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Land use and water quality

Andy Baker*

Centre for Land Use and Water Resources Research, University of Newcastle-upon-Tyne, Newcastle, UK

*Correspondence to:
Andy Baker, Centre for Land Use and Water Resources Research, University of Newcastle-upon-Tyne, Newcastle NE1 7RU, UK.
E-mail: andy.baker@ncl.ac.uk

Water quality is affected by a combination of natural and anthropogenic factors, the relative influences of which change over the range of temporal and spatial scales investigated. Natural factors affecting water quality include precipitation intensity and amount, river discharge, geology and soil type, topography (slope length and gradient) and vegetation cover. Meybeck *et al*. (1989) provide a detailed review. Most of these factors can be, and have been, affected by humans; for example, changes in river discharge due to abstraction, urbanization or impounding; discharges from industry, agriculture or sewerage, etc. Many of these anthropogenic influences are part of the larger process of catchment land use or land cover change that can affect water quality in both rivers and lakes, as well as downstream estuarine and coastal waters. Investigation of the relationship between land cover and water quality is particularly useful when considering diffuse source pollution. Diffuse sources of suspended sediments, pathogens, nutrients and pesticides in agricultural land uses, and of suspended sediments, pathogens, nutrients, oxygen demanders, heavy metals, oil and road salt in urban areas, are often difficult to measure. One aim of understanding land use–water quality relationships would be to be able to use land use to estimate and understand water quality in rivers suffering from diffuse pollution. Another would be to use satellite-derived land cover data to predict water quality in unmonitored catchments. Finally, understanding the relationship between land use and water quality would improve the science and policy of land-use management. For example, it would enable a better understanding of future impacts of changing land use driven by, for example, climate change (Abler *et al*., 2002).

For a relationship between land use and water quality to be observed, a number of criteria have to be met:

1. **As in any water quality investigation, the determinand has to conservative, such that an upstream land-use fingerprint is preserved at the sampling location. For example, many studies have shown that chloride concentration correlates with urbanization at all scales and all stages of urban development. Although natural inputs need to be understood from sea spray/precipitation and, in some cases, geology, this has the potential to be an excellent and easily measured fingerprint of human impact, in part due to its conservative nature.**

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2. Sampling location and frequency have to be appropriate to the size of the catchment and the land-use impact to be monitored. Many studies have focused on simplified experimental conditions to test the land use–water quality relationship: low-order streams in small catchments with a wide variety of land uses sampled over short time periods (<1 year). However, practical land use–water quality issues often occur in larger catchments, which are harder to sample at an appropriate spatial and temporal resolution. Land use–water quality relationships observed at the sub-catchment scale may not be up-scalable, and any compromises in spatial and temporal sampling strategy mean that the land use–water quality relationship obtained will, in part, be a function of the sampling strategy.
3. The land use has to be determined for the catchment, and this is not necessarily a trivial task. For small catchments this can often be obtained by ground survey or map data. For large catchments, satellite imagery (such as the Landsat TM) has to be used to obtain the necessary spatial coverage and then classification schemes, such as the normalized difference vegetation index (NDVI), used to allocate land-use classes. However, these normally contain a not insignificant classification error (see review of remote-sensing applications by Griffith (2002)).
4. The land use–water quality relationship needs investigation over a wider range of land uses and climate zones. A large body of research exists on temperate zone North American and European rivers—exceptions are, for example, Frenzel and Couvillion (2002), Biggs *et al.* (2002), Downing *et al.* (1999) and Ometo *et al.* (2000)—in predominantly agricultural and/or forested regions (for an exception see Frenzel and Couvillion (2002)), the combination of which are, by implication, regions of relatively stable land uses. Fewer studies have been undertaken in tropical and developing countries, often with more rapidly changing land use—for exceptions see Ometo *et al.* (2000) and Biggs *et al.* (2002). North American and European regions, in general, have also moved through the transition from having predominantly point-source pollution problems to a situation where diffuse pollution is more important: fertilizer use is more common and frequently over applied compared with developing countries, and they have land uses that are substantially different from tropical and arctic regions. Studies in temperate regions suggest that nitrate export has increased by between $\times 3$ and $\times 20$ since industrialization due to increased animal and human wastes and increased runoff (Pierls *et al.*, 1991). Large-scale land-use changes are occurring in tropical countries: Will tropical deforestation lead to a similar phenomenon when tropical rivers are naturally high nitrate-transport environments (Downing *et al.*, 1999)?
5. The location of different types of land use within a catchment is the focus of considerable research, primarily driven by the buffer strip concept. However, the impact of buffer strips (riparian zones, land–water ecotones) on water quality appears unclear (Johnson *et al.*, 1997; Sliva and Williams, 2001; Griffith, 2002). It is not clear when, if, or how riparian vegetation maintains water quality, or whether the land use of the entire catchment has a greater effect. For example, Johnson *et al.* (1997) show that landscape characteristics explain some water quality variations in some seasons, but that catchment land use was just as important in predicting water quality. Similarly, too few studies have investigated the relationship between landscape pattern metrics and water quality. Wear *et al.* (1998) looked at a rural–urban gradient and suggested that the most remote portion of the watershed and the outer edge of urban development have disproportionate influences on water quality. Other studies, however, have found no importance of landscape pattern metrics. As for the general relationship between catchment land use and water quality, different landscape pattern metrics and buffer strips will work in different catchments depending on land use, topography, climate, catchment size and soil and geology. A comprehensive review can be found in Griffith (2002).

The land use–water quality relationship is complex and, in general, any correlation observed in one catchment is likely to be site or region specific. However, some water quality determinands and land covers do show reproducible trends. Urban land use often determines chloride concentration. Agricultural land use often determines nutrient concentrations in intensive agricultural regions, and lime-derived anions and cations in both intensive and extensive agriculture. In general, as soon as urban land use increases beyond a small percentage of total land cover ($\sim$5%; the precise amount requires further research), then urban land use impacts on water quality dominate over agricultural impacts. Undisturbed forest cover, in all cases, appears to have no impact on river water quality. However, land use is forever changing, and future land-cover changes will be driven by the interplay between population growth, climate change and policy makers, which will vary in different parts of the world. Understanding human land-use and natural vegetation adaptations to climate change, together with river response, are essential. This will be achieved by improved understanding, and modelling, of the processes driving the observed land use–water quality relationships.

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