

flooding was reported throughout the SWRBD during this period. The lowest discharge was observed in October 2010 at $0.28 \text{ m}^3 \text{ s}^{-1}$. The River Owenabue exhibits a flashy hydrograph with suspended sediment concentrations and sediment associated nutrient concentrations responding quickly to high flow events.

5 4.2 Concentrations

The largest TN concentrations occur during the winter months of November, December and January (Fig. 3a). Concentrations were lowest during the July to September period. The annual mean TN concentrations for 2010 and 2011 are 4.7 and 4.6 mgL^{-1} respectively.

10 The range in TDN was large with concentrations varying between 0.5 and 8.3 mgL^{-1} . The variation in PN was larger with concentrations ranging from 0 to 14 mgL^{-1} . TDN dominates the TN measurement, with the mean TDN content of the samples being 76% . The variation of TDN content was high with a range between 20 and 100% of the TN measurement. Correspondingly, PN constituted 24% of the TN concentrations
15 of the samples, with a range from 0 to 84% .

TP concentrations are generally higher in winter although the winter of 2011 had notably lower concentrations (Fig. 3b). Annual mean TP concentrations were 0.1 mgL^{-1} in both 2010 and 2011. TP is dominated by TDP, with TDP concentrations ranging from 0.01 to 0.19 mgL^{-1} and having an average concentration of 0.06 mgL^{-1} . PP was found
20 to vary from 0.0 to 1.28 mgL^{-1} indicating PP to be much more variable than dissolved phosphorus. The range of TDP within TP samples varied between 11 and 100% with 61% of all samples being dominated by TDP. The range of PP in the TP sample varied between 0 and 89% with an average of 39% .

4.3 Nutrient relationships and yields

Table 1 shows the result of a correlation analysis between the measured nutrient parameters. Both linear and power based regressions were investigated with the largest r^2 values reported.

5 All regressions were found to be statistically significant (p values < 0.001). SSC, TP, TRP, and PP were all found to have r^2 values (coefficient of determination) greater than 0.5 when regressed linearly against in-situ turbidity (Turb_i). In particular, TP and PP were very well correlated with turbidity. Based on the correlation between P parameters and turbidity, all P parameters were extrapolated from their respective regression curves
10 with turbidity. This approach was taken as using a mixed approach for TDP, which was the only P parameter with an r^2 value lower than 0.5 would have introduced a conflict with the TP/PP/TDP ratios. Nitrogen parameters were calculated using the method in Eq. (2).

Yields of nitrogen and phosphorus passing the gauging station are presented in Table 2 for the years 2010, 2011 and also for the entire monitoring period. The mean TN yield is $4004 \text{ kg km}^{-2} \text{ yr}^{-1}$ for the full monitoring period with a mean PN yield of $982 \text{ kg km}^{-2} \text{ yr}^{-1}$, 25% of the TN yield. Mean TP yield is $92.6 \text{ kg km}^{-2} \text{ yr}^{-1}$ with a mean PP yield of $48.7 \text{ kg km}^{-2} \text{ yr}^{-1}$, 53% of the TP yield. These yield values are highly influenced by the major storm event of 2009 as illustrated in Table 2 where the mean
15 yields for the full years of 2010 and 2011 are much lower. The mean contribution of PN and PP is estimated to be 5.66 and 0.28% respectively of the annualised suspended sediment load which is $17\,331 \text{ kg km}^{-2} \text{ yr}^{-1}$.
20

inputs, in particular from diffuse agricultural sources are a significant potential risk given that they are highly dependent on run-off processes, unlike point sources.

TN concentrations were diluted during storm events, despite an initial increase in particulate concentration signifying that its transport mechanism does not respond quickly to river discharge or overland flow. Conversely, TP was found to respond quickly to river discharge and overland flow where both the dissolved and particulate fractions of phosphorus increase during storm events.

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References

- Anon: Water Matters: Our Plan! – South Western River Basin District Management Plan (2009–2015), South Western River Basin District Project Office, Environmental Department, Cork County Council, Inniscarra, Co., Cork, 2010.
- Cohn, T. A.: Recent advances in statistical methods for the estimation of sediment and nutrient transport in rivers, US National Report to International Union of Geodesy and Geophysics (1991–1994), *Rev. Geophys. Suppl.*, 1117–1123, 1995.
- Drewry, J. J., Newham, L. T. H., and Croke, B. F. W.: Suspended sediment, nitrogen and phosphorus concentrations and exports during storm-events to the Tuross estuary, Australia, *Environ. Manage.*, 90, 879–887, 2009.
- Eaton, A. D., Glesceri, L. S., Rice, E. W., and Greenberg, A. E. (Eds.): *Standard Methods for the Examination of Water and Wastewater*, 21st Edn., American Public Health Association, American Water Works Association, Water Environment Association, Washington, D.C., 2005.
- European Communities Environmental Objectives (Surface Water): Regulations 2009, S.I. No. 272 of 2009, Stationery Office, Dublin, 2009.

- Fishman, M. J. and Friedman, L. C. (Eds.): *Methods for the Determination of Inorganic Substances in Water and Fluvial Sediments*, Techniques of Water-Resources Investigations of the USGS, 3rd Edn., chapter A1, Book 5, USGS, Washington, D.C., 545 pp., 1989.
- Gouze, E., Raimbault, P., Garcia, N., Bernard, G., and Picon, P.: Nutrient and suspended matter discharge by tributaries into the Berre Lagoon (France): the contribution of flood events to the matter budget, *C. R. Geosci.*, 340, 233–244, 2008.
- Harrington, S. T. and Harrington, J. R.: *The Influence of Storm Based Events on the Suspended Sediment Flux in a Small Scale River Catchment in Ireland*, Monitoring, Simulation, Prevention and Remediation of Dense and Debris Flows IV, WIT Press, Southampton, UK, 2012.
- Horowitz, A. J.: Determining annual suspended sediment and sediment-associated trace element and nutrient loads, *Sci. Total Environ.*, 400, 315–343, 2008.
- Jarvie, H. P., Whitton, B. A., and Neal, C.: Nitrogen and phosphorus in east coast British rivers: speciation, sources and biological significance, *Sci. Total Environ.*, 210/211, 79–109, 1998.
- Jordan, P., Menary, W., Daly, K., Kiely, G., Morgan, G., Byrne, P., and Moles, R.: Patterns and processes of phosphorus transfer from Irish grassland soils to rivers – integration of laboratory and catchment studies, *J. Hydrol.*, 304, 20–34, 2005.
- Kronvang, B. and Bruhn, A. J.: Choice of sampling strategy and estimation method for calculating nitrogen and phosphorous transport in small lowland streams, *Hydrol. Process.*, 10, 1483–1501, 1996.
- Kyllmar, K., Carlsson, C., Gustafson, A., Ulen, B., and Johnsson, H.: Nutrient discharge from small agricultural catchments in Sweden: characterisation and trends, *Agr. Ecosyst. Environ.*, 115, 15–26, 2006.
- Lalor, S. T. J., Coulter, B. S., Quinlan, G., and Connolly, L.: *A Survey of Fertilizer Use in Ireland from 2004–2008 for Grasslands and Arable Crops*, Johnstown Castle Environment Research Centre, Wexford, Ireland, 2010.
- Lu, X. X., Li, S., He, M., Zhou, Y., Bei, R., Li, L., and Ziegler, A. D.: Seasonal changes of nutrient fluxes in the Upper Changjiang basin: an example of the Longchuanjiang River, China, *J. Hydrol.*, 405, 344–351, 2011.
- Mainstone, C. P., Dils, R. M., and Withers, P. J. A.: Controlling sediment and phosphorus transfer to receiving waters – a strategic management perspective for England and Wales, *J. Hydrol.*, 350, 131–143, 2008.

- Marchetti, R. and Verna, N.: Quantification of the phosphorus and nitrogen loads in the minor rivers of the Emilia-Romagna coast (Italy), a methodological study on the use of theoretical coefficients in calculating loads, *Sci. Total Environ. Suppl.*, 315–336, 1992.
- 5 May, L., House, W. A., Bowes, M., and McEvoy, J.: Seasonal export of phosphorous from a low-land catchment: upper River Cherwell in Oxfordshire, England, *Sci. Total Environ.*, 269, 117–130, 2001.
- McDowell, R. W., Biggs, B. J. F., Sharpley, A. N., and Nguyen, L.: Connecting phosphorus loss from agricultural landscapes to surface water quality, *J. Chem. Ecol.*, 20, 1–4, 2004.
- 10 McGarrigle, M. and Glenaghan, C.: Agriculture and forestry, in: Ireland's Environment 2004, Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland, 2004.
- McGarrigle, M., Bradley, C., and O'Donnell, C.: Water Quality in Ireland 2007–2009, Environmental Protection Agency, Johnstown Castle Estate, County Wexford, Ireland, 2010.
- 15 Moatar, F. and Maybeck, M.: Compared performance of different algorithms for estimating annual nutrient loads discharged by the eutrophic River Loire, *Hydrol. Process.*, 19, 429–444, 2005.
- Neill, M.: Nitrate concentrations in river waters in the south-east of Ireland and their relationship with agricultural practice, *Water Resour.*, 23, 1339–1355, 1989.
- Quilbé, R., Rousseau, A. N., Duchemin, M., Poulin, A., Gangbazo, G., and Villeneuve, J.: Selecting a calculation method to estimate sediment and nutrient loads in streams: application to the Beaurivage River (Québec, Canada), *J. Hydrol.*, 326, 295–310, 2005.
- 20 Salvia-Castellví, M., Iffly, J. F., Borght, P. V., and Hoffman, L.: Dissolved and particulate nutrient export from rural catchments: a case study from Luxembourg, *Sci. Total Environ.*, 344, 51–65, 2005.
- Scanlon, T. M., Kiely, G., and Xie, Q.: A nested catchment approach for defining the hydrological controls on non-point phosphorus transport, *J. Hydrol.*, 291, 218–231, 2004.
- 25 Schindler, D. W.: Recent advances in the understanding and management of eutrophication, *Limnol. Oceanogr.*, 51, 351–363, 2006.
- Smart, T. S., Hirst, D. J., and Elston, D. A.: Methods for estimation loads transported by rivers, *Hydrol. Earth Syst. Sci.*, 3, 295–303, doi:10.5194/hess-3-295-1999, 1999.
- 30 Stutter, M. I., Langan, S. J., and Demars, B. O. L.: River sediments provide a link between catchment pressures and ecological status in a mixed land use Scottish river system, *Water Res.*, 41, 2803–2815, 2007.

- Webb, B. W. and Walling, D. E.: Nitrate behaviour in streamflow in a grassland catchment in Devon, UK, *Water Res.*, 19, 1005–1016, 1985
- Withers, P. J. A., Edwards, A. C., and Foy, R. H.: Phosphorus cycling in UK agriculture and implications for phosphorus loss from soil, *J. Soil Use Manage.*, 17, 139–149, 2001.
- 5 Zamyadi, A., Gallichand, J., and Duchemin, M.: Comparison of methods for estimating sediment and nitrogen loads from a small agricultural watershed, *Can. Biosyst. Eng.*, 49, 127–136, 2007.

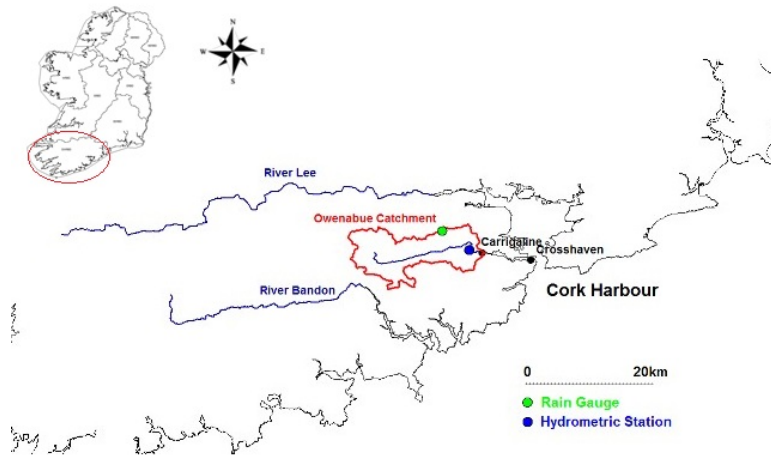


Fig. 1. Location of the River Owenabue catchment and gauging station.

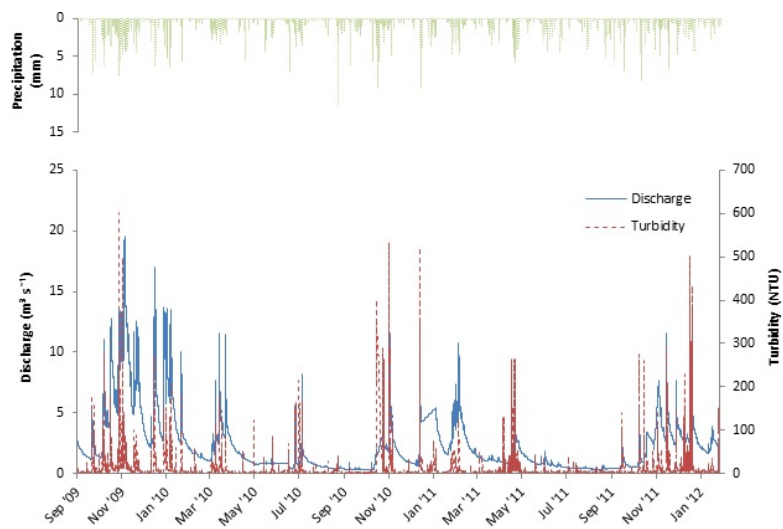


Fig. 2. Precipitation, discharge and turbidity values during the monitoring period.

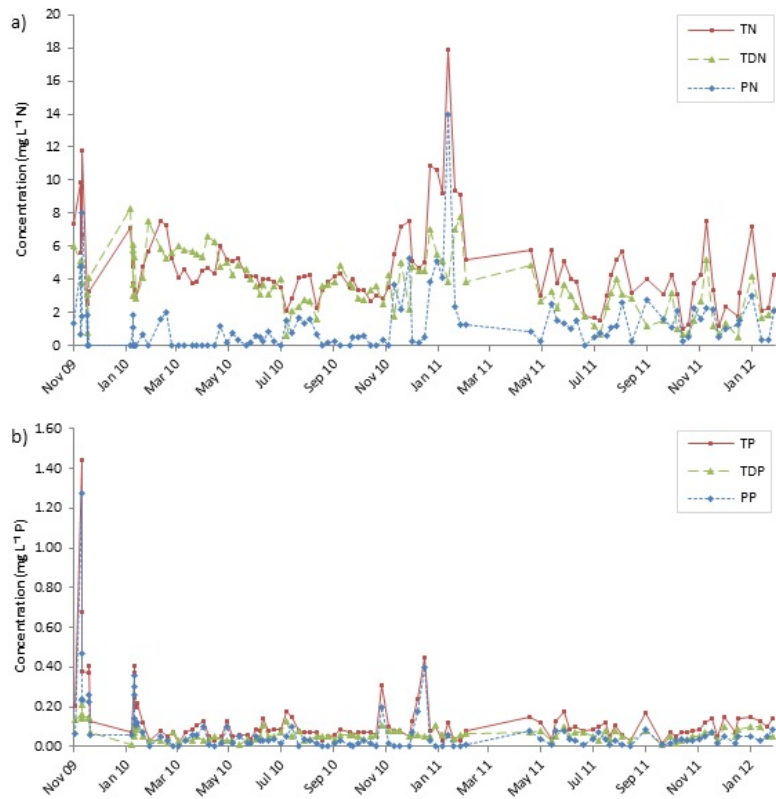


Fig. 3. Mean monthly concentrations of (a) nitrogen and (b) phosphorus.

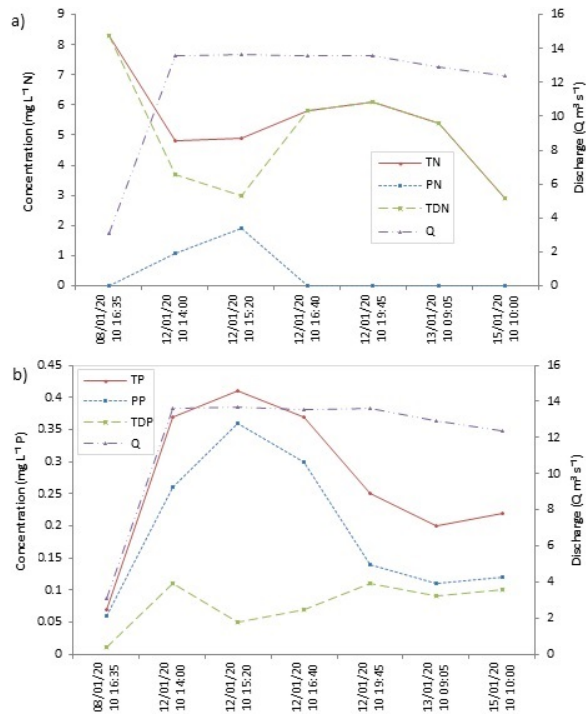


Fig. 4. Discharge and (a) nitrogen and (b) phosphorus concentrations during a storm event from January 2010.

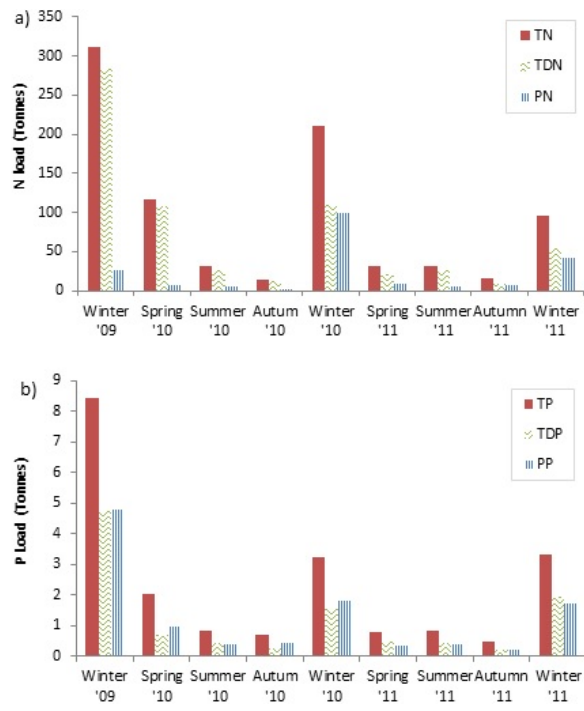


Fig. 5. Seasonal loads of (a) nitrogen and (b) phosphorus on the River Owenabue.