The value of a desk study for building a national river obstacle inventory

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Conflict of Interest

The authors declare that they have no conflict of interest.

Abstract

This study evaluates two desk-based approaches for building an inventory of man-made river obstacles. The creation of a river obstacle inventory is a logical first step in developing a prioritisation process for obstacle removal and/ or modification. In this study, a desktop GIS (Geographical Information System) analysis of two rivers and their tributary network was undertaken, using two different approaches. The first involved analysing historical maps, satellite imagery and Ordnance Survey Ireland (OSI) Discovery Series maps, and producing a geo-referenced layer of all the potential river obstacles. The second involved developing a geo-referenced layer of potential river obstacles based on the intersections between elements of the transport network (roads and railways) and river systems. To determine the effectiveness of the desk studies, the located obstacles were cross-referenced with actual obstacles verified through a field survey.

The desk studies identified several thousand potential obstacles. The study utilising a range of maps consistently located a greater number of actual obstacles than the desk study based on intersections between the transport and river networks.

The results indicate that desk-based research offers an efficient and effective method for locating river obstacles and can guide subsequent field surveys aimed at confirming the presence of obstacles. This is particularly useful for eliminating from study large stretches of rivers that would otherwise need to be walked to confirm the presence, or otherwise, of potential river obstacles. In this regard, desk-based exercises can offer opportunities to save on both time and cost in larger river assessments.

Keywords: GIS, historical map, Reconnect, river barrier, satellite imagery, topographic maps

Introduction

Human activity continues to impose increasing pressures on the world's resources, including our freshwater systems (Vörösmarty et al., 2010). Many rivers now show signs of extensive modification, including regulation through impoundments (dams) and other control structures (weirs, barrages), water abstraction, and morphological alterations such as diversion, canalisation and straightening (Fehér et al., 2012). All this can influence river status under the EU Water Framework Directive 2000/60/EC (WFD), which requires member states to achieve at least good ecological and chemical status in all water bodies (rivers, lakes, groundwater, transitional waters and coastal waters) by 2027. Hydromorphology is recognised as having a supportive yet important role in the ecological condition of a river (Elosegi, Díez, & Mutz, 2010) and must be considered when assigning 'high' status to a waterbody or downgrading its status to 'good'. In the WFD, the hydromorphological quality element in rivers is comprised of three constituent parts; the hydrological regime, the continuity of the river and the morphological condition of the river. A high status river with respect to continuity is defined in the Directive as being "not disturbed by anthropogenic activities" and allowing "undisturbed migration of aquatic organisms and sediment transport". However, few riverine ecosystems remain in this ideal, uninterrupted state (Ward & Stanford, 1983). In Ireland, hydromorphological pressures are the third most significant for placing water bodies at risk of not meeting their high ecological status objectives (Department of Housing Planning Community and Local Goverment, 2018).

A ‘river obstacle’ or ‘barrier’ is a physical structure within the river channel, either natural or man-made, which has the potential to disrupt watercourse continuity/ connectivity by preventing or delaying the up- and/ or down-stream movement of aquatic organisms, together with organic and inorganic material (Bourne, Kehler, Wiersma, & Cote, 2011; Cote, Kehler, Bourne, & Wiersma, 2009; Gauld, Campbell, & Lucas, 2013; Lucas, Bubb, Jang, Ha, & Masters, 2009; Nunn & Cowx, 2012). Such obstacles or barriers within the channel can lead to the fragmentation of the river network. Man-made obstacles include dams, culverts which are perched or have shallow water levels and/or concentrated flow velocities (Mount, Norris, Thompson, & Tesch, 2011), bridge aprons, ford crossings, weirs and sluice gates, and it is estimated that there are several hundred thousand of these structures across Europe (Fehér et al., 2012). All these obstacles have the potential to modify the hydromorphology of a river (Elosegi et al., 2010) and to act as obstacles to the unrestricted movement of aquatic biota through the system (Lucas et al. 2009; Ovidio, Capra, & Philippart 2007; Ovidio & Philippart 2002; Tremblay et al. 2016). The ecological impacts of river obstacles are wide ranging. Obstacles have been shown to halt or delay fish migration (Lucas et al. 2009; Rolls, 2011), delay fish spawning (Lucas and Baras, 2001) and cause changes to upstream habitats and biotic communities (Mueller, Pander & Geist 2011). The impacts of obstacles can also vary depending on the organisms in question. For example, Van Looy, Tormos & Souchon (2014) found that fish are more affected by the fragmentation of rivers by dams, whereas macroinvertebrates experience greater impacts from impoundment induced habitat degradation. Furthermore, the relative impacts of obstacles can vary depending on the scale in question. Van Looy et al. (2014) found that in the Loire Basin in France, dams had a greater impact on the biotic communities at a regional, rather than a local scale.

In accordance with the WFD, the need for a national river obstacle inventory for Ireland has been highlighted in the River Basin Management Plan (Department of Housing Planning Community and Local Goverment, 2018). In other countries, potential river obstacle inventories at both national and regional scales are a prerequisite for prioritising actions aimed at restoring river connectivity and continuity (Januchowski-Hartley et al., 2013; Kroon & Phillips, 2016). While walking the entire length of a river channel is likely to be the most robust method of locating all obstacles, it is time consuming, costly and difficult to implement on a large scale. A potentially more efficient method involves a desktop GIS (Geographical Information System) analysis of the river network focussing on channel crossings that could involve bridges, culverts, or other cartographic indicators of potential obstacles. Desk-based studies of river systems are useful in that they can be carried out on a large scale. Furthermore, many of the required resources are free, widely available and reasonably up-to-date (for example, Google Maps (https://www.google.ie/maps/), Google Earth (https://www.google.com/earth/), Bing Maps (https://www.bing.com/maps) and Here Maps (https://wego.here.com). In Ireland, the MapGenie resource of Ordnance Survey Ireland (https://www.osi.ie/services/mapgenie/) is also of use. While global inventories of dams and reservoirs have been compiled (see for example, Lehner et al., 2011), there remains largely a paucity of information on the location of smaller river obstacles (Januchowski-Hartley et al., 2013) such as poorly constructed/ degraded road-crossings and low-head weirs. Inventories of "potential" river obstacles have been made using existing spatial datasets on road/ rail-river crossings and dams (Januchowski-Hartley et al., 2013) and by generating new datasets of road/ rail and river network intersections on a GIS platform where none existed (Januchowski-Hartley et al., 2013; Kroon & Phillips, 2016). In addition, some studies have utilised maps (Williams & Watford, 1997) and aerial imagery (Nelson, Pope & Voorhis, 2008) to locate potential obstacles. However, the effectiveness of these desk studies and the completeness of the datasets generated have not been assessed.

Here, two different desk study approaches for locating potential obstacles in two Irish river catchments located in the east and south-east of Ireland are presented. The first desk study utilises maps and satellite imagery, displayed in a GIS platform, to locate potential obstacles. The second is a more rapid assessment that is again underpinned by a GIS analysis and which involves identifying intersections of the transport network (roads and railway tracks) with river systems and recording each intersection as a potential obstacle. The effectiveness of both desk studies was assessed and compared by cross referencing the potential obstacles located in the desk studies with the actual obstacles recorded in a walk-over survey of the rivers. The advantages and disadvantages of the different approaches are discussed.

Methods

Study area

The Nore and Dodder catchments were the focus of this study (Table 1, Fig. 1). The River Nore is a designated Special Area of Conservation (SAC) under the EU Habitats Directive. It is an important salmon river and has previously been the focus of river obstacle research (Gargan et al., 2011). Water from the main stem of the river was historically used to power water mills (Hamond, 1990). The River Dodder catchment comprises a sub-catchment of the larger River

Liffey system that discharges into Dublin Bay. Approximately 60% of its catchment is located within the South Dublin City area and is classified as having “Artificial” landcover (Corine Land Cover (CLC) data (2012, Version 18.5.1), Table 1). Historically, numerous industries relied on this river as a source of stream power and this resulted in the river being heavily regulated in the 18th and 19th centuries through the construction of weirs (McEntee & Corcoran, 2016). Although the river does not have SAC status, it is an important recreational angling resource.

Desk study

Potential obstacles in the Nore and Dodder catchments were identified through a desk study using ArcGIS software from ESRI (ArcGIS 10.1). To ensure an unbiased assessment of potential obstacles in both catchments, the desk studies were carried out prior to obtaining the field data on the location of the actual obstacles.

Method I. Using satellite imagery, historical 25” maps and the Discovery Series maps

A number of different map/ shapefile layers, summarised in Table 2, were used to locate potential obstacles in each river channel. The Nore and Dodder catchments, as defined on the Irish Environmental Protection Agency’s (EPA) “WFDSub-catchments” shapefile, were the focus of the study, and the river systems as mapped by the EPA in the “WFDRiverWaterbodies” shapefile identified the two rivers and their tributary networks.

The main stem and tributary networks of both the Nore and Dodder River catchments were assessed for potential obstacles from sea to source, in c. 250 m segments from the “WFDRiverWaterbodies” GIS layer. The same segment was viewed with ESRI’s “World Imagery” satellite imagery, historical 25” and Discovery Series map layers (Fig. 2). In places where the resolution of the satellite imagery was poor, the same location was also viewed on Google Maps (https://www.google.ie/maps) and Here Maps (https://maps.here.com/). Potential obstacles (road crossings, weirs, culverts etc.) were marked as a point in a new ArcMap shapefile. The point was placed at the centre of each potential obstacle and for each potential obstacle, the following meta-data were recorded: a unique ID code, river name, catchment/ sub-catchment ID, object type, location, the type of map that indicated the potential obstacle and its geo-referenced coordinates (easting and northing).

For clarity, the term “actual obstacle” will be used when referring to obstacles that were identified through field survey. The term “potential obstacle” refers to the obstacles located using the desk-based methods.

Method II. Intersecting the transport network with the river network

As before, the Nore and Dodder catchments identified in the EPA's "WFDSub-catchments" shapefile were used as the boundary for this exercise. The EPA's river network GIS layer "WFDRiverWaterbodies" was intersected with the © OpenStreetMap (https://www.openstreetmap.org) data layer on the road and rail network in the catchments. The OSM data are freely available under the Open Data Commons Open Database License (ODbL) by the OpenStreetMap Foundation (OSMF).

Surveys and field data

Physical obstacles to fish migration were recorded during the bankside surveys of the Nore and Dodder catchments, mentioned above. The River Nore was walked in winter 2007-2008 by Inland Fisheries Ireland (Gargan et al., 2011). The Dodder catchment was walked in summer 2016 by the research team in University College Dublin (UCD). Obstacles recorded included any physical structures in the river channel that the field surveyors judged to have the capacity to prevent or delay the upstream movement of fish, including Atlantic salmon (*Salmo salar* L.), brown trout (*S. trutta* L.), sea lamprey (*Petromyzon marinus* L.), shad (*Alosa* sp.), the European eel (*Anguilla Anguilla* L.), pike (*Esox Lucius* L.) and cyprinids. The obstacles included perched culverts, culverts with shallow water depths, weirs, bridge aprons and ford crossings. The co-ordinates of each obstacle were recorded, and a GIS layer of the obstacles was generated.

Cross referencing actual obstacles with potential obstacles

To determine obstacle numbers and locations using desk-based methods, it was necessary to match the potential obstacle points with the actual obstacle points in ArcMap. The "buffer" tool was used in conjunction with the "select by location" tool in ArcMap to isolate the actual obstacles located in the desk study. A circular buffer zone with a 20 m radius was placed around each potential obstacle point. Any actual obstacles within this buffer zone were considered 'hits' (i.e., obstacles which were located using the desk study). Those obstacles located outside this buffer zone were considered 'misses' (i.e., obstacles which were not located using the desk study). Each 'miss' was individually verified, because in some cases the 20 m buffer zone was too small to locate the field obstacle GPS location (e.g. where the reading was taken on the bank of a large channel).

Data analysis

Standard verification techniques for dichotomous (obstacle is present or not present) forecasting were applied to the field and desk study data. Contingency tables (2 x 2) were generated that highlighted the frequency of "present" and "not present" predictions by the desk studies, and the occurrences identified by the field study. Predictions in this instance were the potential obstacles identified via the desk study, and occurrences were the actual obstacles recorded in the field. The number of type I and type II errors made were counted and displayed (Table 3). Analogous to its use in statistical hypothesis testing, a Type I error occurred when a desk study identified a potential obstacle where the field work showed none existed and a Type II error was recorded when the desk study failed to indicate a potential obstacle where the field study confirmed that one existed. Three performance indicators were calculated based on these contingency tables for the River Dodder and each sub-catchment of the River Nore: (i) the probability of detection (POD), (ii) the false alarm rate (FAR) and (iii) the critical success index (CSI). The POD indicates the proportion of the actual obstacles which were correctly identified. The FAR indicates the proportion of the identified potential obstacles that were not actual obstacles in the field. These included structures such as road crossings which were not deemed obstacles (clear span bridges or culverts without a downstream drop and with adequate water depths for fish passage) and weirs or fords which were either no longer present or were broken through, and were therefore no longer impeding fish passage. The CSI indicates how well the identified potential obstacles corresponded to the actual obstacles recorded in the field. This index is sensitive to hits, and takes both false alarms and misses into consideration (Weeink, 2010). Using values taken from the contingency tables, the indices were calculated as follows:

$$POD: \frac{Hits}{Hits+Misses} \quad \text{(i)}$$

$$FAR: \frac{False\ Alarms}{Hits+False\ Alarms} \quad \text{(ii)}$$

$$CSI: \frac{Hits}{Hits+Misses+False\ Alarms} \quad \text{(iii)}$$

Results

River Nore catchment

A total of 508 actual obstacles were recorded in the Nore catchment in the walkover survey carried out by Inland Fisheries Ireland (Gargan et al., 2011). Both the detailed desk study (Method I) and the rapid desk study (Method II) overestimated this number (Table 4). The total number of potential obstacles amounted to 2,917 in Method I, and 1,492 in Method II. Of the

2,917 potential obstacles identified in Method I, over 90% (2,697) were road-river crossings (bridges, culverts, fords).

The detailed mapping study undertaken for Method I consistently achieved equal or higher POD rates in the 21 sub-catchments of the Nore and its mainstem (96% over the entire catchment) compared with Method II. All of the actual obstacles on the mainstem and in eleven of the sub-catchments were successfully identified via Method I (Table 4). The POD for Method II was lower (84% over the entire catchment) and out of the 21 sub-catchments in the Nore, a 100% POD was only achieved in two sub-catchments, while five obstacles on the mainstem were missed.

A total of 19 obstacles were missed by Method I in the entire Nore catchment, and these were located on 1^{st} to 3^{rd} order streams (Fig. 3, Fig. 4). These were mostly natural obstacles (rock and bedrock formations), weirs and fords. Seventy-seven obstacles were missed via Method II, and these were located on 1^{st} to 6^{th} order streams (Fig. 3). These misses consisted of weirs, culverts, bridge aprons, bridges and natural obstacles. The FAR was high in both desk studies (Table 4). Because almost 450 of the 508 obstacles on the Nore were road crossings, the satellite and historical maps were not essential for their locating, as most were visible on the Discovery Series maps. Only about 5% of the hits were a result of either satellite imagery or historical maps alone.

River Dodder catchment

A total of 189 actual obstacles were recorded during the walkover survey of the Dodder catchment. As in the River Nore, Method I and Method II overestimated this number (Table 4). However, differences between the two desk study methods were more notable in the Dodder catchment, with a higher number of potential obstacles generated through Method II. Despite the increase in potential obstacles, the POD for Method II (43.4%) was almost half of what was observed in Method I (85.2%). The FAR was considerably lower in the Dodder (58.9%) than the values observed in the Nore and its sub-catchments (Table 4). Satellite imagery and historical maps were particularly important for locating obstacles in the Dodder. Thirty percent of the obstacles were located via satellite imagery alone (25 weirs and 19 road-crossings), and 21% of the obstacles were located via historical 25” maps alone (27 weirs, 3 waterfalls and 4 road-crossings). The remaining obstacles were visible on two or more maps. Of the 392 potential obstacles located via Method I, over 60% (242) were road-river crossings.

Discussion

Two key challenges faced by managers attempting to restore river connectivity/ continuity are, firstly, recording where in the river catchment the discontinuities occur (Januchowski-Hartley et al., 2013; Ovidio et al., 2007) and, secondly, deciding which of the discontinuities to prioritise for remediation works (Kemp & O'Hanley, 2010). This study addresses the first challenge - building a river obstacle inventory is a vital first step for implementing restoration action (Kroon & Phillips, 2016), and it is necessary to have an efficient, consistent and cost-effective means of building this inventory.

Method I, which used various maps to locate potential obstacles, detected 96% of the river obstacles in the Nore (count over the entire catchment), and 85% of them in the Dodder. With the exception of some peer-reviewed studies (Williams & Watford, 1997), the only mention of the application of detailed topographic maps to locate obstacles is in published reports (Beatty et al., 2013; Clarkin et al., 2005; Lawrence, Sully, Beumer, & Couchman, 2010; Nelson et al. 2008).

Method II had a consistently lower POD compared to Method I. This shows the importance of using a variety of maps to locate obstacles. The 25" historical maps were useful for identifying structures which were not on the Discovery Series maps, and which were hidden by tree cover in the satellite imagery.

A large number of potential obstacles relative to the number of actual obstacles in the catchments was observed, regardless of which desk study method was used. Surprisingly, the number of potential obstacles generated by intersecting the transport network with the river network on the Dodder was higher than that generated through the detailed desk study. This is likely to be contributed to by the heavily urbanised nature of the River Dodder. More than 2.5 km of the River Dodder and its tributary network (152.6 km in length) is culverted. Method II did not detect these stretches of culverted river (average culvert length 67 m; range between 4 m and >1 km), resulting in the number of road-river crossings being overestimated. Previous research using this desk-based approach has also reported high numbers of potential obstacles. Kroon and Phillips (2016), for example identified 5,536 potential obstacles (all road/ rail-river crossings) in the wet tropics region of Australia. It is worth noting that the authors of this study excluded 1st order streams and were limited to detecting obstacles at a scale of 1:100,000. This coupled with the fact that the authors did not include other obstacle types in their study (e.g. weirs) means that this figure is likely to reflect an underestimation of the true number of potential obstacles (Kroon & Phillips, 2016). Furthermore, Williams and Watford (1997) located over 5,300 structures potentially restricting tidal flow (this study was restricted to the coastal zone of rivers) in New South Wales, Australia. A case study on a small river network (total length 107 km) described in Beatty et al. (2013) located 288 potential obstacles.

Method I gave a consistently higher POD than Method II, particularly in the Dodder catchment. The gain in time with Method II was at the expense of a loss in accuracy, however. Only 43.4% of the obstacles in the Dodder catchment were correctly located using the road/ rail-river intersections. On the other hand, Method I located over 85% of the actual obstacles present in the catchment. The high number of weirs in the catchment (c. 113) contributed to this. The historical maps and satellite imagery were particularly useful for locating these structures. In the Dodder catchment for example, almost half of the correctly identified obstacles were only found because they were visible on either historical maps or satellite imagery. While the authors recognise that the road map data layer from OSM was potentially incomplete, the present study nonetheless indicates that intersecting the road and river network alone would not be sufficient to locate all the river obstacles in a river system. In addition, even the most extensive road data layers may not account for every road-river crossing, including, for example, those connecting two fields within a farm.

The FAR was consistently high for both desk study methods in both river catchments. This makes sense as many road/ rail-river crossings are not obstacles. However, a high FAR is preferable to a low POD. With this in mind, the desk studies described here (in particular Method I) take a precautionary approach to locating river obstacles, with a high number of false alarms being recorded, coupled with a high POD. This trend was reflected in the CSI values, which were low for both the Nore and Dodder river systems. This could have implications for the subsequent field work that must be carried out. Both desk studies overestimate the true number of river obstacles, so ground-truthing the potential obstacles is required. However, the desk study largely eliminates the need to walk entire river catchments to locate obstacles, allowing more focussed site visits. It is also important to note that a large number of the potential obstacles were road-river crossings (over 60% in the Dodder and over 90% in the Nore). The subsequent ground-truthing associated with these structures can be rapid, as the site can be readily accessed by road. If the structure is not an obstacle, this can be quickly noted, and the surveyor can move on to the next site. While it was not possible to estimate the time taken to carry out a desk study plus field verification in the catchments described here, this methodology has been applied to other catchments in Ireland and has been shown to save significant time in the field. For example, only 2% of the total river channel had to be walked in the most recent survey carried out on the Owenboliska River in County Galway, Ireland (Atkinson, unpublished data). The issue of large numbers of false alarms was considered by Kroon and Phillips (2016) and Mount et al. (2011). Kroon and Phillips (2016) recommended considering the distribution and abundance of fish species (both native and non-native), stream order, location within the catchment and the quality and quantity of upstream habitat to reduce the number of site visits. Alternatively, to focus field surveys on particular hydrological regions and structures, Januchowski-Hartley, Diebel, Doran & McIntyre (2014) attempted to predict the passability of road culverts in the Laurentian Great Lakes Basin, north-eastern North America, using remotely sensed data. Mount et al. (2011) carried out a similar process of elimination to that of Kroon and Phillips (2016), to help guide field assessments. They indexed culverts based on the amount of habitat available to fish upstream. Culverts on stream reaches without suitable fish habitat were excluded from further study. This index was used to prioritise culverts for potential remediation. Such an index could also be applied to prioritise potential obstacles for ground-truthing. Gargan et al. (2011) also eliminated 1st order streams and those that exceeded 4% gradients in their GIS risk assessment of the obstacles in the Nore catchment. While there is clear value in having a fully complete river obstacle inventory, the extent of the desk study and resultant field study research could be reduced by carrying out an initial characterisation of headwater streams and eliminating from further consideration those which are unsuitable for sustaining fish. These refinement processes could be readily applied to future obstacle inventory building protocols. In addition, surveyors should liaise with local stakeholders (anglers, kayakers etc.) prior to conducting field surveys, as these groups are likely to know the river system well and may be aware of the locations of obstacles. Citizen scientist records may also be a useful source of information when constructing river obstacle inventories. The River Obstacles website (https://www.river-obstacles.org.uk/), for example, contains numerous records, many of which are uploaded by citizen scientists using the “River Obstacles” app. This app was introduced in Ireland in 2016.

The desk studies presented are limited by data availability and the age of the satellite images used. However, considering that OSM is actively updated and maintained, and other mapping resources (Google, Bing, Here – links can be found above) are freely available and being continually updated, we think this limitation is minor. While it is possible that certain structures will be missed, the present study suggests that this number is likely to be small.

While it is clear from this study that not every road crossing is an actual river obstacle, each road crossing does have that potential and should be considered thus until proven otherwise. The authors recommend using the more detailed mapping desk study for future river obstacle mapping efforts. Indeed, coupling this with the rapid road-river intersect study would improve the efficiency of the desk work. The desk studies described above can help guide the field survey, making it more efficient and targeted. In particular, the desk study lends itself to remote locations, where walk-over surveys of the river network may be especially difficult and time-consuming. In Ireland, for example, 77% of the total river network are headwater streams (Strahler 1^{st} and 2^{nd} order), amounting to a total length of 56,743 km (McGarrigle, 2014). These streams are typically isolated, overgrown and difficult to access. Furthermore, while obtaining landowner permission to access sites is necessary, the desk study followed by ground-truthing the potential obstacles reduces the amount of land that requires access, thus reducing the time and effort involved in locating and contacting landowners.

Regardless of difficultly, river obstacle inventories are a necessary resource for effective river management. Knowing the locations of obstacles in river systems can guide managers to make informed decisions pertaining to structures that should be prioritised for removal or remediation, contributing ultimately to improved riverine connectivity.

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Tables

Table 1. Catchment characteristics of the Dodder and Nore. Figures are based on EPA data (catchment area, river length), OpenStreetMap data (transport network length) and Corine Land Cover (CLC) data (2012, Version 18.5.1).

River	**Catchment Area (km^2)**	**Total river network length (km)**	**Transport network length (km)**		**Land cover (expressed as percentage contribution)**				
			Railway	Road	Artificial surface	Agriculture areas	Forest and semi-natural areas	Wetland	Waterbodies
Nore	2585.49	2208.4	124.8	4676.3	1.4	85.7	10.8	2.1	0.2
Dodder	167.77	152.6	61.2	2305.9	61.3	17.7	9.6	11	0.4

Table 2. The various map layers and data sources used for the desk studies.

File Type	Source	Link	Description
Raster Map Layer	Ordnance Survey Ireland (OSI)	https://www.osi.ie/	1:50,000 Discovery series map
			Historic 25" map (1897-1913)
	Environmental Systems Research Institute (ESRI)	Available in ArcMap base layers	World imagery, high resolution satellite and aerial imagery (2011+)
Shapefile	Environmental Protection Agency, Ireland (EPA)	http://gis.epa.ie/	'WFDRiverWaterbodies' (mapped at 1:50,000 scale)
			'WFDSubcatchments'
	© OpenStreetMap contributors	https://www.openstreetmap.ie/resources/data/	Open source data on road and rail network

Table 3. The 2x2 contingency table template used to compare the results of the desk study with the results of the walkover survey of the Nore and Dodder river catchments.

		Actual Obstacles (Occurrences)	
		Present	**Not present**
Potential Obstacles (Predictions)	**Present**	Hits (Correct Positive Identification)	False Alarm (Type I error)
	Not present	Misses (Type II error)	Correct Negative Identification (n/a)

Table 4. Data from the sub-catchments of the Nore and the Dodder catchment, showing river length, the number of actual obstacles and the number of potential obstacles in each sub-catchment. The number of hits (correctly identified actual obstacles), number of misses (actual obstacles that the desk study failed to locate) and indices for each sub-catchment calculated from the 2x2 contingency table are also shown for the two desk studies carried out (Method I (M I) and Method II (M II)).

Subcatchment	**River Length Assessed**	**Actual Obstacles**	**Potential Obstacles**		**Number of Hits**		**Number of Misses**		**Number of False Alarms**		**Probability of Detection (%)**		**False Alarm Rate (%)**		**Critical Success Index (%)**	
			M I	**M II**	**M I**	**M II**	**M I**	**M II**	**M I**	**M II**	**M I**	**M II**	**M I**	**M II**	**M I**	**M II**
Nore_Mainstem	96	20	82	39	20	15	0	5	62	24	100.0	75.0	75.6	61.5	24.4	34.1
Glory_SC_010	55.1	13	44	42	13	12	0	1	31	32	100.0	92.3	70.5	72.7	29.5	26.7
Dinin[North]_SC_010	161.5	22	257	95	21	20	1	2	236	79	95.5	90.9	91.8	79.8	8.1	19.8
Munster_SC_010	135.7	16	259	77	16	16	0	0	243	61	100.0	100.0	93.8	79.2	6.2	20.8
Dinin[South]_SC_010	88.4	6	91	51	4	4	2	2	87	47	66.7	66.7	95.6	92.2	4.3	7.5
Goul_SC_010	106.7	19	126	77	19	18	0	1	107	59	100.0	94.7	84.9	76.6	15.1	23.1
Erkina_SC_010	116.3	60	178	87	60	51	0	9	118	39	100.0	85.0	66.3	43.3	33.7	51.5
King's[Kilkenny]_SC_010	178	17	247	115	16	14	1	3	231	101	94.1	82.4	93.5	87.8	6.5	11.9
Nore_SC_010	169.6	58	193	128	56	53	2	5	137	76	96.6	91.4	71.0	58.9	28.7	39.6
Nore_SC_020	141.8	21	98	62	21	16	0	5	77	47	100.0	76.2	78.6	74.6	21.4	23.5
Nore_SC_030	61.4	17	93	44	17	15	0	2	76	29	100.0	88.2	81.7	65.9	18.3	32.6
Nore_SC_040	104.2	0	127	94	0	0	0	0	127	94	n/a	n/a	100.0	100.0	0.0	0.0
Nore_SC_050	108.8	11	131	83	11	10	0	1	120	73	100.0	90.9	91.6	88.0	8.4	11.9
Nore_SC_060	99.7	21	127	68	21	19	0	2	106	51	100.0	90.5	83.5	72.9	16.5	26.4
Nore_SC_070	98.5	34	134	70	30	30	4	4	104	40	88.2	88.2	77.6	57.1	21.7	40.5
Nore_SC_080	92.5	17	105	60	17	15	0	2	88	47	100.0	88.2	83.8	75.8	16.2	23.4
Nore_SC_090	58.1	5	104	47	5	5	0	0	99	42	100.0	100.0	95.2	89.4	4.8	10.6
Nore_SC_100	72.8	46	149	76	43	39	3	7	106	40	93.5	84.8	71.1	50.6	28.3	45.3
Nore_SC_110	111	17	159	63	17	14	0	3	142	50	100.0	82.4	89.3	78.1	10.7	20.9
Nore_SC_120	75.9	34	95	48	32	22	2	12	63	25	94.1	64.7	66.3	53.2	33.0	37.3
Nore_SC_130	59.3	40	103	58	37	29	3	11	66	31	92.5	72.5	64.1	51.7	34.9	40.8
Nore_SC_140	17	14	15	8	13	12	1	2	2	6	92.9	85.7	13.3	33.3	81.3	60.0
Dodder	152.6	189	392	450	161	82	28	107	231	368	85.2	43.4	58.9	81.8	38.3	14.7

Figure Headings

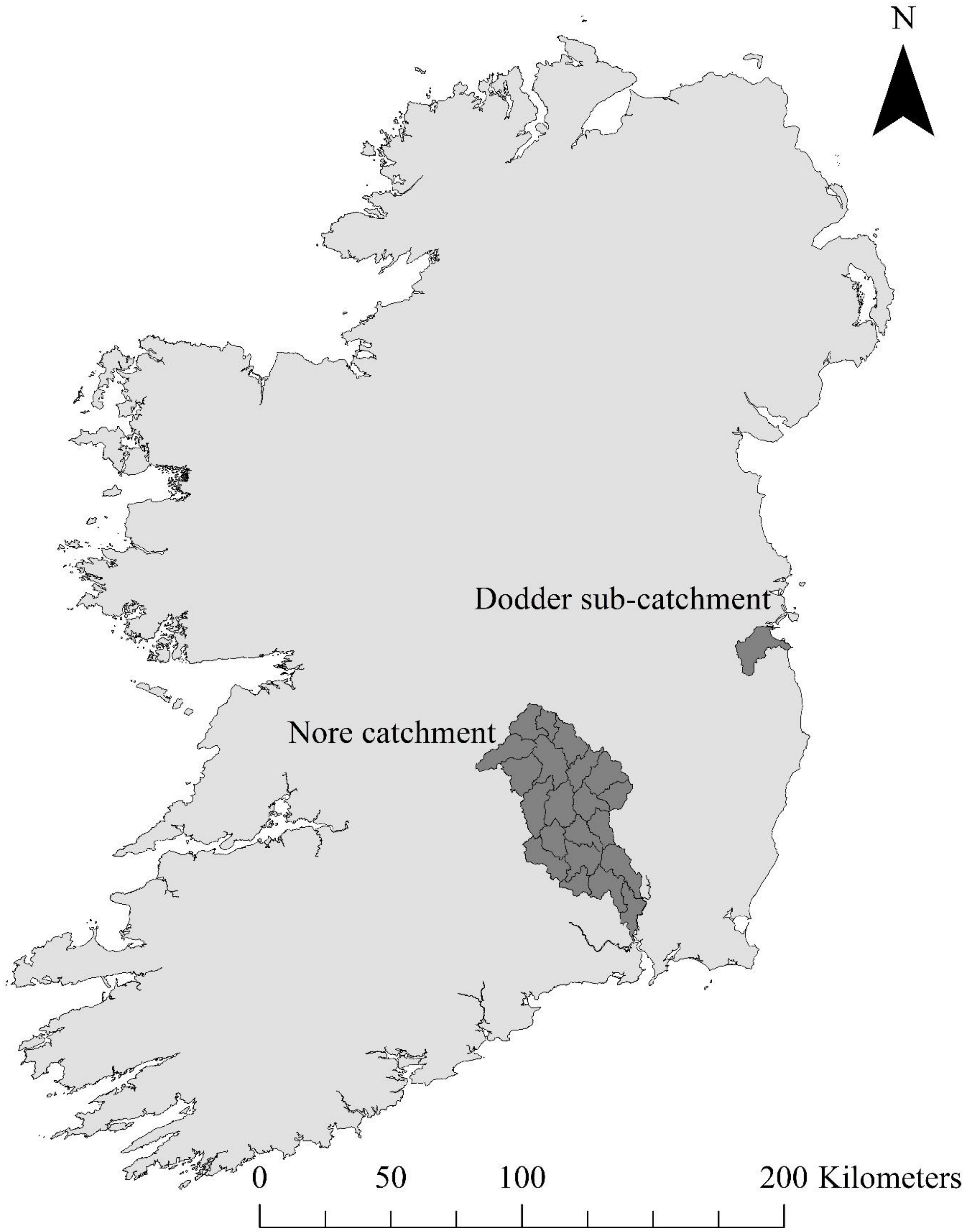

Figure 1. Map showing the location of the Nore catchment and Dodder sub-catchment in Ireland.

Figure 2. Examples of the map layers used to locate potential obstacles in Method I. The weir pictured in (d) and indicated with a star (a-c) was only visible on the historical 25” map layer (a). The satellite image (b) and Discovery Series map (c) were unable to indicate the obstacle.

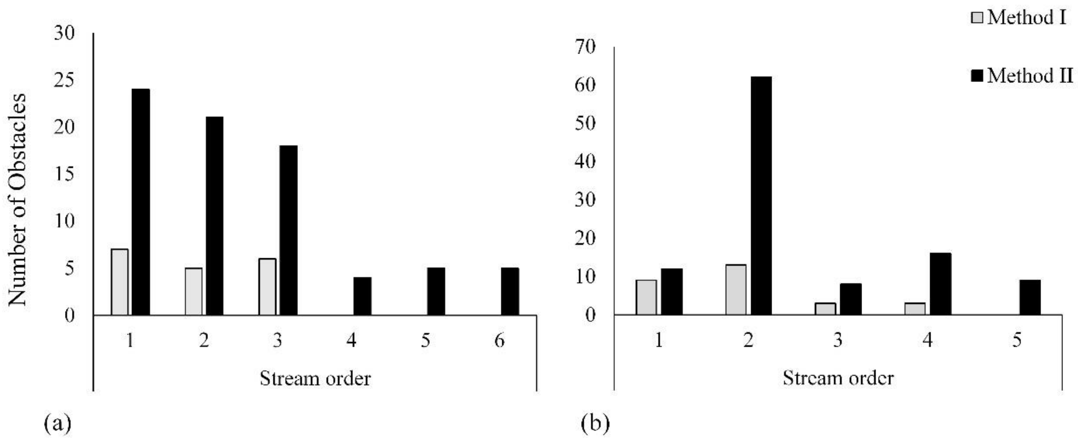

Figure 3. Graphs showing the number of missed points on (a) the Nore and (b) the Dodder catchments, and the Strahler stream order of the river segment where these were located. Columns in grey represent the misses from Method I and columns in black represent the misses from Method II.

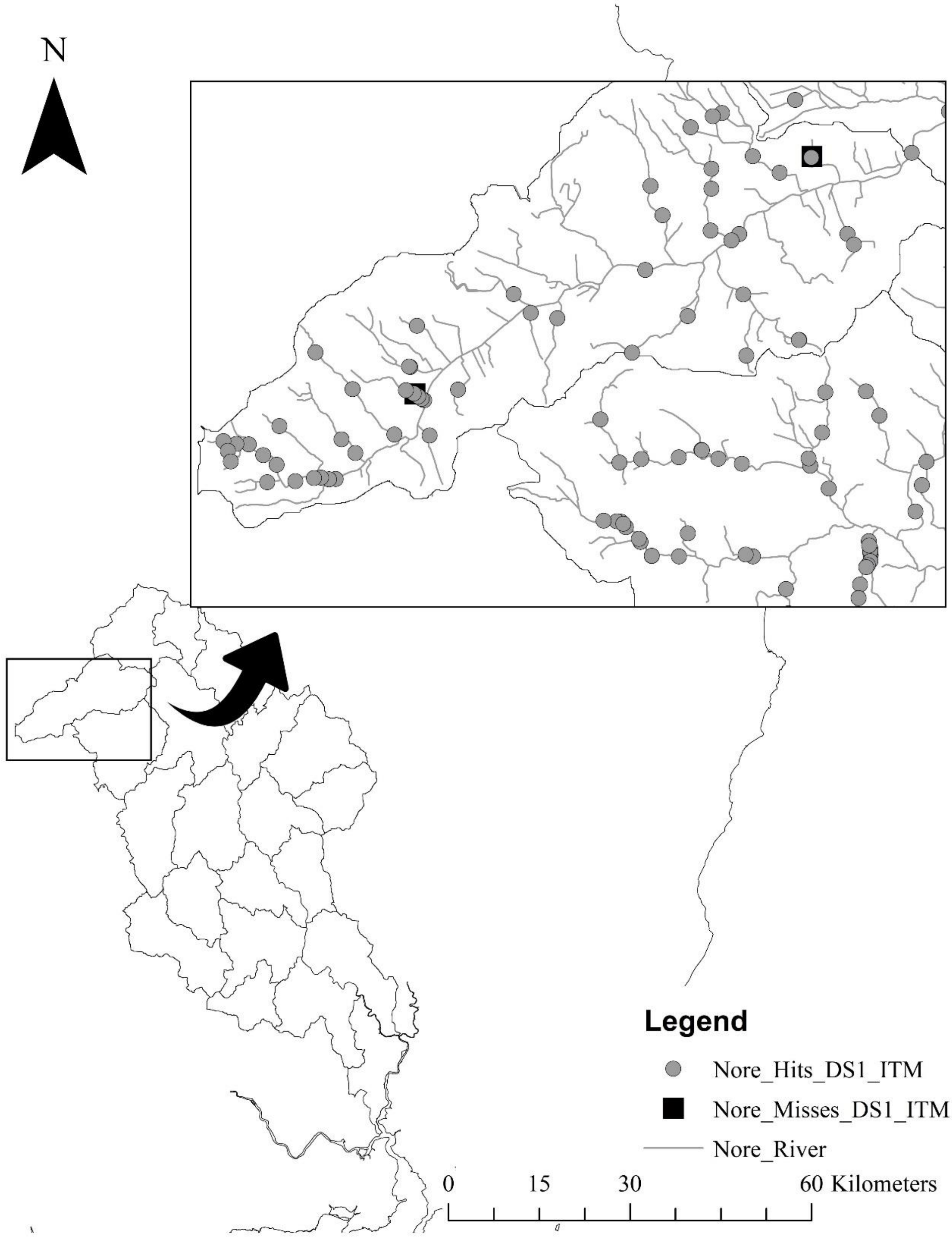

Figure 4. Map showing the locations of the hits and misses in one of the Nore sub-catchments (Nore_SC_010) from Method I.