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An assessment of the suspended sediment rating curve approach for load estimation on the Rivers Bandon and Owenabue, Ireland

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ABSTRACT

This paper presents an assessment of the suspended sediment rating curve approach for load estimation on the Rivers Bandon and Owenabue in Ireland. The rivers, located in the South of Ireland, are underlain by sandstone, limestones and mudstones, and the catchments are primarily agricultural. A comprehensive database of suspended sediment data is not available for rivers in Ireland. For such situations, it is common to estimate suspended sediment concentrations from the flow rate using the suspended sediment rating curve approach. These rating curves are most commonly constructed by applying linear regression to the logarithms of flow and suspended sediment concentration or by applying a power curve to normal data. Both methods are assessed in this paper for the Rivers Bandon and Owenabue.

Turbidity-based suspended sediment loads are presented for each river based on continuous (15 min) flow data and the use of turbidity as a surrogate for suspended sediment concentration is investigated. A database of paired flow rate and suspended sediment concentration values, collected between the years 2004 and 2011, is used to generate rating curves for each river. From these, suspended sediment load estimates using the rating curve approach are estimated and compared to the turbidity based loads for each river. Loads are also estimated using stage and seasonally separated rating curves and daily flow data, for comparison purposes.

The most accurate load estimate on the River Bandon is found using a stage separated power curve, while the most accurate load estimate on the River Owenabue is found using a general power curve. Maximum full monthly errors of −76% to +63% are found on the River Bandon with errors of −65% to +359% found on the River Owenabue. The average monthly error on the River Bandon is −12% with an average error of +87% on the River Owenabue. The use of daily flow data in the load estimation process does not result in a significant loss of accuracy on either river. Historic load estimates (with a 95% confidence interval) were hindcast from the flow record and average annual loads of 7253±673 tonnes on the River Bandon and 1935±325 tonnes on the River Owenabue were estimated to be passing the gauging stations.

1. Introduction

Numerous qualitative and quantitative studies of suspended sediment have been undertaken to address issues such as contaminant transport, water quality trends, reservoir sedimentation, channel and harbour sedimentation and recreational impacts on water bodies (Angino and O'Brien, 1968; Walling, 1977a,b; Littlewood, 1992; Horowitz, 2003). Analysis and monitoring of sediment transport increases our understanding of the variability of pollutants, especially contaminants associated with sediment transport including heavy metals and phosphorus (Schindler, 2006; Edwards and Withers, 2007; Horowitz, 2008).

The most accurate method of estimating a pollutant load is to combine continuous suspended sediment concentration (SSC) and flow rate (Q) records (Walling, 1977a). Phillips et al. (1999) stated that the efficiency of a load calculation method should be assessed in terms of precision (dispersion) and accuracy (bias) which means the true accuracy can only be determined if the true load is known. The true precise load can only be found when continuous data on SSC and Q are available. Even then, the question remains at what sampling frequency is the true load measured. Typically a sampling frequency of once every 15 min is sufficient. However, monitoring SSC at 15 minute intervals is not practical, especially in the long term due to the significant time and resources required. When no 'true' load data are available it is more difficult to assess the accuracy of estimated loads. Two options are available: (i) to compare the results of different load estimators using the same dataset or (ii) to compare other relevant studies for similar types of watershed locally. Load estimation techniques have been described and reviewed by

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Walling (1977a), Littlewood (1992), Phillips et al. (1999), Smart et al. (1999), Zamyadi et al. (2007) and Horowitz (2008). It is important to utilise storm based event sampling in the load calculation (Rovira and Batalla, 2006; Horowitz, 2008) particularly where streamflow patterns are variable as is the case for the rivers studied in this paper. Preston et al. (1989) compared averaging methods, ratio estimators and rating curves and concluded that no single load estimation method is better than another in all cases. Quilbé et al. (2006) suggested that correlations between SSC and Q should first be investigated. If the coefficient of determination (r^2) of the rating curve is greater than 0.5 they suggest that it is likely to be the best estimator. When correlations are inadequate, they recommend the use of the ratio method. However, justification for selection of a rating curve should not be based on a goodness-of-fit indicator, because this does not ensure that the rating curve will be a good predictor of the load. Instead, loads generated using rating curves should be compared to the true load.

In Ireland, streamflow has been monitored widely on a continuous basis since the mid-1950s, however, continuous suspended sediment concentration measurements have not generally been undertaken to date. The study of suspended sediment in rivers in Ireland has been limited to date to sparse data collected by the Irish Environmental Protection Agency (EPA), the Local Authorities and the Sediment Research Group at Cork Institute of Technology. The National University of Ireland Galway have also carried out some preliminary work on sediment loads as have Teagasc, the agriculture and food development authority in Ireland. The lack of availability of sediment data for Ireland has been highlighted in a recent Europe wide study of sediment yields (Vanmaercke et al., 2011). Ireland's only attempt to-date to estimate suspended sediment loads (SSL) has been as part of the OSPAR RID programme (OSPAR, 2009). These estimates are based on a mean flow weighted estimation method carried out on very limited data sets (6–7 paired SSC-Q values per year on selected rivers); high flow events are not often included in the estimates. Suspended sediment load estimates based on such methodologies are thus likely to underestimate the SSL. Sediment loads from Ireland are of particular interest because Ireland is one of the most deforested countries in Europe and despite a doubling of forestry cover in the last 30 years less than 10% of the country is under forest (Bacon, 2003). This study will seek to determine the accuracy of the sediment rating curve approach, which if implemented could help Ireland meets its commitments under the Water Framework Directive. It will also contribute to addressing the paucity of suspended sediment yield data for Ireland, particularly at the catchment scale and provide a baseline for future suspended sediment and nutrient studies in catchments where the target goal is to bring forestry cover to 17% by 2030 (Ní Dhubháin et al., 2009).

Commencing in September 2009, continuous turbidity monitoring has been undertaken on the River Owenabue by the Sediment Research Group at Cork Institute of Technology. Monitoring on the River Bandon commenced in February 2010, allowing the accurate estimation of the true load on these rivers to be determined for the first time. The turbidity based SSL estimates for these rivers, which are taken as being the true load, are compared to the SSL estimates using sediment rating curve methods to assess the accuracy of applying such load estimation techniques in small to medium scale Irish agricultural catchments.

2. Catchment descriptions

The River Bandon and the River Owenabue which are located in the South Western River Basin District (SWRBD) which was established under the Water Framework Directive (WFD). The SWRBD covers an area of 11,180 km^2, has a temperate maritime climate where annual average rainfall is approximately 1219 mm at the nearby Cork Airport gauging station. These lowland catchments are adjacent to one another as shown in Fig. 1. The main pressures to water quality in both rivers have been identified as being from diffuse agricultural sources and from underperforming domestic wastewater treatment plants (Cork County Council, 2010). Table 1 presents details on the rivers and their catchments.

The 74 km long River Bandon emerges at an elevation of 210 m Ordnance Datum (OD), drains an area of 608 km^2 and has an average gradient of 2.8 m km^{-1}. It is large in size in terms of Irish catchments where the average catchment area is approximately 160 km^2. The river discharges to Kinsale Estuary, which has been identified as being seriously euthrophic due to excess nitrogen (Cork County Council, 2010). The northern section of the catchment is underlain by approximately 40% Devonian Old Red Sandstone, while the remainder consists of Dinantian mudstones and sandstones. Subsoil in the catchment is primarily of three types. The northern section of the catchment is generally Devonian sandstone till, the south consists of Devonian and Carbonifierous sandstone and shale tills while the west of the catchment has considerable amounts of bedrock (calcareous and non-calcareous). The most common soils in the catchment are acid brown earths and brown podzolics which dominate the catchment. In the western section there is greater variablility with lithosols, regosols, peaty podzols, blanket peats and surface and grounds water gleys (Fig. 2). Agricultural land, primarily under pasture and tillage, dominates land use comprising 93.8% of the total catchment area while forestry, urban areas and quarries account for 5.4%, 0.7% and 0.1%, respectively, of the catchment. Forestry in the catchment is mainly located in the upper catchment to the west.

The 22.7 km long River Owenabue is a 105 km^2 sub-catchment of the greater River Lee catchment. The river emerges at an elevation of 110 m OD and has an average gradient of 6.3 m km^{-1}. The catchment hill slopes are quite steep and response to rainfall is quick, with a noticeable increase in river stage within an hour of a significant rainfall event with an associated suspended sediment response. The basin is underlain primarily by Dinantian mudstones and sandstones which account for 49% of the catchment and are located centrally within the catchment. Comprising 34% of the total catchment area, Devonian Old Red Sandstone is located under the northern section of the catchment. The southern section of the catchment is underlain by Namurian sandstone (17%) and the remainder (<1%) consists of limestones. The most common sub-soils are Devonian sandstone till, Devonian and Carboniferous sandstones and shales and Namurian shales and sandstones. Bedrock at the surface occurs with calcareous and non-calcareous rock types present. Soil cover consists mainly of acid brown earths and brown podzolics, located in the northern section of the catchment. Considerable amounts of surface/groundwater gleys are present in the southern section of the catchment along with small amounts of lithosols, regosols and peaty podzols. Agricultural land, primarily under tillage and pasture, dominates land use, comprising 97% of the total catchment area. Forestry, urban areas and quarries account for 1.5%, 0.9% and 0.6%, respectively, of the catchment. Two large quarries are located adjacent to the river with one being just 2 km upstream of the gauging station at Ballea Bridge Upper.

3. Methodology

3.1. Load estimation

The theoretical load of suspended sediment transported in a river over a given time interval is:

$$L_s = \int_{t_1}^{t_2} Q_t SSC_t \, dt \quad (1)$$

where L_s is the load over a time period $(t_2 - t_1)$, Q_t is the flow rate at time t, SSC_t is the suspended sediment concentration at time t, and dt is the time interval $(t_2 - t_1)$. SSC is measured in mg l^{-1} and Q is measured in m^3 s^{-1} yielding L_s in g for the selected time period. The sediment rating curve approach has been widely used