03 - POST-CONSTRUCTION MONITORING OF CULVERT CROSSINGS OF WATERCOURSES IN SACs

Patrick Purcell[1], Letizia Cocchiglia[2], Mary Kelly-Quinn[2]

[1]*School of Civil, Structural and Environmental Engineering,*
University College Dublin, Newstead, Dublin 4, Ireland.
[2]*School of Biology and Environmental Science,*
University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

This paper describes a monitoring programme undertaken during the construction of watercourse culvert crossings of recently completed National Road Schemes traversing Special Areas of Conservation. The monitoring programme encompassed: water quality; fish and mammal passage; culvert geometry. The water quality was monitored both by manual sampling and by real-time continuous data logging. Fish passage was assessed by monitoring water velocities through the culverts and by electrofishing the salmonids, marking the fish before the fish were released at a culvert entrance and counting the number of fish re-captured at the exit from the culvert. Mammal ledges were assessed with respect to culvert passage by terrestrial animals. Key dimensions of as-built culverts were recorded and checked for compliance with respect to relevant national guidelines.
keywords: *culvert, fish passage, mammal ledge, special area of conservation, water quality.*

1. INTRODUCTION

Poorly designed watercourse crossings, such as culverts or bridges, without consideration of a river's natural hydrology, can result in scour around these structures and erosion of banks (SEPA, 2008). In addition to potential disruption of a watercourse's natural hydrology, crossing structures can also alter habitats and disrupt ecological continuity. Such barriers to the movement of aquatic species can spatially fragment populations, increase genetic isolation and decrease the long-term viability of species (Votapka 1991).

There is little evidence in the literature that clear span bridges block the passage of fish. Poorly designed culverts can, however, be a major barrier to the movement of both migratory and resident fish and can interrupt spawning and seasonal migrations, restrict access to food resources or habitat, increase the chance of predation and reduce the genetic flow between populations. In studies in the US, it is estimated that an average of 66 percent of culverts were either total or partial barriers to fish movement (Blank 2010).

In addition to fish passage, due consideration should be given at the design stage to providing safe passage for terrestrial mammals, either through the provision of a separate 'dry' passage or the inclusion of a dry ledge within a culvert crossing of a watercourse (Swiss Association of Road and Transport Experts, 2011).

The construction of culverts usually entails the temporary diversion of the natural watercourse to enable the culvert to be constructed. The ecological impacts of sediment transport arising from earthworks activities associated with river crossing construction are well documented (Vice *et al.* 1969, Wellman *et al.* 2000, Lane & Sheridan 2002, Cerdà 2007). In these studies, the authors have documented an increase in suspended solids (SS) or turbidity above natural levels during the construction period. Mitigation of potential impacts of road crossings on watercourses is required at the planning, design and construction stages. Mitigation entails implementing measures to avoid, reduce and, where necessary, remedy significant adverse effects (EPA 2002). Such mitigation measures include:

- The incorporation of controls to attenuate the impact of runoff, during and post construction;

- The appropriate design of river and stream diversions to reflect natural conditions;
- The avoidance of in-stream works in watercourses frequented by salmon or trout during their spawning season, typically the beginning of October to the end of February;
- The capture and translocation of salmonids, crayfish and lamprey prior to re-diverting these rivers through newly constructed culverts;
- The use of buffer strips, where feasible, between the watercourses and construction activity to preserve bankside vegetation intact and minimise suspended solids input to adjacent watercourses.

2. MOTORWAY LOCATIONS AND MONITORING PROGRAMME

An intensive monitoring programme was undertaken to examine the effects of river crossings on the adjacent aquatic environment associated with the construction of two motorway schemes (M3, Clonee to Kells) and the M7 (Castletown to Nenagh) that traversed special areas of conservation (SACs), as illustrated in Fig. 1. The M3 crosses the River Boyne and its tributaries, which are in the Eastern River Basin District. The main channel of the Boyne is a designated SAC, particularly because it is a salmonid river. The M7 crosses the River Nore, which is in the South-Eastern River Basin District. The main concern in this SAC is the protection of pearl mussel populations in the main channel of the River Nore, downstream of the M7 crossing of the river. In addition to M3 and M7 motorway schemes, culverts along the following national road schemes were examined: M4, M8 and M9, as illustrated in Figure 1.
The monitoring programme encompassed:

- Water quality;
- Fish and mammal passage;
- Culvert geometry.

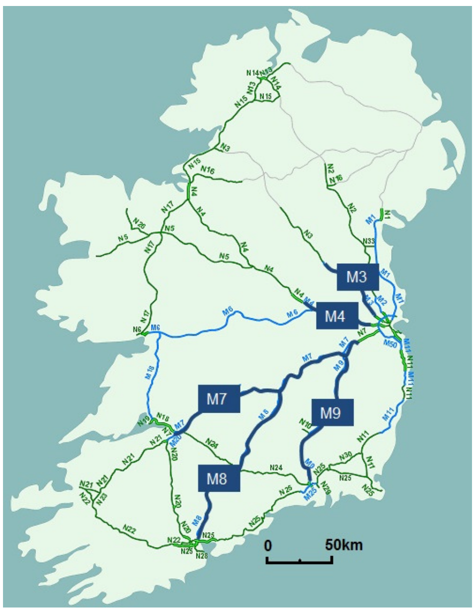

Figure 1: *Schematic location of national road schemes examined*

3. WATER QUALITY

The primary water quality parameter that is likely to be impacted from motorway earthworks and drainage is the suspended solids concentration of adjacent watercourses, arising from sediment transport, as illustrated in Fig. 2. Regulatory agencies generally attempt to control sediment input into watercourses by placing a limit on suspended solids (SS) or turbidity, specified as either absolute values, or permissible exceedances above natural background levels.

The water quality monitoring programme encompassed physico-chemical and biological water quality analyses. Manual sampling and real-time water quality monitoring was undertaken. Examples of suspended solids concentrations recorded at the sampling points on a quarterly basis are presented in Table 1. The corresponding biological water quality, as measured by the EPA biotic index, is presented in Table 2. Examination of Table 1 and Table 2 shows that, although there were occasional spikes in SS concentrations, the biological quality of the water does not appear to have been significantly impacted. The real-time water quality monitoring station at a River Boyne tributary is illustrated in Fig. 3(a) and sample data is presented in Fig. 3(b).

Figure 2: *Earthworks associated with culvert and drainage construction illustrating SS transport to adjacent watercourses – M3 motorway*

Table 1: *Suspended solids concentrations at water quality sampling locations downstream of river crossings, M7 motorway (Laois County Council, 2010)*

	Site No.	EIS 2003	Jun. 2008	Sept. 2008	Dec. 2008	Mar. 2009	Jun. 2009	Sept. 2009	Dec. 2009	Mar. 2010	Jun. 2010	*Annual average 2009*
Test sites (Suspended solids mg/l)	1	<10	4	2	12.2	1	4.8	2	5	2.2	3.2	<25mg/l
	2	<10	27.8	18.8	17.8	2.6	2.2	13	6.2	5.2	3.4	<25mg/l
	3	20	-	9.8	23.3	9.4	8	344	5.2	1.0	-	91.7
	4	<10	9.8	4.3	2.6	2	-	0.8	1.8	1.8	2.6	<25mg/l
	5	<10	38.8	8	2.8	4	2.8	1.8	1.2	20.4	3.2	<25mg/l
	6	16	5.5	29.5*	6.6	5.4	3	437.5*	159.7*	117.8*	44.5*	151.4
	7	16	4.5	20.3	9.3	4.4	64.4*	38,180*	4.2	6	51.7	9563.2
	8	-	1.8	1.8	1.8	2	2.2	2	3.2	2	7.7	<25mg/l
	9	-	10	2.5	2.2	3.4	9.6	4	4.4	8.4	5.1	<25mg/l
	10	<10	2.5	3.3	5.8	3.2	6.6	6.5	5.4	3	5.4	<25mg/l
	11	<10	3	2.5	2.8	1.6	11.6	2.3	3.4	4.2	3.7	<25mg/l
	12	<10	8	17	5.4	2.6	3.6	7.3	46.7*	126.5*	6.7	<25mg/l
	13	<10	2.5	5.5	2.2	9.6	5.2	2.8	5.4	4.4	3.7	<25mg/l

Table 2*: M7 motorway macroinvertebrate Q-values (Laois County Council, 2010)*

Order	Family	Site 1	Site 2	Site 3[7]	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site10	Site 11	Site 12	Site 13	Tolerance
Snails	Lymnaeidae					**						**			C
Worms	Oligochaeta		*****			**	****			****	**	***		***	C
Q Rating	**June 2010**	Q4	Q2	-	Q2	Q3-4	Q3	Q3	Q3	Q3	Q3-4	Q3-4	Q3	Q3-4	
Q Rating	**March 2010**	Q4	Q2	Q4	Q3	Q3-4	Q3	Q3	Q3	Q3-4	Q4	Q3-4	Q3	Q3-4	
Q Rating	**December 2009**	Q4	Q2-3	Q4	Q3	Q3-4	Q3	Q3	Q3	Q3-4	-	Q3-4	Q3	Q3-4	
Q Rating	**September 2009**	Q4	Q2-3	Q3	Q3	Q3-4	Q3	Q2	Q3	Q3	-	Q3	Q3	Q3-4	
Q Rating	**June 2009**	Q4	Q2-3	Q4	Q3	Q3	Q3	Q3	Q3	Q3	Q3	Q3	Q3	Q3-4	
Q Rating	**March 2009**	Q4	Q2-3	Q4	Q3	Q4	Q3	Q3	Q3	Q3	-	Q3	Q3	Q3-4	
Q-Rating*	**December 2008**	Q4	Q3	Q4	Q3	Q4	Q3	Q3	Q3	Q3	-	Q3	Q3	Q4	
Q-Rating	**September 2008**	Q4	Q3	Q4	Q3	Q4	Q3	Q3	Q3	Q3	-	Q3-4	Q3	Q3	

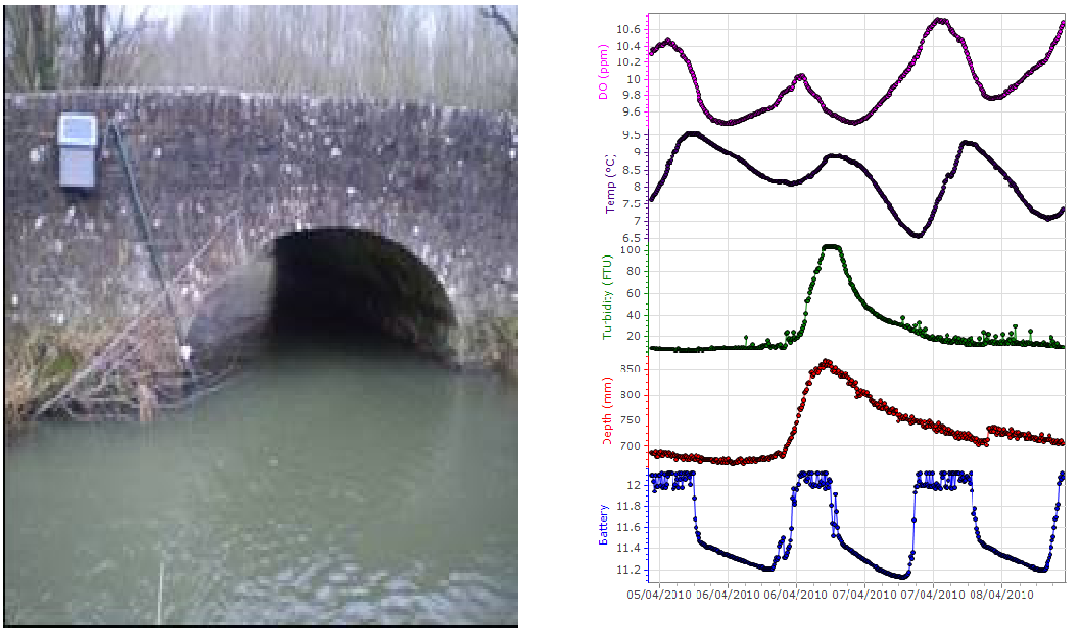

Figure 3: *(a) Real-time water quality monitoring; (b) Typical water quality data, River Boyne tributary M3 motorway*

4. FISH PASSAGE

Culverts can block fish passage if the water velocity through the culvert is excessive for fish to swim upstream or if there are any physical barriers to fish movement (Evans and Johnston, 1980), as illustrated in Fig. 4.

Water velocities through culverts were measured during high-flow and low-flow events using a current meter (Fig. 5). Fig. 6 shows an example of velocity contours at various cross-sections through a culvert and through a control section of a watercourse during a high-flow event. Examination of Fig. 6 shows that measured velocities through the culvert were generally within the limit value of 0.9 m/s.

Fish movement through culverts was assessed by electrofishing the salmonids, marking the fish before the fish were released at a culvert entrance and counting the number of fish re-aptured at the exit from the culvert (Fig. 7). Examination of Fig. 7 shows that fish movement through culverts was possible.

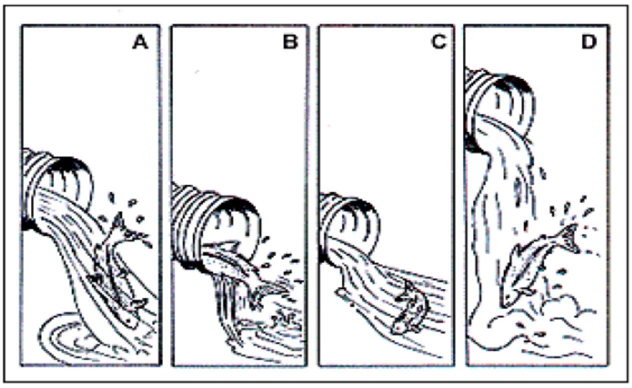

Figure 4: *Culverts can block fish passage (a) water velocity too great for fish to swim upstream, (b) water in culvert too shallow, (c) no resting pool below culvert, (d) jump too high. (Evans and Johnston, 1980)*

Figure 5: *Electrofishing River Skane, M3 motorway crossing*

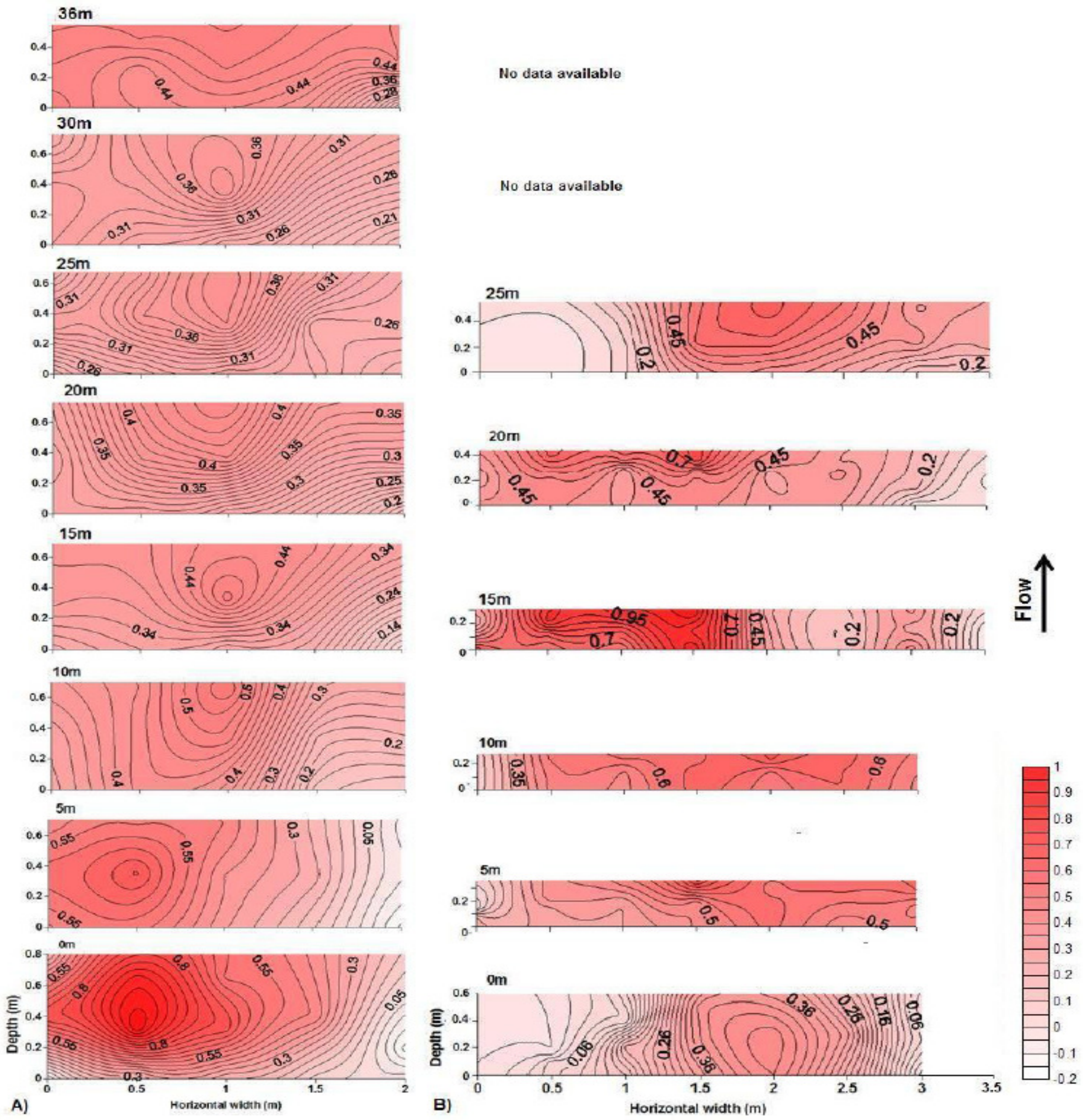

Figure 6: *Velocity contours (m/s) during high flow event: (a) through culvert (b) along control section (maximum permissible velocity = 0.9 m/s)*

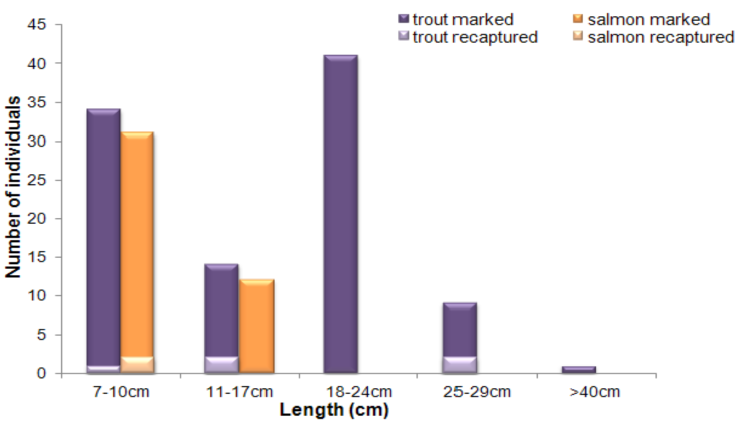

Figure 7: *Number and lengths of fish marked and re-captured upstream of culvert along Boyne tributary crossing of M3.*

5. CULVERT GEOMETRY

Key culvert dimensions, as illustrated in Fig. 8, were recorded and checked for compliance with respect to relevant national guidelines, as summarised in Table 3. The culvert soffit must be set at least 300 mm above the 100-year flood level to satisfy OPW requirements and NRA guidelines specify that the mammal ledge should be at least 150mm above the 5-year flood level, with at least a 600mm freeboard (Fig. 9). The width of the culvert should generally be at least the bankfull width to avoid flow constriction. For example, many States in the U.S. recommend a culvert width of 1.2 times bankfull width (Massachusetts, 2006).To ensure adequate light penetration through the culvert to avoid behavioral issues with fish and mammals and ensure plant growth, height/length should be sufficient. For example, the former Southern Regional Fisheries Board (2007) required that box culverts exceeding 25m, 50m and 75m in length be a minimum of 2.4m, 2.7m and 3.3m respectively in height. A widely used parameter in the US for assessing the 'openness' of culverts is the 'openness ratio' (see Fig. 10), which is recommended to be at least 0.25, defined as:

$$\text{Openness ratio} = \frac{\text{Culvert cross - sectional area (m}^2\text{)}}{\text{Culvert length (m)}}$$

Some examples of culvert designs are illustrated in Figs. 11, 12, 13. Fig. 11 shows a twin-box culvert crossing of the M3 motorway with what would appear to be a concrete ledge that is inaccessible to mammals from the bank and partially drowned, even in dry weather. Fig. 12 shows a box culvert crossing of the M7 motorway with a galvanised steel ledge accessible to mammals and in compliance with NRA width and headroom requirements. Fig. 13 shows an arched culvert crossing of the M9 motorway, showing an example of best practice re. mammal passage, providing a 'walkable' ledge using natural materials and good approach conditions. A summary of 'snags' identified in 18 culverts surveyed and the 'openness ratio' for these culverts is presented in Fig. 14 and Fig. 15 respectively.

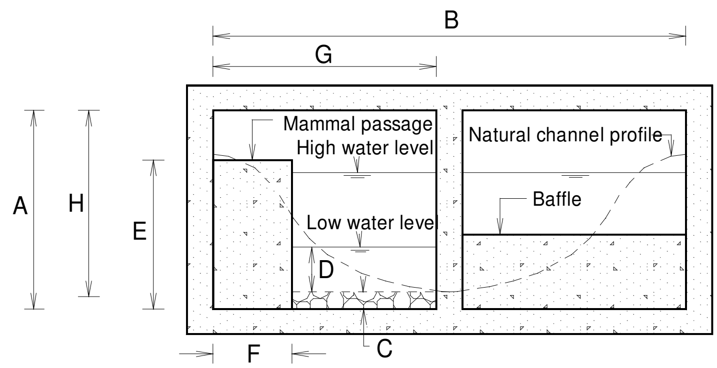

Figure 8: *Schematic cross-section of culvert, showing key geometric parameters*

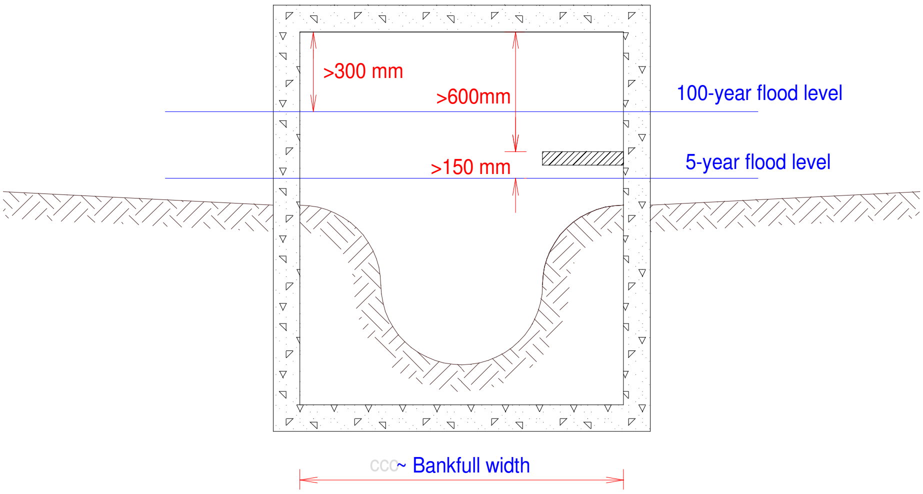

Figure 9: *Schematic of culvert showing width and height dimension requirements*

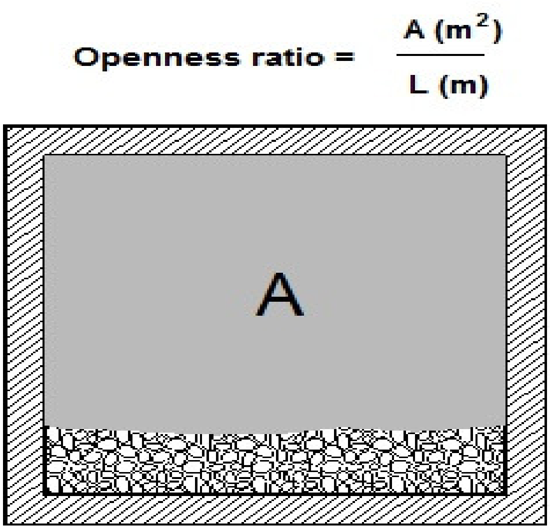

Figure 10: *Culvert 'openness-ratio'*

Table 3: *Summary of relevant national culvert guidelines*

Culvert geometry	**Culvert length**	<60m, if greater special consideration needed for fish passage [n]
	Culvert width	Similar to natural low flow channel, >0.9m [n] or natural stream channel width [s]
	Culvert height	Minimum 2.4, 2.7 or 3.0m height for a 25,50 or 75m long box culvert [s]
Fish passage requirements	**Velocities**	≤1.2m/s in culverts<24m ≤0.9m/s in culverts >24m [n]
	Resting pool	Must be present at both upstream and downstream inlets.
	Water depth	Upstream invert to remain backwatered (drowned) under low-flow conditions, to a depth suitable for the easy passage of the largest species frequenting the stream, e.g. 0.1m trout & 0.15m for salmon. [n] Upstream invert to remain backwatered in low flow to a depth ≥0.5m [n & e] or ≥0.4m [s]
Mammal ledge	**Width of ledge**	0.5m [n]
	Headroom height	>0.6m [n]
	Height above water	0.15m above for a 1 in 5 year flood event [n]
	Accessibility	Ledge must be accessible at both ends [n]
Substrate	**Benthic Substrata**	Natural substrate composition must be maintained 0.3m depth [s] or 0.5m depth [n & e]

[n]NRA guidelines, [e] ERFB guidelines, [s] SRFB guidelines

Figure 11: *M3 twin-box culvert with concrete mammal ledge*

Figure 12: *M7 box culvert with galvanised steel mammal ledge*

Figure 13: *M9 arch culvert with stone mammal ledge*

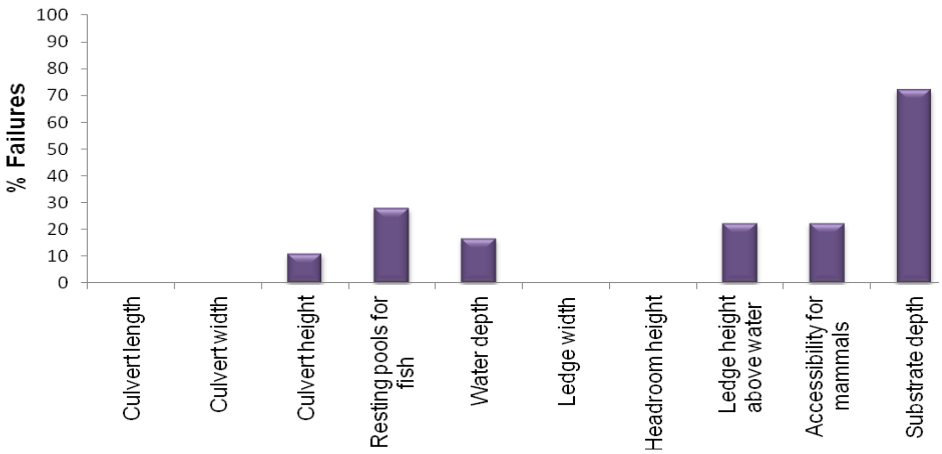

Figure 14: *Culvert 'snag' list*

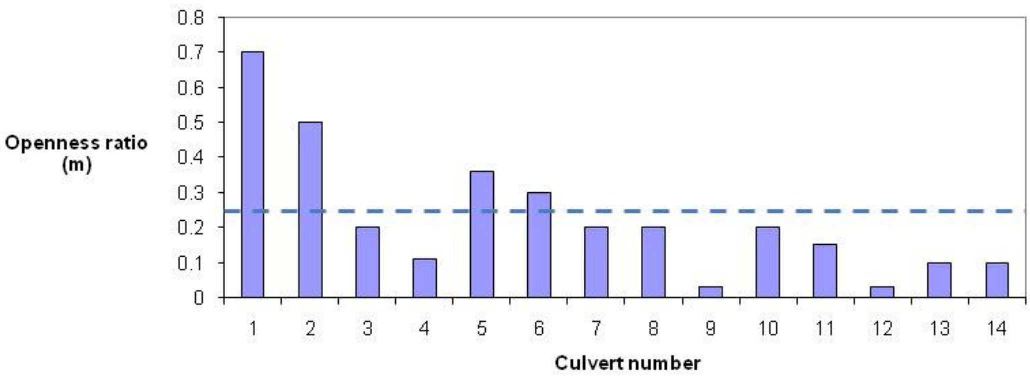

Figure 15: *'Openness' ratio for culverts surveyed (dashed line minimum recommended)*

6. CONCLUSIONS

The earthworks associated with clear-span bridge construction had no detectable impacts on adjacent water quality. In contrast, the earthworks associated with culvert construction resulted in spikes in SS concentrations during storm events but the average concentrations were generally within permissible limits. There was much evidence of good practice in mitigating the effects on the adjacent aquatic environment, for example, by the use of buffer strips, soil covering, settlement ponds etc. There was also evidence of instances of poor practice resulting in SS transport to adjacent watercourses, for example, leaving earthworks embankments adjacent to culverts un-vegetated for long periods.

Real-time monitoring provides useful water quality data at high frequency, enabling fluctuations in parameters to be recorded and their compliance with limit values to be assessed. Although there were episodic spikes in SS concentrations, it would appear that there were not any significant impacts on the aquatic ecology. Fish passage through the culverts examined was possible but the provision of mammal passage varied considerably across the motorways examined, ranging from those that met best practice to cases where mammal passages were impassable, even in dry weather conditions.

7. REFERENCES

Blank. M.D. (2010). Safe Passages, Chapter 4, Safe Passages for Fish and Other Aquatic Species, 75-96, Island Press.

Cerda, A. Soil water erosion on road embankments in eastern Spain. Science of the total environment 2007**,** *378* (1-2), 151-155.

EPA. *Guidelines on the information to be contained in Environmental Impact Statements,* Ireland, E. P. A.: Wexford, 2002; 1-45.

Faune et traffic, Amenagement des ponceaux respectueux de la faune, (2011) Swiss Association of Road and Transport Experts, SN 640696.

Lane, P. N.; Sheridan, G. J. Impact of an unsealed forest road stream crossing: water quality and sediment sources. Hydrological Processes 2002**,** *16* (13), 2599-2612.

Massachusetts River and Stream Crossing Standards (2006) Developed by the River and Stream Continuity Partnership, http://www.mass.gov/dep/water/laws/wlhappe.pdf

SEPA (2008) Engineering in the water environment good practice guide: Construction of river crossings. Scottish Environment Protection Agency.

Southern Regional Fisheries Board (2007) Maintenance and protection of the Inland Fisheries resource during road construction and improvement works.

Swiss Association of Road and Transport Experts (2011) Faune et Traffic: amenagement des ponceaux respecteux de la faune.

Vice, R.; Guy, H.; Ferguson, G. *Sediment movement in an area of suburban highway construction, Scott Run Basin, Fairfax County, Virginia, 1961-64,* 1591; Virginia, 1969; 1-41.

Votapka. F.E. (1991). Considerations for fish passage through culverts. Transportation Research Record 1291: 347-353.

Wellman, J., Combs, D., Cook, S. Long-term impacts of bridge and culvert construction or replacement on fish communities and sediment characteristics of streams. Journal of Freshwater Ecology 2000**,** *15* (3), 317-328.

ACKNOWLEDGEMENTS

This research was supported by a National Roads Authority of Ireland Fellowship award.