult salmonids and cyprinids. The increased water depths will result in a high impact partial barrier (score 0.3) score for upstream passage at these locations. Adult lamprey and juvenile salmonids could make passage at transversal two or three, a situation that will remain unchanged by elevated flows.

Downstream migrants of all species were best catered for by transversal two. There was no barrier (score 1.0) to downstream passage for any species except adult salmon. For adult salmon a low impact partial barrier (score 0.6) existed, which will be ameliorated in high flows. Transversal two had the best passibility for species overall, both upstream and downstream. Transversal one was the most difficult transversal to surmount for species overall, both upstream and downstream, despite being designed for fish passage.

Table 9: Final Passability Assessment for Celbridge Abbey Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon	current conditions				✗		✗		
(AS)	high flows			✗		✗			
Adult Trout	current conditions				✗	✗			
(AT)	high flows			✗		✗			
Cyprinids	current conditions				✗	✗			
(C)	high flows			✗		✗			
Adult Lamprey	current conditions			✗					
(AL)	high flows			✗					
Juvenile Eel	current conditions	✗							
(JE)	high flows	✗							
Juvenile	current conditions			✗		✗			
Salmonids (JS)	high flows			✗		✗			
Juvenile	current conditions					✗			
Lamprey (JL)	high flows					✗			
Adult Eel	current conditions					✗			
(AE)	high flows					✗			

9. Temple Mills Weir

The Temple Mills Weir is 0.84km upstream from Celbridge Abbey Weir and 21.08 km upstream from the tidal limit at Island Bridge. Located on the border of Celbridge Abbey and Newtown, the weir is parallel to the Chelmsford housing estate. The weir separates a canalised section from the main channel, which merges again with the river after half a kilometre. The weir is constructed from corrugated steel and masonry. It has a total hydraulic head height of 1.91m. The total width of the weir along its crest is 45m, all of which were wetted on the date of survey. The channel width at this point is 35m. This sloping weir presented three transversal sections, which are described below.

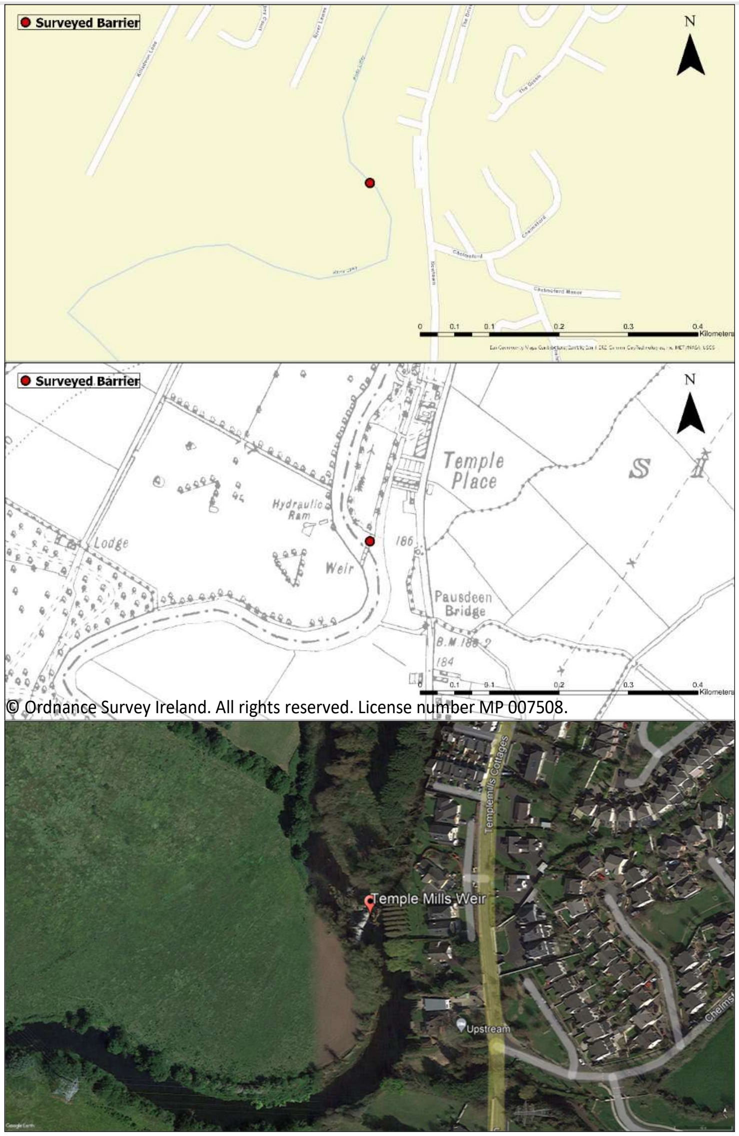

Figure 43. The location of Temple Mills Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2021).

Transversal 1:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to juvenile salmonids, cyprinids and adult lamprey. For juvenile eel, the available climbing substrate resulted in the weir face presenting no barrier (score 1.0). For adult salmonids, multiple elements combined to act as high impact partial barriers (score 0.3). The slope (44.63%), high levels of turbulence, and lip at the weir outlet were among the primary obstructions. Cyprinids, adult lamprey, and juvenile salmonids were completely impeded by the slope and turbulence (score 0.0). Downstream migrants encountered no barrier (score 1.0) at this transversal.

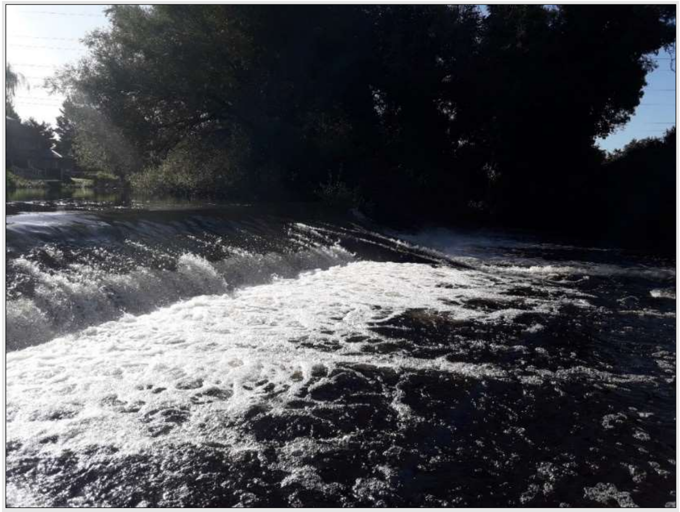

Figure 44. Weir face (TS1).

Transversal 2:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to the upstream migration of all species. High velocities at the outlet (2.95m/s to 3.34m/s) and midpoint (3.03m/s to 3.45m/s) formed an effective swim barrier. The slope (6.2%) and high levels of turbulence were additional complete barriers for all species except adult salmonids. Downstream migrants encountered no barrier (score 1.0) at this transversal.

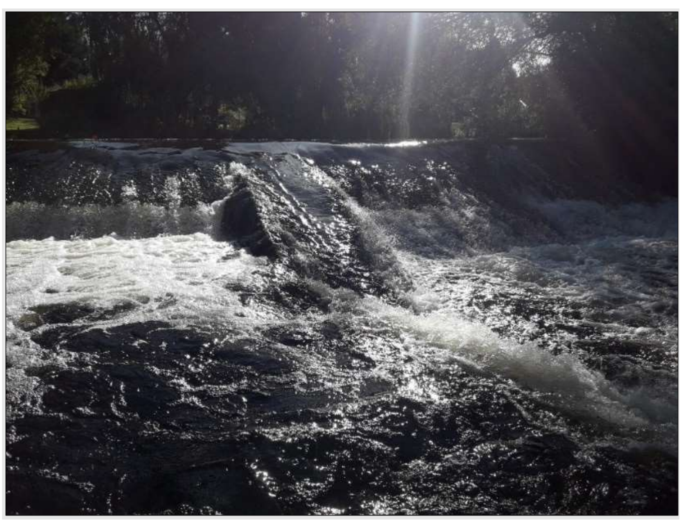

Figure 45. Fish passage option (TS2).

Transversal 3:

In prevailing conditions, this transversal was a high impact partial barrier (score 0.3) to upstream migration for all species except cyprinids and juvenile eel. For juvenile eel, the transversal posed no barrier (score 1.0), as climbing substrate was available. For cyprinids, the slope represented a complete barrier (score 0.0) due to the effective length (28m). The lip at the crest was a limiting factor for the upstream passage of the remaining species. Adult lamprey and juvenile salmonids were additionally restricted by medium levels of turbulence and the effective length of the transversal. In high flows, with the potential for increased velocity and turbulence, this transversal could become a complete barrier for adult lamprey. With regards to downstream movement, almost all species encountered no barrier (score 1.0). However, depths of 0.09m to 0.12m at the crest created a low impact partial barrier (score 0.6) for the downstream passage of adult salmon. In high flows, this barrier will be removed due to increased depths.

Figure 46. Weir face (TS3).

Passability Assessment for Site

On the day of survey, Temple Mills Weir was a high impact partial barrier (score 0.3) to the upstream migration of salmonids and adult lamprey (Table 10). For cyprinids, the weir represented a complete barrier (score 0.0). For juvenile eel, no barrier (score 1.0) was encountered due to the climbing substrates available at transversals one and three. Adult salmonids could also negotiate transversals one and three. However, adult lamprey and juvenile salmonids could only move upstream at transversal three (score 0.3). High flows will be unlikely to increase the species' passage options. In fact, adult lamprey will potentially be left with no viable routes for upstream migration in elevated flows. Downstream migrants were presented with no barriers (score 1.0) and could utilize any of the three transversals to traverse the structure. Transversal three had the best passibility overall, facilitating the upstream migration of all species but cyprinids. Transversal two was the most difficult route overall, being unsuitable for any species, despite being designed for fish passage.

Table 10: Final Passability Assessment for Temple Mills Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			✗		✗			
	high flows			✗		✗			
Adult Trout (AT)	current conditions			✗		✗			
	high flows			✗		✗			
Cyprinids (C)	current conditions				✗	✗			
	high flows				✗	✗			
Adult Lamprey (AL)	current conditions			✗					
	high flows				✗				
Juvenile Eel (JE)	current conditions	✗							
	high flows	✗							
Juvenile Salmonids (JS)	current conditions			✗		✗			
	high flows			✗		✗			
Juvenile Lamprey (JL)	current conditions					✗			
	high flows					✗			
Adult Eel (AE)	current conditions					✗			
	high flows					✗			

10. Straffan Weir

This weir is 8.26km upstream from the previous barrier and 29.33km upstream from the tidal limit at Island Bridge. The barrier is located immediately upstream of Straffan Bridge, Co. Kildare. The current structure was built circa 1930, however a weir at the same location is also visible in the historic OSI maps dating from the early 19th century (Figure 47). The weir is of masonry construction with a total hydraulic head height of 2.28m. The estimated width of the barrier along the crest is 50m, all of which were wetted on the date of survey. The estimated channel width at this point is 30m. The weir offered three transversal sections which are detailed below.

Figure 47. The location of Straffan Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2018).

Transversal 1:

In prevailing conditions, this transversal was a complete barrier (score 0.0) for the upstream migration of all species, except juvenile eel. Juvenile eel could avail of the climbing substrate to surmount the structure, and therefore encountered no barrier (score 1.0). Slope (20.36%) was the primary obstacle for the remaining species. The high levels of turbulence were an additional complete barrier for cyprinids, adult lamprey, and juvenile salmonids. Adult salmon also faced a compounding obstruction, represented by impassable low depths at the midpoint (≤0.06m). Low depths (≤0.11m) at the crest of the transversal limited the migration of adult salmon travelling in the opposite direction, resulting in a low impact partial barrier (score 0.6). However, the depth barrier to downstream migration will be removed in high flows. No barrier (score 1.0) existed for the remaining downstream migrants.

Figure 48. Weir face (TS1).

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species, except juvenile eel. Juvenile eel encountered no barrier (score 1.0) due to the available climbing substrate. Slope (17.54%) was the primary obstacle for the remaining species. High velocities (1.71m/s to 2.45m/s) recorded along the extent of the transversal, in addition to high levels of turbulence, were further barriers to upstream passage for cyprinids, adult lamprey, and juvenile salmonids. Downstream migration was negatively impacted by high velocities (2.07m/s to 2.42m/s) at the transversal crest. This swim obstacle created a low impact partial barrier (score 0.6) for adult salmonids, a high impact partial barrier (score 0.3) for juvenile salmonids, a complete barrier (score 0.0) for cyprinids, and no barrier (score 1.0) for juvenile lamprey and adult eel.

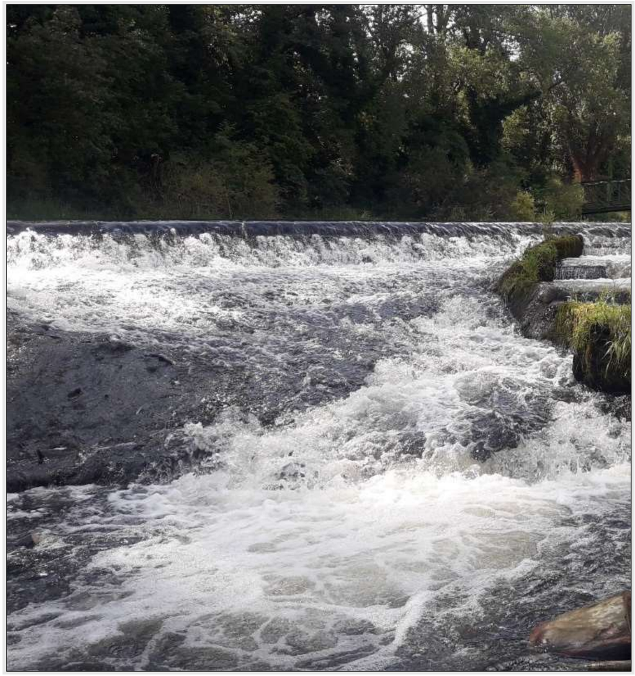

Figure 49. Weir face (TS2).

Transversal 3:

In prevailing conditions, this fish passage option was a complete barrier (score 0.0) to the upstream migration of all species except adult salmonids. Although passable for adult salmonids, there were multiple obstacles limiting the species' migration success. The height (0.68m) and water depth (0.72m) of the steps, the presence of a crest lip, and high levels of turbulence, all individually relegated this transversal to a high impact partial barrier (score 0.3) for adult salmonids. The step height and turbulence had a greater impact on passage for cyprinids, adult lamprey, juvenile eel, and juvenile salmonids. These obstacles created a complete barrier for these species. High weir crest velocities (2.07m/s to 2.42m/s) formed an additional complete barrier for cyprinids, adult lamprey, and juvenile eel.

Downstream migration was also impeded by the high crest velocities. This swim obstacle resulted in a low impact partial barrier (score 0.6) for adult salmonids, a high impact partial barrier (score 0.3) for juvenile salmonids, a complete barrier (score 0.0) for cyprinids, and no barrier (score 1.0) for juvenile lamprey and adult eel.

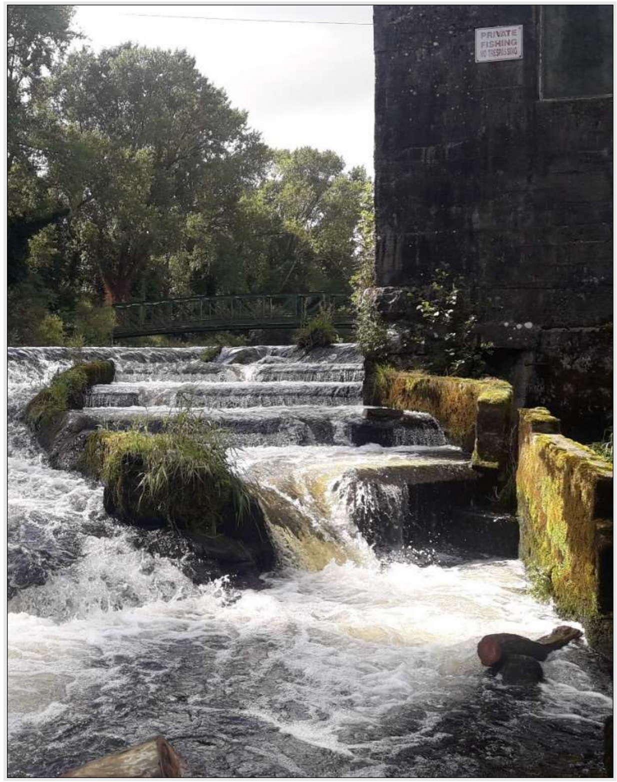

Figure 50. Fish passage option (TS3).

Passability Assessment for Site

On the day of survey, Straffan Weir was a complete barrier (score 0.0) to the upstream migration of all species, except adult salmonids and juvenile eel (Table 11). For juvenile eel, transversals one and two provided climbing substrates that allowed the species to circumvent the water flow. This resulted in no barrier (score 1.0) being encountered by the species. Of the three potential routes, adult salmonids could only make passage at transversal three. Although designed to accommodate fish passage, transversal three was a high impact partial barrier (score 0.3) for adult salmonids and failed to facilitate the upstream migration of other species. With regards to downstream migration, transversal one offered the best passage. Species other than adult salmon faced no barrier (score 1.0). Adult salmon experienced a high impact partial barrier (score 0.3) which will be eliminated in higher flows.

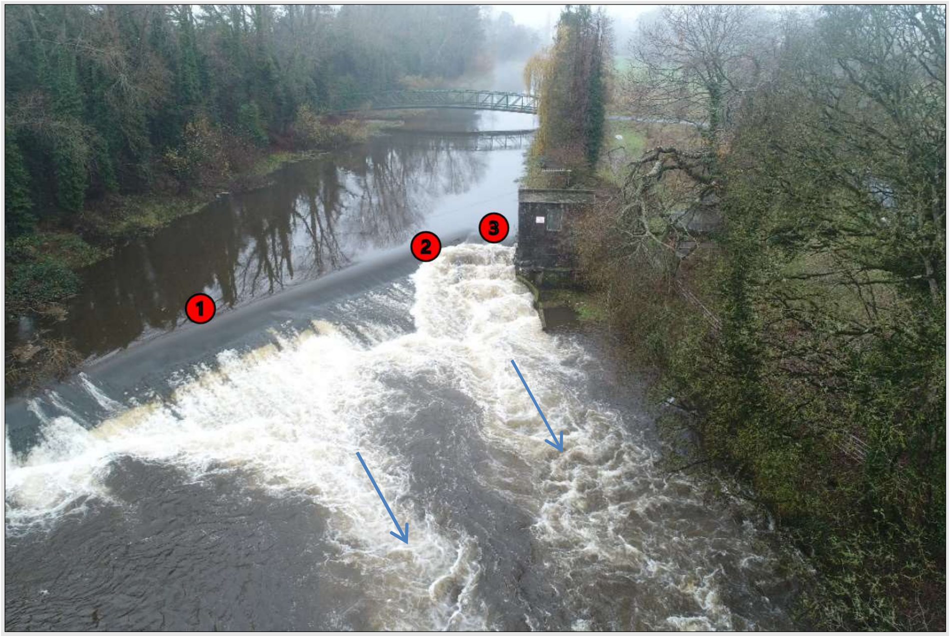

Figure 51. Drone image of Straffan Weir taken by IFI, December 2018. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 11: Final Passability Assessment for Straffan Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			X			X		
	high flows			X		X			
Adult Trout (AT)	current conditions			X		X			
	high flows			X		X			
Cyprinids (C)	current conditions				X	X			
	high flows				X	X			
Adult Lamprey (AL)	current conditions				X				
	high flows				X				
Juvenile Eel (JE)	current conditions	X							
	high flows	X							
Juvenile Salmonids (JS)	current conditions				X	X			
	high flows				X	X			
Juvenile Lamprey (JL)	current conditions					X			
	high flows					X			
Adult Eel (AE)	current conditions					X			
	high flows					X			

11. Morristown Lattin Weir

This weir is 19.43km upstream from the previous barrier and 48.77km upstream from the tidal limit at Island Bridge. It is located in Morristown Lattin, Co. Kildare, on the border with Yeomanstown and immediately upstream from Victoria Bridge. The weir segregates the main river channel from a mill race, which previously supplied power to a corn mill (Figure 52). The weir is constructed from masonry but is in a state of significant disrepair. The total hydraulic head height of the weir, at 0.64m, is the lowest of the thirteen barriers detailed in this report. The total width along the crest is estimated to be 100m, a quarter of which was estimated to have been wetted on the date of survey. The channel width at this point is approximately 32m.The sloping Morristown Lattin Weir offered two transversal sections to migratory fish, which are described below.

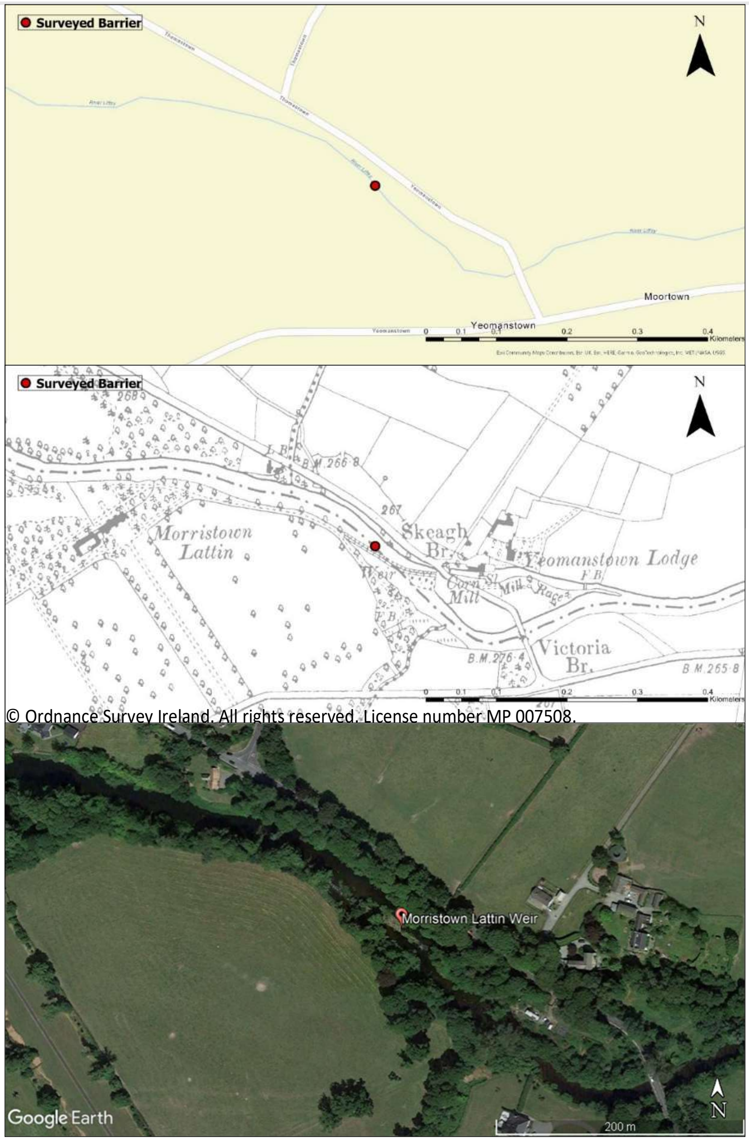

Figure 52. The location of Morristown Lattin Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2018).

Transversal 1:

In prevailing conditions, this transversal was a high impact partial barrier (score 0.3) to the upstream migration of salmonids and cyprinids. For adult lamprey and juvenile eel, the transversal was a complete barrier (score 0.0) due to the outlet velocities (1.56m/s to 1.76m/s). For salmonids and cyprinids, debris blocking the transversal was the primary obstacle to upstream passage. However, juvenile salmonids and cyprinids also faced additional barriers, such as slope (15.61%) and medium levels of turbulence. Downstream migrants of all species encountered a high impact partial barrier (score 0.3) due to the same debris restricting upstream movements.

Figure 53. Transversal section (TS) 1.

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species, except adult salmonids. For adult salmonids, the transversal was a high impact partial barrier (score 0.3). High levels of turbulence were the primary obstacle for all species. Juvenile eel also had to contend with an additional swim barrier caused by velocities greater than 0.8m/s at the midpoint and crest. Downstream migrants of all species encountered no barrier (score 0.0) at this transversal.

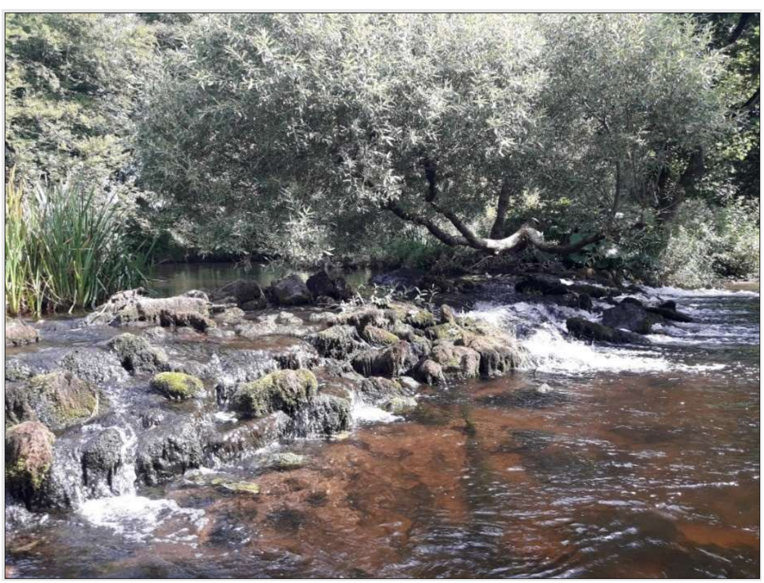

Figure 54. Transversal section (TS) 2.

Passability Assessment for Site

On the day of survey, Morristown Lattin Weir was a high impact partial barrier (score 0.3) to the upstream migration of all species, except adult lamprey and juvenile eel (Table 12). For adult lamprey and juvenile eel, the structure was a complete barrier (score 0.0). Adult salmonids could make upstream passage at either transversal one or two, but juvenile salmonids and cyprinids were only able to navigate transversal one. Downstream migrants of all species were best catered for at transversal two, where they encountered no barrier (score 1.0).

Figure 55. Google Earth ortho-image of Morristown Weir, June 2018. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 12: Final Passability Assessment for Morristown Lattin Corn Mill Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon (AS)	current conditions			✘		✘			
	high flows			✘		✘			
Adult Trout (AT)	current conditions			✘		✘			
	high flows			✘		✘			
Cyprinids (C)	current conditions			✘		✘			
	high flows			✘		✘			
Adult Lamprey (AL)	current conditions				✘				
	high flows				✘				
Juvenile Eel (JE)	current conditions				✘				
	high flows				✘				
Juvenile Salmonids (JS)	current conditions			✘		✘			
	high flows			✘		✘			
Juvenile Lamprey (JL)	current conditions					✘			
	high flows					✘			
Adult Eel (AE)	current conditions					✘			
	high flows					✘			

12. Newbridge College Weir

The Newbridge College Weir is 6.93km upstream of the previous barrier and 55.70km upstream from the tidal limit at Island Bridge. It is located immediately adjacent to Newbridge College, Co. Kildare. The weir is constructed from masonry and corrugated steel, with a total hydraulic head height of 0.92m. The total width of the weir along its crest is 70m, of which 65m were wetted on the date of survey. The width of the river channel at this point is 25m. This sloping structure offered two transversal sections, which are described below.

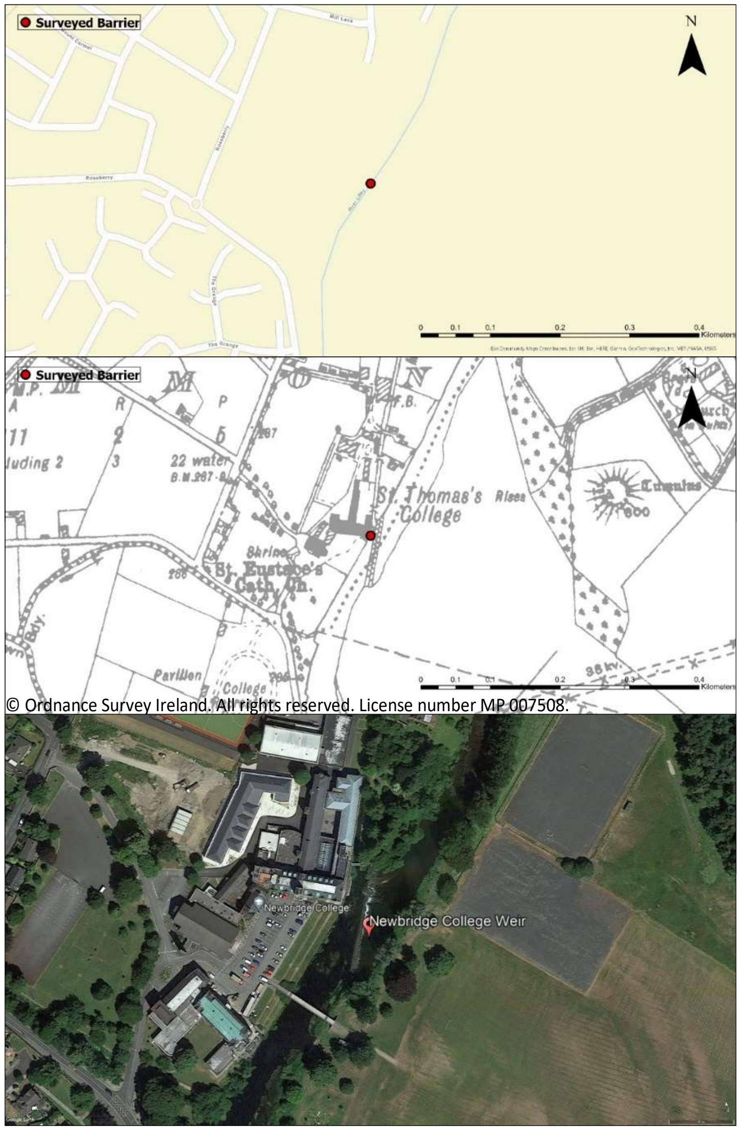

Figure 56. The location of Newbridge College Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2018).

Transversal 1:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of all species, except adult trout and juvenile eel. For adult trout, the transversal was a high impact partial barrier (score 0.3) caused by a crest lip and low outlet depths (≤0.07m). For juvenile eel, the transversal posed no barrier (score 1.0) due to the available climbing substrate. The low outlet depths entirely prohibited the passage of adult salmon. The remaining species (cyprinids, adult lamprey, and juvenile salmonids) were prevented from passing the transversal by the vertical drop (0.35m) at the broken edge of the weir outlet. Downstream migrants predominantly experienced no barrier (score 0.0) at this transversal. However, for adult salmon, low depths (≤0.1m) at the crest created a high impact partial barrier (score 0.3). This barrier will be removed in high flows. High flows will improve passage for all salmonids. With regard to upstream migration, High flows will convert the transversal to a low impact partial barrier (score 0.6) for adult salmonids, and a high impact partial barrier (score 0.3) for juvenile salmonids.

Figure 57. Weir face (TS1).

Transversal 2:

In prevailing conditions, this transversal was a high impact partial barrier (score 0.3) to the upstream migration of all species, except adult salmonids and juvenile eel. For adult salmonids, the transversal presented a low impact partial barrier (score 0.6). For juvenile eel, no barrier (score 1.0) was encountered as a climbing substrate was available. Medium levels of turbulence were the primary obstacle to passage. Adult salmon were also hindered by outlet depths less than 0.11m, while cyprinids faced an additional upstream barrier in the form of the effective length (6.4m). Downstream migration was unimpeded, and species faced no barrier (score 1.0).

Figure 58. Broken section of weir (TS2).

Passability Assessment for Site

On the day of survey, Newbridge College Weir was a high impact partial barrier (score 0.3) to the upstream migration of all species, except adult salmonids and juvenile eel (Table 13). For adult salmonids and juvenile eel, the structure represented a low impact partial barrier (score 0.6) and no barrier (score 1.0) respectively. Transversal two offered the best upstream passability for all species, although adult trout and juvenile eel could also navigate transversal one. Downstream migrants faced no barrier (score 1.0) and were facilitated by both transversals one and two. Newbridge College Weir was the first barrier of the selection discussed in this report to support the upstream passage of all species in prevailing conditions.

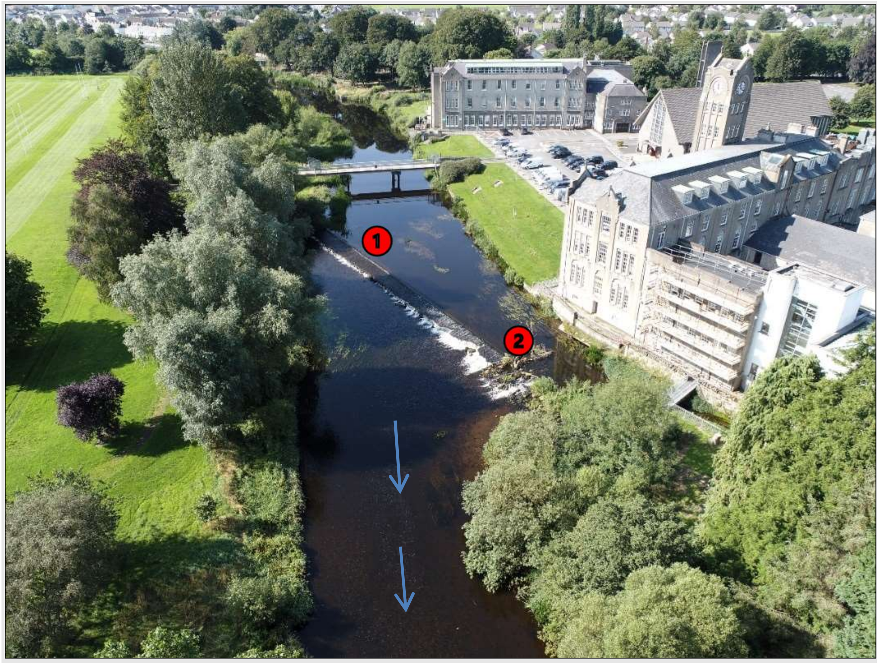

Figure 59. Drone image of Newbridge Weir taken by IFI, August 2021. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 13: Final Passability Assessment for Newbridge College Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon	current conditions		X			X			
(AS)	high flows		X			X			
Adult Trout	current conditions		X			X			
(AT)	high flows		X			X			
Cyprinids	current conditions			X		X			
(C)	high flows			X		X			
Adult Lamprey	current conditions			X					
(AL)	high flows			X					
Juvenile Eel	current conditions	X							
(JE)	high flows	X							
Juvenile	current conditions			X		X			
Salmonids (JS)	high flows			X		X			
Juvenile	current conditions					X			
Lamprey (JL)	high flows					X			
Adult Eel	current conditions					X			
(AE)	high flows					X			

13. Athgarvan Weir

Athgarvan Weir is located 6.72km upstream from Newbridge College weir, and 62.41km upstream from the tidal limit at Island Bridge. It is situated immediately upstream of Athgarvan Bridge. The weir separates the main channel from a millstream associated with the 19th century Athgarvan Malthouse on the left bank of the river. Constructed from masonry and corrugated steel, the weir has a total hydraulic head height of 1.53m. The total width of the barrier along the crest is 138m, of which 130m were wetted on the date of survey. The river channel width at this point is 30m. The structure presented four transversal sections for potential fish passage, which included both vertical and sloping aspects.

Figure 60. The location of Athgarvan Weir on ESRI world street map, historic 6-inch OSI map (1829-41), and Google Earth ortho-imagery (2018).

Transversal 1:

In prevailing conditions, this fish passage option was a high impact partial barrier (score 0.3) to the upstream migration of all species except juvenile eel and adult lamprey. For adult lamprey, the midpoint velocities (1.57m/s to 2.33m/s) created a complete barrier (score 0.0). For juvenile eel, a climbing substrate resulted in no barrier (score 1.0). For the remaining upstream migrants, cyprinids and salmonids, the presence of a standing wave was the common obstacle. Cyprinids and juvenile salmonids also faced additional barriers in the form of medium levels of turbulence and an effective slope length of 18m. All species, save adult salmon, encountered no barrier (score 1.0) when migrating downstream. For adult salmon, crest depths less than 0.13m constituted a low impact partial barrier (score 0.6) to downstream movement.

Figure 61. Fish passage option (TS1).

Transversal 2:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of adult salmonids and cyprinids. Low water depths (≤ 0.05m) at the weir crest created an insurmountable obstacle for these species. For adult lamprey and juvenile salmonids, this section of the weir face constituted a high impact partial barrier (score 0.3). The low crest water depths, crest lip, slope (18.43%), and lack of effective resting locations all individually warranted the high impact partial barrier score. Juvenile eel had a climbing substrate available to them, resulting in no barrier (score 1.0) at this transversal. With the exception of juvenile lamprey, all downstream migrants were impeded by shallow depths at the transversal crest. For adult salmonids and cyprinids, the low water depth was a complete barrier (score 0.0). However, for juvenile salmonids and adult eel, it represented a high impact partial barrier (score 0.3). High flows will improve the passage, both upstream and downstream, for adult salmonids and cyprinids. The downstream movements of adult eel and juvenile salmonids will also be better facilitated in elevated flows.

Figure 62. Weir face (TS2).

Transversal 3:

In prevailing conditions, this vertical drop was a complete barrier (score 0.0) to the upstream passage of all species except juvenile eel. For juvenile eel, the limited water depths (≤ 0.04m) at the transversal crest created a low impact partial barrier (score 0.6). For the remaining species, the hydraulic head (1.58m) was the primary obstacle. Limited crest depths were an additional complete barrier for adult salmonids and cyprinids. A further limiting factor for the upstream passage of adult salmonids was the shallow plunge pool depth (0.45m).

All downstream migrants, with the exception of juvenile lamprey, were restricted to varying degrees by the low water depths at the crest of the transversal. Adult salmonids and cyprinids faced a complete downstream barrier (score 0.0), while juvenile salmonids and adult eel were presented with a high impact partial barrier (score 0.3). In high flows, with increased depths, downstream passage will be better facilitated.

Figure 63. Vertical drop (TS3).

Transversal 4:

In prevailing conditions, this transversal was a complete barrier (score 0.0) to the upstream migration of cyprinids and adult salmonids. Limited depths (≤ 0.04m) at the transversal crest were an insurmountable obstacle. Elevated flows will mitigate this issue. For adult lamprey and juvenile salmonids, the transversal was a high impact partial barrier (score 0.3). The low crest depths, crest lip, slope (10.63%), and effective length of the weir face (14.4m) all individually warranted the high impact partial barrier score. Juvenile eel had a climbing substrate available to them, resulting in no barrier (score 1.0) at this transversal.

All downstream migrants, with the exception of juvenile lamprey, were restricted to varying degrees by the low depths at the crest of the transversal. Cyprinids and adult salmonids faced a complete downstream barrier (score 0.0), while juvenile salmonids and adult eel were presented with a high impact partial barrier (score 0.3). In high flows, with increased depths, downstream passage will be better facilitated.

Figure 64. Weir face (TS4).

Passability Assessment for Site

On the day of survey, Athgarvan Weir was a high impact partial barrier (score 0.3) to the upstream migration of all species except juvenile eel (Table 14). For juvenile eel, the structure presented no barrier (score 1.0). Although species predominantly faced the same level of barrier, some migrants had more route options than others. Juvenile eel could make passage at any of the four available transversals. Juvenile salmonids could negotiate transversals one, two, or four. Adult lamprey had access to transversals two and four. However, adult salmonids and cyprinids were only capable of navigating transversal one. Downstream migrants of all species were best catered for at transversal one, where all except adult salmon encountered no barrier (score 1.0). For adult salmon, a low impact partial barrier existed, which will be removed in high flows. Athgarvan Weir is the second barrier of the selection discussed in this report to support the upstream passage of all species in prevailing conditions.

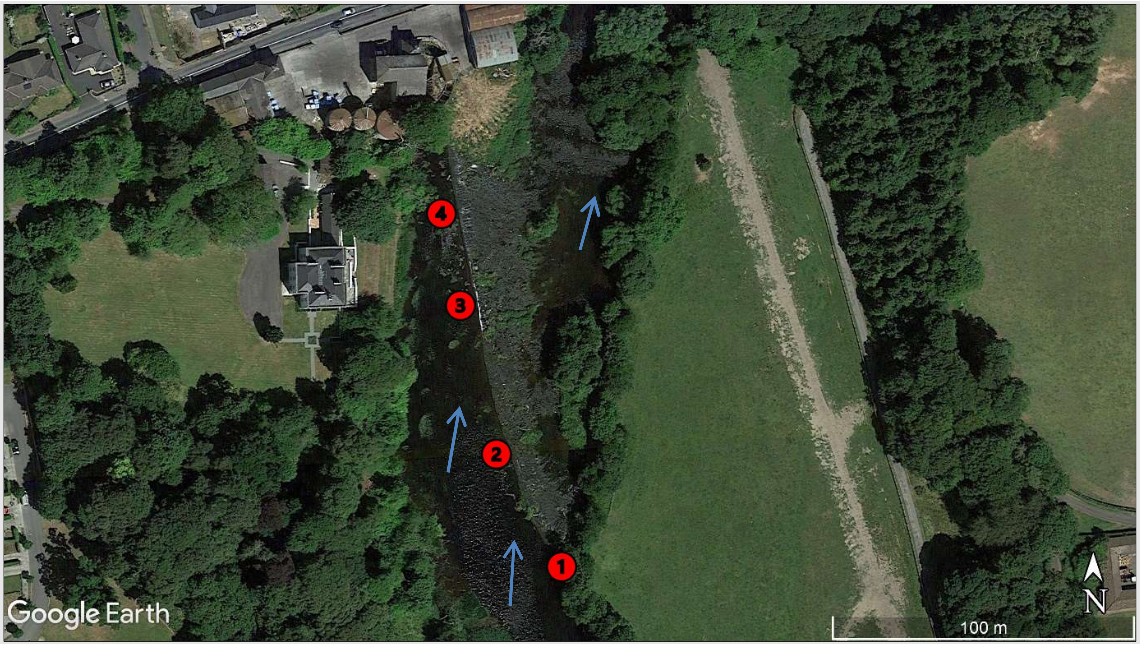

Figure 65. Google Earth ortho-image of Athgarvan Weir, June 2018. Blue arrows denote flow direction and red circles indicate transversal section number.

Table 14: Final Passability Assessment for Athgarvan Weir

		UPSTREAM MIGRATION				DOWSTREAM MIGRATION			
		No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0	No barrier 1	Partial barrier Low impact 0.6	Partial barrier High impact 0.3	Complete barrier 0.0
Adult Salmon	current conditions			✘			✘		
(AS)	high flows			✘		✘			
Adult Trout	current conditions			✘		✘			
(AT)	high flows			✘		✘			
Cyprinids	current conditions			✘		✘			
(C)	high flows			✘		✘			
Adult Lamprey	current conditions			✘					
(AL)	high flows			✘					
Juvenile Eel	current conditions	✘							
(JE)	high flows	✘							
Juvenile	current conditions			✘		✘			
Salmonids (JS)	high flows			✘		✘			
Juvenile	current conditions					✘			
Lamprey (JL)	high flows					✘			
Adult Eel	current conditions					✘			
(AE)	high flows					✘			

Methods for Improving Connectivity in the Liffey

Over the centuries, the Liffey has provided power generation, transport for trade, drinking water, an aesthetic focal point for the Capital of Ireland, and recreation in the form of kayaking and angling. In fact, Dublin is unusual amongst capital cities in that it continues to host a wild salmon fishery. In return for providing these services, the river has been compartmentalised, its flow diminished, and it's carrying capacity reduced. The impact of a restricted carrying capacity is not limited to the instream ecosystem. Terrestrial wildlife such as otters and certain native birds are also linked to the success of the aquatic environment. The anthropogenic fragmentation of the Liffey that enables it to provide services such as electricity generation, put at risk the natural, usually unseen, and more often undervalued, ecosystem services that the river provides in its fully connected state.

The Liffey and its native inhabitants have historic and cultural importance, as evidenced by the town name, “Leixlip”. Translated as “salmon leap”, the name is derived from the Norse for salmon, *lax*. This heritage, and the natural ecosystem services supplied by the Liffey, are threatened for future generations by the artificial structures and physical habitat modifications which result in poor ecological and hydrological connectivity.

As previously noted, artificial barriers impair the migration of fish and other stream biota to and from the habitats they require to spawn, feed, and seek refuge. Several smaller patches of relatively good habitat that are isolated from each other within a matrix of degraded habitat are created. Without access to these habitats, aquatic biota cannot complete their life cycle and sustain their populations. Larval lamprey, for example, require fine sediment, while gravels are necessary for adult spawning. The species must be free to travel to a variety of aquatic environments. The sequence of barriers presents a challenge for species movement, which becomes cumulatively harder as biota move through the system. Amelioration of artificial structures can be achieved to varying degrees by removal, breaching, or installation of a fish passage structure. Remediation efforts aimed at improving connectivity should target both barrier mitigation and habitat improvements. Below, potential mitigation options and their pros and cons are provided.

Barrier removal: Barrier removal is the preferred option from a continuity perspective because it is most effective at reconnecting isolated habitat patches. This approach facilitates the longitudinal passage of biota, but also improves water flow and sediment movement, which is critical to habitat forming processes. However, removal is not always undertaken due to issues related to the current use or ownership of the structure. As an alternative, existing structures may be modified, or new functioning structures installed in order to achieve partial connectivity.

Barrier breaching: Barrier breaching is the next best option. Similar results to barrier removal are achieved, while retaining some part of the original weir structure (Figure 66). It solves all upstream and downstream fish passage issues, is cheaper than a built fish passage option, addresses other problems such as structural safety, and does not hinder future options. However, as with barrier removal, there may be some societal and cultural issues. For example, some weirs have historical value or form part of the social heritage of an area.

Figure 66. Photos of breached weirs: (A) Ballyclough Weir in the Mulkear River, Co. Limerick, and (B) Kent Dam in the Cuyahoga River, Ohio, USA (breach in far right of image).

Fish passage structure: River infrastructure provides services that may be deemed too expensive or impractical to remove. Sometimes there can also be opposition to the proposed decommissioning projects. Retrofitting of barriers with fish passage structures (i.e. bypass channels or fishways) is therefore an option where removal is not feasible. There are two components to effective fish passage:

> **Attraction** - which involves designing fish passage options to ensure that the hydraulic conditions (flow paths and turbulence) near the structure guide fish to the fishway entrance or entrances.
>
> **Passage** - which involves the hydraulic and structural design of the fishway itself.

Fish passage must be constructed to accommodate the range of needs and swimming abilities of the many species of concern. After this consideration, basic approaches and principles can be identified for the design of fish passage facilities in all river systems. These are:

1. The smallest migrants usually have the weakest swimming ability, and this determines the maximum water velocity, turbulence, and gradient of upstream fishways.
2. The largest migrants and the volume of migratory biomass desired will determine the size, depth, space, and flow required in the fishway.
3. Headwater and tailwater levels determine the depths, operating range, length, and gradient of fishways.
4. Fishway entrances and designs may be substantially different for fish migrating at high flows during the wet seasons and fish migrating at low flows during the dry season.
5. For fish that only migrate during the daylight hours or the night-time hours, the fishway may need to incorporate large resting pools.
6. To meet fish passage objectives, upstream passage needs to consider adult fish (of varying sizes) and juvenile eel, while downstream passage needs to consider adult fish returning to sea, eggs, larvae, and juveniles.

Well-designed bypass channels can afford passage both upstream and downstream for fish and other stream biota (Figure 67). These will attempt to replicate conditions in natural channels by providing appropriate flow conditions, substrate type, plant cover and resting areas for fish. Bypass channels may also, to some extent, accommodate more natural flow and sediment movement downstream.

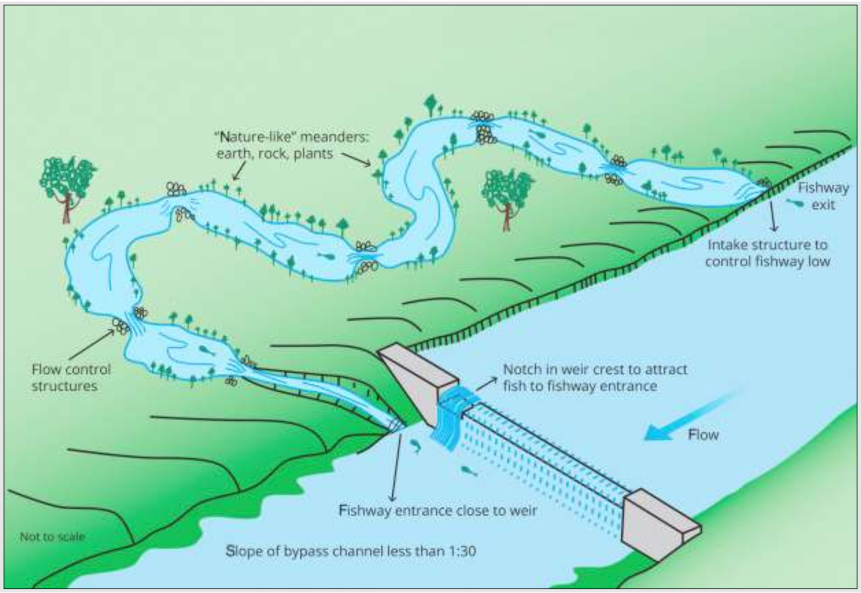

Figure 67. Illustration of a bypass channel for promoting fish and other stream biota passage (Thomas, 2017).

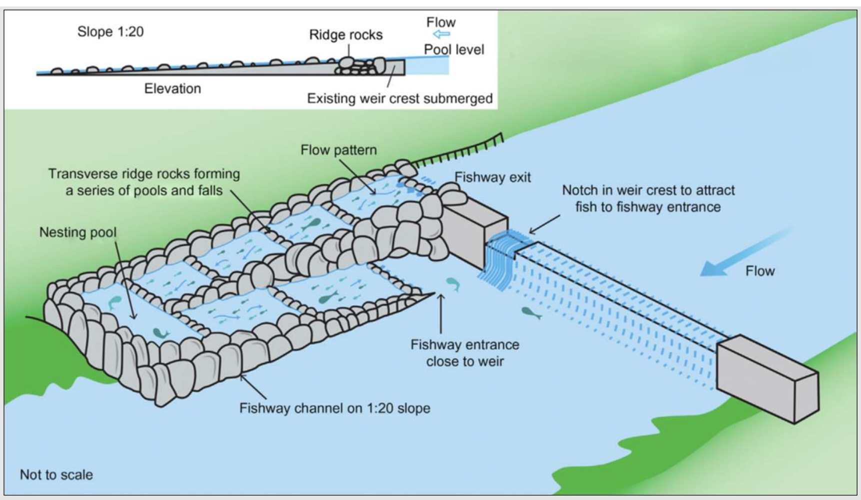

Figure 68. Illustration of partial-width pool and boulder rock-ramp fishway (Thomas, 2017).

A final mitigation option is the provision of a fishway (Figure 68 and 69). This is the most limited option in terms of connectivity, but it will at least provide for fish passage, if designed correctly. Fishways are low-gradient, stair-like structures featuring a series of steps interspersed with resting areas. They are designed to dissipate flow velocity and turbulence, thereby allowing fish to swim up and over barriers. Globally, fishways have proven most effective at facilitating the passage of large-bodied salmonids, but are often ineffective for smaller-bodied, slower swimming species (Mallen-

Cooper & Brand, 2000; Katopodis & Aadland, 2006). As such, due care must be taken during design to achieve effective fish passage for all species of concern.

Figure 69. A full width pool and boulder rock ramp type fishway at Tuckmill Bridge, River Slaney, designed to mitigate the barrier impact of a bridge apron/culvert.

The pool and boulder rock ramp fishway is considered to be among the most effective form of fish pass (Figures 68 and 69). Its gentle gradient, availability of resting places within the pools and appropriately sized gaps between the transverse rock ridges can accommodate a large variety of fish species.

Barrier Mitigation in the River Liffey

A well-connected river habitat is more resistant and resilient to negative events and pressures because it allows the natural recolonisation of upstream, downstream, and tributary environments by stream biota. It also allows natural habitat forming processes, like downstream sediment transport, to take place. The movement of substrate replenishes spawning areas and dwelling habitats for fish, invertebrate and plant species. Additionally, longitudinal connectivity supports a natural flow and temperature regime, which favours the adaptations of native species and increases the river's resilience to climate change.

The documented weirs on the Liffey offer a mix of vertical, sloping, and stepped aspects and are constructed predominantly of concrete and masonry. The original purpose of some of these structures is now mostly obsolete and they should be removed, breached, or mitigated wherever possible. Barrier removal or breaching will require the relevant structural, hydrological, and hydromorphological surveys to assess feasibility. Bypass channels may be a viable alternative in some cases but opportunities for their construction will be limited in urbanised environments, due to a lack of lateral space. The last option is mitigation via the installation of a fish pass. In this event, the preference is for the construction of a gently sloping pool and boulder rock ramp (Figure 70).

Figure 70. A full-width pool and boulder rock ramp fish pass designed to mitigate the impact of a weir on fish passage https://catchmentsolutions.com.au/portfolio/rock-ramp-fishway/

Whenever it is practical, the removal of artificial barriers to create a naturally connected river habitat is preferable to installing engineered fishways. Man-made fish passage options are expensive and require long-term maintenance. The fish passage options on the structures detailed in this report are, more often than not, in a state of disrepair and unfit for purpose. Of the 13 weirs, 10 have fish passage options designed to facilitate fish migration (Table 15). The Lucan West, Morristown Lattin, and Newbridge College weirs have no fish passage option, contrary to current legislation. Five of the 10 fish passes are complete barriers to all species. In certain cases, such as at The Wren's Nest Weir, the weir face itself provides better passage than the fish passage option. The remaining fish passes are accessible primarily to adult salmonids. However, none score better than 0.3 (high impact partial barrier) for adult salmonid upstream passage. If these fishways were repaired, starting at Island Bridge Weir and moving upstream, adult salmonid migration in the Liffey would improve. However, the restored fishways would still insufficiently service other important native fish, such as the Annex II listed lamprey species. This is due to the salmonid-orientated design of historical fish passes.

Table 15. The passability score calculated for each weir, per species. A complete barrier scores 0, a high impact partial barrier score 0.3, a low impact partial barrier scores 0.6, and no barrier scores 1.

Weirs encountered travelling upstream from sea		Fish passage option present?	Migrating Upstream					
			Adult Salmon	Adult Trout	Cyprinids	Adult Lamprey	Juvenile Eel	Juvenile salmonids
1	Island Bridge Weir	Yes	0.3	0.3	0	0	1	0
2	Chapelizod Weir	Yes	0.3	0.3	0	0	1	0
3	Palmerstown Lower Weir	Yes	0.3	0.3	0	0	1	0
4	The Wren's Nest Weir	Yes	0.3	0.3	0	0.3	1	0.3
5	Anna Liffey Weir	Yes	0.3	0.3	0	0	1	0.3
6	Lucan Weir	Yes	0	0	0	0	1	0
7	Lucan West Weir	No	0.3	0.3	0	0	0	0
8	Celbridge Abbey Weir	Yes	0	0	0	0.3	1	0.3
9	Temple Mills Weir	Yes	0.3	0.3	0	0.3	1	0.3
10	Straffan Weir	Yes	0.3	0.3	0	0	1	0
11	Morristown Lattin Weir	No	0.3	0.3	0.3	0	0	0.3
12	Newbridge College Weir	No	0.6	0.6	0.3	0.3	1	0.3
13	Athgarvan Weir	Yes	0.3	0.3	0.3	0.3	1	0.3

Thirteen large weirs fragment the main stem of the middle and lower River Liffey. Their mitigation should be considered in four stages. Lucan Weir (6) and Celbridge Abbey Weir (8) are the priority candidates for mitigation. These structures are currently complete barriers for multiple species, including adult salmonids. Their mitigation would grant adult salmonids greater access to the substantial yet currently under-utilised Rye Water and Morell tributaries. These rivers are important spawning and recruitment areas for brown trout and Atlantic salmon. However, in a 2019 survey, salmon were found at only 2 of the 15 sites fished in the Morell sub-catchment (IFI, 2019). None were recorded in the Lyreen, a tributary of the Rye Water (IFI, 2019).

The next stage should involve alleviating the impact of weirs 1 to 5, and 7. The mitigation of these structures should be carried out in chronological order, beginning at Island Bridge Weir (1) and moving upstream. This work would continue to enhance salmonid migration but is specifically targeted towards creating better access to suitable upstream habitat for non-salmonids, such as the Annex II listed lamprey species. The quick succession of large barriers within a 13-kilometre stretch, from Island Bridge Weir (1) to Lucan West Weir (7), prevents native non-salmonids from accessing some of the Liffey's major tributaries.

The third stage would require the amelioration of weirs 9 to 11. This would admit species to considerable sections of the River Liffey with a "Good" WFD ecological status. Downstream of Temple Mills Weir (9), species are confined to habitat that is predominantly of either "Poor" or "Moderate" quality.

Lastly, Newbridge College Weir (12) and Athgarvan Weir (13) if mitigated would allow fish access to additional tributaries and further areas of "Good" WFD status. These weirs should be mitigated last as they allow some level of passability for all species. Therefore, the financial investment of mitigation will equate to a better ecological reward if spent at weirs that are currently complete barriers. Additionally, Newbridge College and Athgarvan weirs are the furthest upstream, and so the ecological value of their mitigation hinges on the passability of the preceding downstream barriers. The success of each mitigation stage depends upon the completion of earlier work on higher priority structures.

Conclusions

The River Liffey has a range of barrier types disrupting habitat quality and ecological connectivity. The weirs listed in this report are significantly disruptive. Measures aimed at mitigating artificial barriers, such as removal, breach, or bypass, are likely to improve ecological connectivity and benefit a range of stream biota.

The Liffey still retains considerable ecological potential. The density and dispersal of migratory species such as Atlantic salmon would improve with mitigation efforts. By improving longitudinal connectivity, the habitat available to other important native species would also increase. This would help to enhance the fish community status of the upstream sections of the River Liffey as required under the Water Framework Directive.

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