

Water quality monitoring during the construction of the M3 motorway in Ireland

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Abstract

The M3 motorway in Ireland was constructed between the years 2007 and 2010. The motorway crosses a Special Area of Conservation, the River Boyne and its tributaries which are designated salmonid waters under the EU Freshwater Fish directive. The paper describes the planning, design and construction measures taken to mitigate any potential impacts which the road scheme might have had on the aquatic environment and the water quality of the Boyne watercourses before, during and post construction. The success of the mitigation measures undertaken is assessed by: (a) comparing pre-construction, during-construction and post-construction water quality data, (b) comparing measured water quality with relevant standards, (c) comparing water quality data upstream and downstream of river crossings, (d) the establishment of a pilot-scale real-time water quality monitoring station at the downstream end of the works prior to discharge into the river Boyne. The analysis of the data suggests that the measures taken to protect the watercourses traversing M3 motorway have been successful in minimising the water quality impacts associated with the road scheme crossing of the Boyne watercourses. Recommendations for future full-scale deployment of real-time water quality monitoring systems are discussed.

Keywords

EU Freshwater Fish Directive, M3 motorway, mitigation measures, River Boyne, river crossings, road construction, Special Area of Conservation, water quality.

INTRODUCTION

The newly constructed M3 motorway, replacing the existing National Primary N3 dual carriageway, is one of the principal routes linking Dublin to the north-west of Ireland (Fig. 1). The total scheme length is approximately 60km and traverses Special Areas of Conservation which are of archaeological and ecological importance. Construction commenced in April 2007 and the motorway officially opened in June 2010.

The principal watercourse in the vicinity of the scheme is the River Boyne. The Boyne and its tributaries are one of Ireland's premier game fisheries and offer a wide range of angling from fishing for spring salmon and grilse to sea trout fishing and extensive brown trout fishing. Atlantic salmon (*Salmo salar*) use the tributaries and headwaters as spawning grounds. Although this species is still fished commercially in Ireland, it is listed in Annex II of the EU Habitats Directive (CEC, 1992). The River Boyne and its tributaries are designated salmonid waters under the EU Freshwater Fish Directive (CEC, 2006).

Construction of river crossings on road schemes has the potential to impact on sensitive river ecosystems containing protected species, particularly those prone to siltation. Road crossings, and especially culverts, can alter habitats and disrupt ecological processes both in the short term and longer term. In the short term, for example, temporary works to facilitate bridge foundation construction can have significant adverse impacts on water suspended solids concentration downstream of the river crossing. Adverse impacts of construction, such as those caused by erosion and sedimentation, resulting in a deterioration in the colour and turbidity of the water are quickly obvious. By contrast, impacts that result from the disruption of ecosystem processes, including the restriction of animal movement, are not as obvious and may take many years to fully manifest themselves (Jackson, 2003).

There are many past studies noting specific impacts of road construction on the aquatic environment. A limnological investigation to examine the effects of highway construction on a small stream found that suspended solids concentrations increased to values as high as 1390mg/l during construction, but later returned to pre-construction levels of <5mg/l (Barton, 1977). The deleterious effects of high suspended solid loads and sedimentation on riverine habitats are well documented (Wood et al., 1997). In a study to examine the long-term impacts of bridge and culvert construction, it was found that culverts, but not bridges, caused sediment accumulation but that this impact was not sufficient to impact on fish communities (Wellman et al., 2000). In a study of fish movement in small streams traversed by three separate types of road crossings (clear-span bridges, box culverts and tube culverts), it was found that some culverts affected fish movement by acting as physical barriers or by altering flows (Benton et al., 2000).

During the course of the M3 motorway construction across the River Boyne and its tributaries, the authors undertook a programme of water quality monitoring (both physico-chemical and biological) to assess the impacts of road construction activity on the aquatic environment. This paper presents the findings of the physico-chemical water quality monitoring of the River Boyne and its tributaries and reports on the experience in deploying a pilot-scale real-time water quality monitoring system. The results of the biological water quality monitoring programme is the subject of a separate paper.

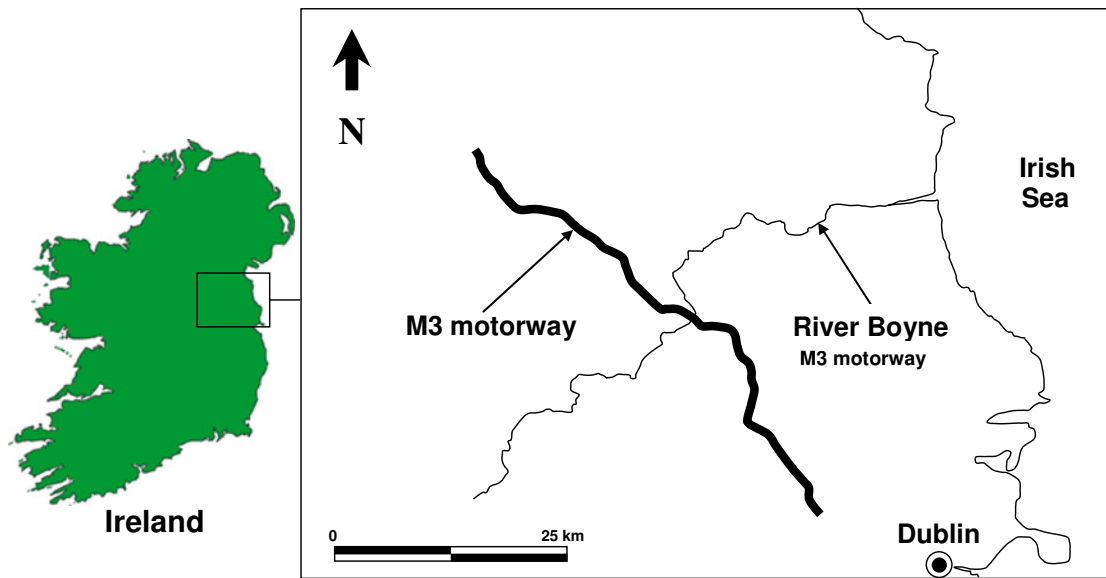


Fig. 1 Location of M3 motorway in Ireland

(Ordnance Survey of Ireland coordinates of M3 crossing of River Boyne 689292, 762622)

LEGISLATION AND WATER QUALITY STANDARDS

The degree of protection afforded Special Areas of Conservation (SACs) varies considerably but most are legally protected under national legislation, EU directives or other international conventions. At European level, the Habitats Directive (CEC, 1992) and the Water Framework Directive (CEC, 2000) are the most important relating to the protection of aquatic ecosystems. The Water Framework Directive sets out that a Member State shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water, and shall protect, enhance and restore all bodies of surface water with the aim of achieving good status by 2015. For the protection of fisheries, Ireland supports a network of Salmonid Waters designated under the EU Freshwater Fish Directive (CEC, 2006).

In a recent ‘Status of EU Protected Habitats and Species in Ireland’ report (DOELG, 2007), many habitats associated with water were considered to be in a ‘bad’ condition. According to the report, even moderate declines in water quality make rivers and lakes unsuitable for many fish and invertebrate species. For example, there is a real fear that the freshwater pearl mussel, which can live to an age of 130 years, is on the brink of extinction in Ireland due to eutrophication and siltation of the riverbeds (Moorkens, 1994).

The physical and chemical status required of fresh waters to support fish life is specified in European Union Directive 2006/44/EC and is summarised in Table 1.

Table 1 Freshwater (salmonid) quality regulations (EU Directive 2006/44/EEC)

Parameter	Guide limit	Mandatory limit	Comment
Temperature	-	1.5°C	Thermal discharge must not raise temperature by more than limit
Dissolved Oxygen (mg/l O ₂)	50% of samples ≥ 9 100% of samples ≥ 7	50% of samples ≥ 9	When D.O. <6 competent authority must prove no harmful consequences for fish
pH		6 - 9	
Suspended solids (mg/l)	≤ 25		
BOD ₅	≤ 3		
Total phosphorus (mg/l P)	≤ 0.2	≤ 0.2	
Nitrites (mg/l NO ₂)	≤ 0.01		
Non-ionised ammonia (mg/l NH ₃)	≤ 0.005	≤ 0.025	
Total ammonium (mg/l NH ₄)	≤ 0.04	≤ 1	
Phenolic compounds (mg/l C ₆ H ₅ OH)	-	-	An examination by taste
Petroleum hydrocarbons	-	-	A visual examination
Total residual chlorine (mg/l HOCl)	-	≤ 0.005	
Total zinc (mg/l Zn)	-	≤ 0.3	
Dissolved copper (mg/l Cu)	≤ 0.04	-	

Examination of Table 1 shows that the EU Directive 2006 /44/EC specifies a guide suspended solids limit of 25mg/l for fresh waters to support fish life. Elevated suspended solids concentrations may result in their deposition on the streambed, thereby covering the spawning gravels or sources of fish food such as benthic invertebrates. Consequently, regulatory agencies endeavour to control sediment input to watercourses by placing limits on suspended solids (or turbidity), either absolute values or permissible exceedances above ‘natural background levels’. For example, in contrast to the EU Directive suspended solids value of 25mg/l, a number of states in the USA specify numerical turbidity standards for the protection of fish and wildlife habitats (Table 2).

Turbidity and suspended solids are related measures of water quality. Turbidity is an index of water clarity or opacity, measured by the degree of light scattering by suspended solids in a water sample, and is quantified in Nephelometric Turbidity Units (NTU). While the suspended solids concentration is an absolute measure of sediment concentration, because the parameter requires laboratory determination, it is clearly limited in terms of its usefulness from an operational perspective. Turbidity, in contrast, can be measured on-line and in real-time. Consequently, much research has been undertaken to correlate turbidity and suspended solids concentrations (Packman, 1999).

Table 2 Freshwater turbidity standards for protection of fish and wildlife habitats in U.S. states arising from anthropogenic activities (Bash et al., 2001)

State	Turbidity (NTU)
Alaska	25 units above natural
California	20% above natural, not to exceed 10 units above natural
Idaho	5 units above natural
Minnesota	10 units
Montana	10 units (5 units above natural)
Oregon	10% above natural
Washington	5 units above natural for ‘excellent’ waters and 10 units above natural for ‘good’ waters
Wyoming	10 units above natural

DESCRIPTION OF STUDY AREA

The main watercourses that are crossed by the route of the M3 motorway are part of the Boyne river system (Fig. 2). These watercourses include the main channel of the Boyne, the Skane and Lismullin rivers. The water quality sampling locations illustrated in Fig. 2 were situated (a) just downstream of the road crossings of the Boyne watercourses and (b) at an upstream reach of each river, unaffected by motorway construction activity. Both the River Skane and the River Lismullin, shown in Fig. 2, were culverted at a number of locations to enable the motorway and associated secondary roads to traverse these watercourses. Thus, the location of the real-time monitoring station was chosen at a point just downstream of the confluence of these two rivers to enable the aggregate effect of the upstream

earthworks activities to be monitored (see Fig. 2). The most important characteristics of the key watercourses in the Boyne River system are summarised in Table 3.

Table 3 Key characteristics of Boyne watercourses

Watercourse	Boyne	Skane	Lismullin
Width (m)	25 - 30	4 - 5	2-3
Depth (m)	0.5 – 2.0	0.2 - 1	0.2 – 0.6
Water quality status	Slightly polluted	Moderately polluted	Moderately polluted

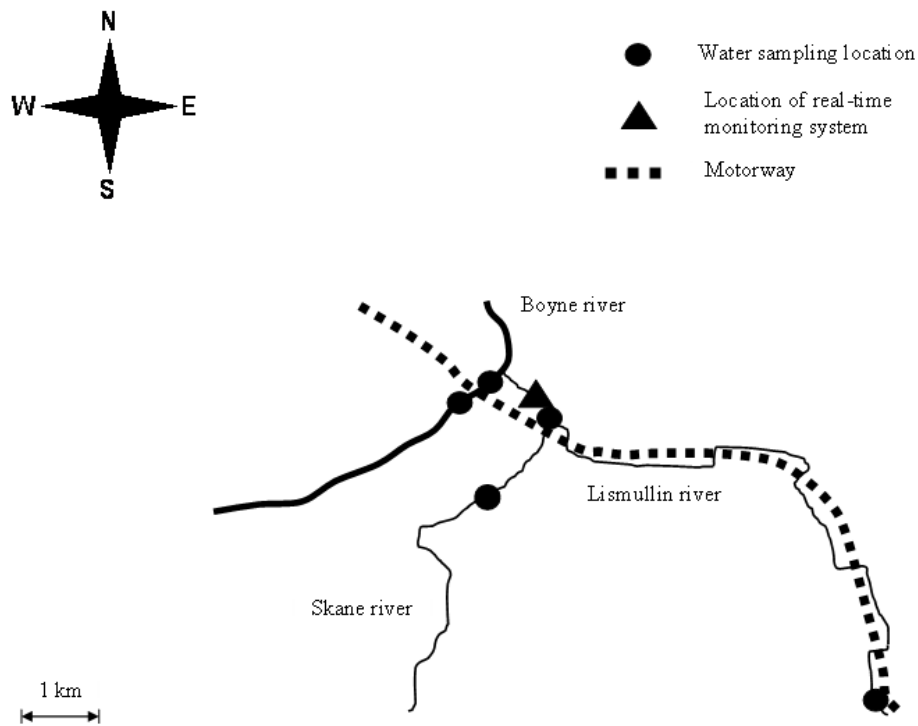


Fig. 2 River Boyne and its tributary rivers showing water quality sampling locations
(Ordnance Survey of Ireland coordinates of M3 crossing of River Boyne 689292, 762622)

MITIGATION MEASURES

Arising from the designated status of the Boyne River and its tributaries, special measures were taken at the planning, design and construction stage of the M3 crossing of the Boyne and its tributaries to minimise the impacts associated with the road scheme crossing these watercourses. The crossing point of the M3 motorway on the River Boyne was the most ecologically sensitive because of the river's designation as a salmonid water. Consequently, the M3 crossing of the River Boyne was by means of a single-span bridge, while the smaller rivers Skane and Lismullin were culverted. The mitigation measures taken included:

- The use of a 50m single span bridge across the river Boyne, negating the need for piers within the river, thus avoiding in-river construction (see Fig. 3);
- The incorporation of holding ponds and interceptors to attenuate the impact of runoff, during and post construction;
- The use of bottomless culverts to preserve the natural river characteristics to facilitate fish passage under all but extreme flow conditions;
- Appropriate design of river and stream diversions to reflect natural conditions;
- 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 the newly constructed culverts under licence from the relevant fishing authority;
- The use of buffer strips, where feasible, between the watercourses and construction activity to preserve bankside vegetation intact and minimise suspended solids input to watercourses.



Fig. 3 M3 single-span bridge crossing of river Boyne, October 2010

WATER QUALITY MONITORING PROGRAMME

The key objective of the research was to undertake an integrated programme of monitoring the river water quality in the vicinity of the River Boyne and its tributary crossings by the M3 motorway construction. The methodology used to assess any potential impacts of the construction activity was as follows:

- (a) Monitoring water quality upstream and downstream of the bridge and culvert crossings;
- (b) Monitoring the performance of suspended solids control measures;
- (c) Comparing pre-construction river water quality with the water quality measured during the motorway construction;
- (d) Comparing post-construction river water quality with the water quality measured during the motorway construction;
- (e) Comparing the water quality during construction with salmonid water quality standards;
- (f) Establishing a real-time water quality monitoring station at the confluence of the Skane and Lismullin rivers, prior to their discharge into the River Boyne.

The frequency of manual sampling was as follows:

- (a) Turbidity/suspended solids measurements were undertaken during hydrological events (floods and droughts);
- (b) The full suite of salmonid water quality parameters were measured on a quarterly basis.

In waterbodies with marked temporal variability, traditional manual sampling is unlikely to capture the true maximum/minimum water quality parametric values and the use of continuous monitoring deploying in-situ sensors is a superior measurement methodology (O'Flynn et al, 2010). Thus, in addition to periodic manual sampling of water quality, a pilot-scale on-line, real-time water quality data acquisition system has been deployed on this project to enable temporal variations in the quality of the receiving waters to be recorded (see Fig. 4). The data acquisition system is located at the confluence of the rivers Skane and Lismullen, a short distance upstream of their discharge point into the River Boyne and close to where the M3 motorway crosses the River Boyne. The water quality sensors are powered by a solar panel and a data acquisition system enables the data recorded to be instantaneously transmitted via a mobile phone link to an on-line web site (<http://89.124.67.3/ucd/>). The system enables the following water quality parameters to be monitored in real-time at 10-minute intervals: temperature, turbidity, pH, dissolved oxygen and chlorophyll concentration. Real-time data acquisition, with alarms set at water quality limit values, enables any deleterious effects of construction activities on the adjacent watercourses to be rapidly detected and corrective action to be taken in a timely fashion.



Fig. 4 Real-time water quality monitoring station at confluence of rivers Skane and Lismullin

WATER QUALITY RESULTS

Suspended solids concentrations and control measures

Sample measurements of suspended solids concentrations along Boyne watercourses' crossings of M3 motorway are presented in Fig. 5 and the corresponding suspended solids/turbidity relationship is given in Fig. 6.

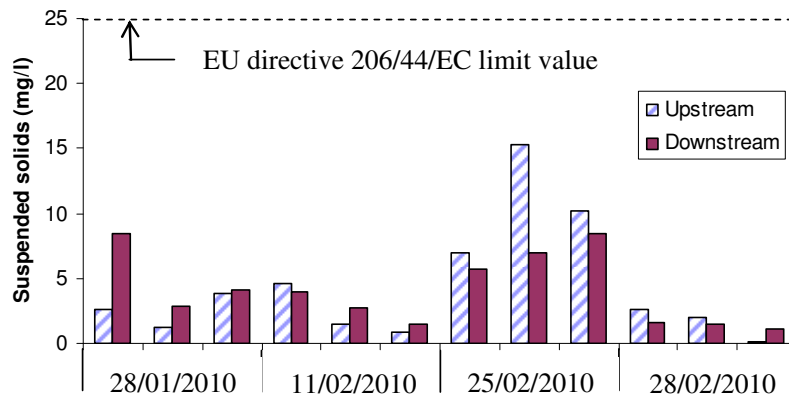


Fig. 5 Suspended solids concentrations upstream and downstream of Boyne watercourse crossings during construction of M3 motorway

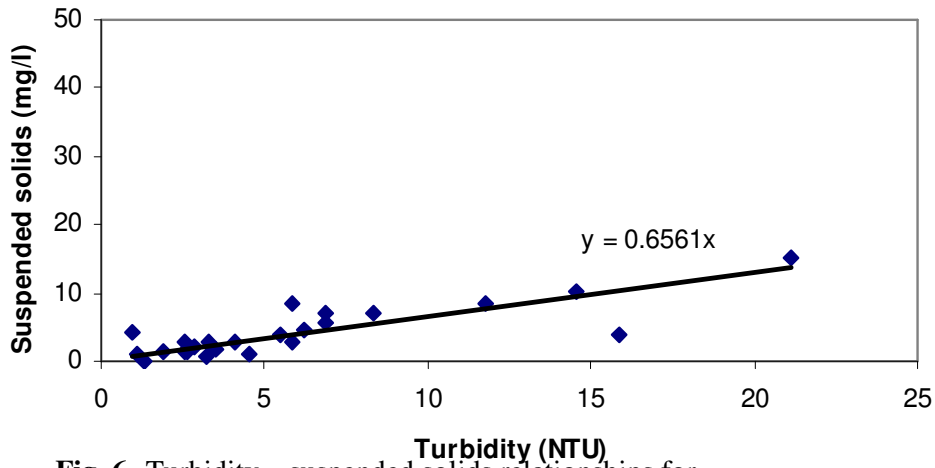


Fig. 6 Turbidity – suspended solids relationships for Boyne, Lismullin and Skane rivers along M3 motorway

Typical performance of a settlement pond constructed adjacent to the River Boyne to control the discharge of suspended solids arising from dewatering the sheet-piled excavations for the Boyne bridge crossing shown in Fig. 3 is presented in Fig. 7. The turbidity of the water entering and discharging from the settlement pond, prior to its discharge into the River Boyne is shown. In addition, the turbidity of the River Boyne upstream and downstream of the M3 motorway crossing is also presented in Fig. 7.

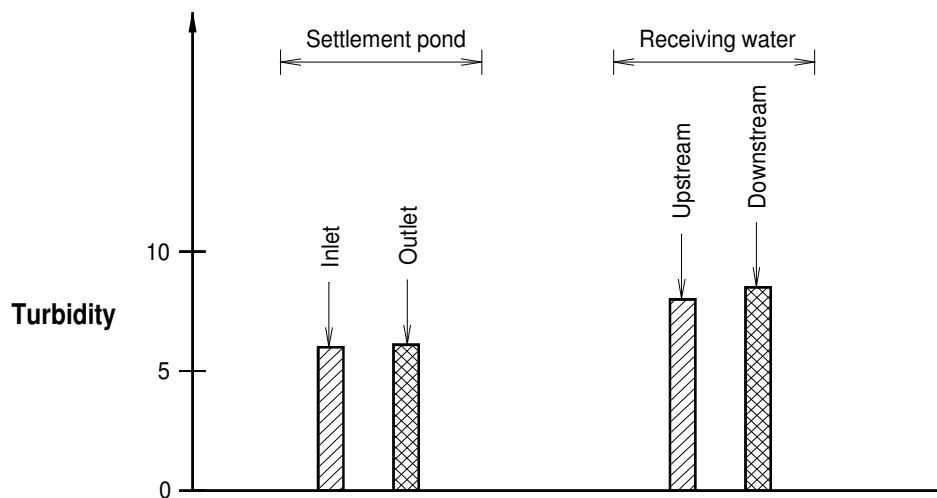


Fig. 7 Performance of suspended solids settlement pond adjacent to River Boyne

Water quality during construction

Sample water quality for the River Boyne pre-construction (2000, taken from the EIS) and during construction (2010) of the Boyne River are presented in Table 4. The corresponding guide values for the salmonid regulations (EU Directive 206/44/EC) are also shown in the Table.

Table 4 Comparison of River Boyne water quality
pre-construction and during construction

Parameter	Average in period January – June 2000 *	Recorded in period January – June 2010	Salmonid regulations guide values
Dissolved Oxygen (mg/l O ₂)	12.0	77% of samples ≥ 9	50% of samples ≥ 9
pH	8.1	7.9 – 8.35	6 - 9
Suspended solids (mg/l)	< 20	0.2 – 15.2	≤ 25
BOD ₅ (mg/l)	3.4	< 2	≤ 3
Total phosphorus(mg/l P)	-	< 0.1	≤ 0.2
Orthophosphate (mg/l PO ₄)	0.4	-	-
Nitrites (mg/l NO ₂)	0.10	<0.07	≤ 0.01
Non-ionised ammonia (mg/l NH ₃)	0.11	< 0.12	≤ 0.025

* Halcrow Barry, 2002

Real-time measurements of water quality

Sample real-time data, from the data acquisition system shown in Fig.4, recorded during a storm event, is presented in Fig. 8. The figure shows the water dissolved oxygen concentration (D.O.), water turbidity, water depth and photovoltaic charge (battery) powering the measurement sensors recorded over the four-day period 5/4/2010 to 8/4/2010.

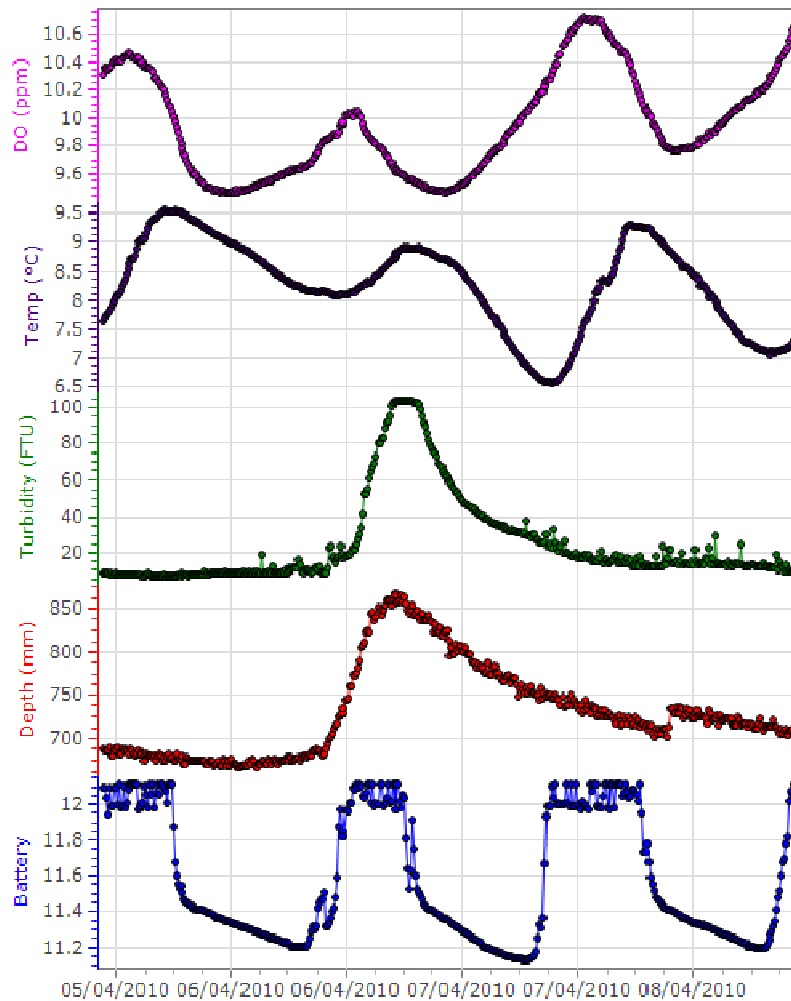


Fig. 8 Typical real-time water quality data at confluence of rivers Skane and Lismullin, just upstream of discharge to river Boyne during construction of M3 motorway

Post-construction water quality measurements

For comparison purposes, real-time turbidity, water level and rainfall data during road construction and post-construction are presented in Fig. 9(a) and Fig. 9(b) respectively. Fig. 9(a) shows the recorded data during topsoiling of earthworks slopes, as illustrated in the photograph in Fig. 9(a), prior to the opening of the motorway in June 2010. The corresponding data following the re-vegetation of the topsoiled surfaces a number of months following completion of the motorway, as illustrated in the photograph, is also presented in Fig. 9(b).

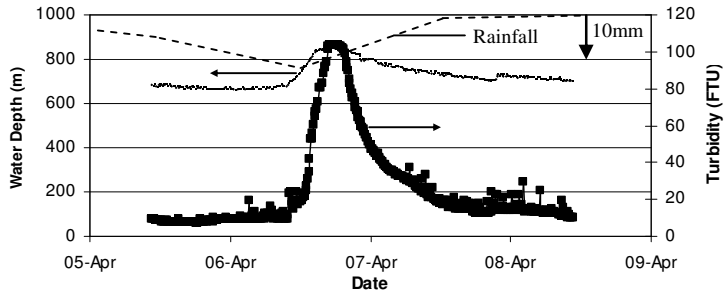


Fig. 9(a) Turbidity levels during motorway construction in April 2010

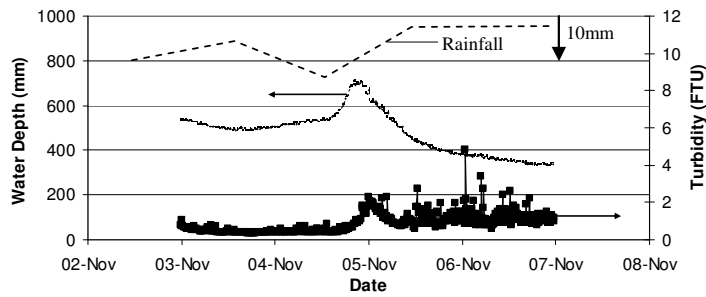


Fig. 9(b) Turbidity levels approximately six months after opening of motorway in June 2010

DISCUSSION

Sample measured suspended solids concentrations of the Boyne watercourses upstream and downstream of road crossings of these watercourses are presented in Fig. 5. Examination of the suspended solids data presented in Fig. 5 above shows that the suspended solids concentrations in all the grab samples taken during the sampling period are within permissible limits. If significant solids loads were generated as a result of construction activities, then it might reasonably be expected that this would be reflected in increased solids concentrations at downstream locations. Examination of the figure shows that there are a small number of samples where the downstream suspended solids values exceed the upstream (control) values, but that these data are well within permissible limits.

The data presented in Fig. 5 is clearly discontinuous and of limited duration. Continuous water quality turbidity measurements were recorded at the real-time monitoring station at much higher frequency (10-minute intervals) and over a more prolonged duration to ensure that the extreme values were captured (Fig. 9). The turbidity-suspended solids relationship presented in Fig. 6 enables real-time turbidity data presented above to be converted to corresponding suspended solids concentrations. The turbidity values for the water entering and leaving the settlement ponds shown in Fig. 7 relates to water pumped from excavations for the Boyne bridge foundations. Examination of the data shows very low turbidity values, indicative of the low solids in the water seeping from the River Boyne through the rock formation on which the bridge abutments were founded.

The data in Table 4 shows a comparison between water quality pre-construction, as reported in the EIS (Halcrow Barry, 2002), and sample parametric values measured during construction, in addition to the salmonid guide values. Examination of the Table shows that the parametric values recorded during the relevant phase of motorway construction are within the statutory limits, with the exception of the nitrogenous concentrations, indicative of some nutrient enrichment of the water, hence the classification of the Boyne tributary watercourses as being moderately polluted in Table 3 above.

Examination of the real-time data during motorway construction presented in Fig. 8 shows a number of interesting features:

- (a) A diurnal variation in dissolved oxygen (D.O) levels clearly mirrors the photo-voltaic charging by the solar panel. D.O. levels increase during daylight, as a result of increased algal photosynthesis and decrease in darkness, but remain above the minimum D.O. level of 9mg/l recommended for salmonid waters.
- (b) A diurnal variation in water temperature is evident and this is clearly a further factor that influences D.O. levels.
- (c) Short-term turbidity (and by corollary suspended solids) levels of the water dramatically increase (>100NTU) following the rapid increase in water depth during the storm event, exceeding the standards set out in Table 2 above. The peak turbidity value recorded (converted to solids concentration using the calibration in Fig. 6) corresponds to a solids concentration of about 70mg/l, significantly in excess of the 25mg/l limit value in the salmonid regulations. The dry-weather turbidity value of about 10mg/l corresponds to a suspended solids value of about 6.5 mg/l, within the permissible value.

The real-time monitoring system has clearly proven invaluable, enabling water quality to be monitored at 10-minute intervals, thereby permitting short-term fluctuations in water quality to be recorded. Further real-time turbidity, water level (used as a surrogate parameter for flow) data in addition to rainfall data, following the opening of the motorway, is shown in Fig 9. Note that the rainfall data in Fig. 9 is plotted relative to the upper horizontal axis in the downward direction for clarity. Examination of Fig. 9 shows that, although the baseflows in Fig. 9(a) and Fig. 9(b) are slightly different, the daily incremental increase in the antecedent rainfall of about 7mm and the corresponding increase in water level of about 200mm are similar in both Fig. 9(a) and Fig. 9(b). A dramatic decrease, relative to the data recorded during the construction of the motorway shown in Fig. 9(a), in both the dry-weather and storm turbidity levels following re-vegetation of the top-soiled surfaces adjacent to the Boyne watercourses is evident in Fig. 9(b). Fig. 9(a) reflects conditions during construction in April 2010, approximately three months prior to the motorway completion in June 2010, while Fig. 9(b) relates to motorway conditions in November 2010, approximately six months following the opening of the motorway.

This pilot study demonstrates how cost-effective, state-of-the-art technology can be deployed to continuously monitor in real-time water quality impacts of motorway construction through ecologically sensitive watercourses. Clearly, in any future full-scale monitoring programme a more extensive network of sensors located at key watercourse crossings would be desirable. Traditional grab sampling is unlikely to provide data at sufficient frequency in water bodies with marked temporal variability. The monitoring protocols developed in this pilot-scale study are already being incorporated into the proposed environmental management of other motorway construction schemes in Ireland, for example, the Environmental Impact Study for the M20 motorway. This road scheme will cross over rivers containing the endangered pearl mussel, an aquatic species which is highly sensitive to suspended solids input. The real-time monitoring system will enable any potential elevation in solids levels due to construction activities to be rapidly detected and corrective action to be taken in a timely fashion to prevent any detrimental effects on the pearl mussel.

CONCLUSIONS

- (1) The measures taken at the planning, design and construction stages of the M3 crossing of the Boyne and its tributaries would appear to have been successful in minimising the water quality impacts associated with the road scheme crossing these watercourses;
- (2) Dry-weather solids concentrations were within permissible limits during the course of the motorway construction, but solids concentrations exceeded permissible limit values for short periods during storm events;
- (3) A very significant decrease in the solids concentrations was recorded following the re-vegetation of top-soiled surfaces;
- (4) A pilot-scale, relatively low-cost, state-of-the-art, real-time water quality data acquisition system was invaluable for monitoring and controlling the effects of construction activities on watercourses, particularly in an ecologically sensitive catchment.

ACKNOWLEDGEMENTS

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