Defining spatial relationships between forestry operations and surface water quality in Ireland

S. Blacklocke*, M. Bruen*, M. Kelly-Quinn, H. Feeley****

*University College Dublin, School of Architecture, Landscape and Civil Engineering, Newstead Building, Belfield, Dublin 4, Ireland.
**University College Dublin, School of Biology and Environmental Science, Science Building, Belfield, Dublin 4, Ireland.

Keywords: spatial statistics, forestry diffuse pollution, geographically weighted regression

The HYDROFOR Project is currently Ireland's largest research effort to aid foresters and water resources managers in their efforts to cooperatively develop cost-effective programmes of measures to mitigate key adverse surface water impacts inherent in common Irish forestry operations. HYDROFOR builds on a legacy of similar previous studies and on a number of concurrent complimentary collaborating projects.

The HYDROFOR team also spans the entire spectrum of relevant professions, including foresters, civil engineers, ecologists, hydrologists, water chemists, and an economist. This eclectic group and its many predecessors and collaborators have generated and continue to generate an ever-growing body of Ireland-based data useful in better understanding the source-receptor pathways of forestry-related diffuse pollutants and forestry-operation hydro-modifications. Also accumulating are data potentially useful in estimating the effectiveness of water-resource-impact mitigation measures. These effectiveness estimates are prerequisites to identifying cost-effective sets of measures pursuant to the new requirements of Ireland under the European Union's Water Framework Directive.

Arguably lacking in Ireland at present, however, is a comprehensive assessment of the potential of these data to be employed in the development of empirical models – ones that can much more explicitly explain and predict these forestry practice impacts. In particular, data currently being generated on the precise spatial relationships between specific attributes of forests and forestry operations, mitigation measures, and water quality and aquatic ecology sampling locations have yet to be put to use for this purpose in any significant way. Expanding datasets on the key explanatory variables of such models, such as forest species and age composition, forestland slope/aspect/geology/soil, and relevant ambient water quality parameters (e.g., pH, suspended solids, phosphorous, etc.), to name only a few, are all on hand, as are time and location-based data on forestry practices and mitigation measures.

Key to the determination of the utility of these data in developing such regression models is a contemporaneous assessment of the relevant statistical techniques that might be employed to make optimal use of the information these datasets hold. And perhaps among the most promising techniques are those emerging in the field of spatial statistics.

Literature *exclusively* relevant to assessing spatial statistical techniques to inform the development of empirical models for the prediction of forestry practice impacts on surface waters is quite scarce. But there is a fast-emerging body of very recent work coming from the traditional disciplinary sources of spatial statistics - such as general statistics and demography, econometrics, epidemiology and geography - that can be drawn upon to achieve, in part, the objectives of the HYDROFOR spatial statistics techniques assessment exercise. Fortunately, increasingly forthcoming also are published efforts to employ modern spatial statistical techniques in the fields of water chemistry, water resources engineering, environmental economics, hydrology, aquatic ecology and forestry, respectively. The multi-disciplinary HYDROFOR team is uniquely well suited to conduct a comprehensive review of this larger body of peripherally relevant literature. For the reasons heretofore presented, the team views

investment in this effort worthwhile given the high potential for producing the most project-objective-relevant and practically applicable research findings. The paper described in this extended outline is the output of this assessment of HYDROFOR-relevant spatial statistical techniques.

Presented are key works explaining the general motivation for including spatial effects in regression models such as those under development by the HYDROFOR Project. For example, findings of a typical demographic study of 1900 rural Canadian communities demonstrated that the explanatory power of two-thirds of the independent variables used in traditional Ordinary Least Squares (OLS) regression analysis were significantly understated due to the lack of accounting of their inherent spatial heterogeneity. The understatement was determined by comparing OLS parameters with those of a new and more suitable regression technique that takes account of spatial heterogeneity in its variables – Geographically Weighted Regression (GWR). GWR is a relatively recent advancement in statistical modelling that allows regression analysts to account explicitly for spatial non-stationarity in its regressors (Brunsdon et al. 1998).

There is a reasonably extensive body of literature describing the use of various spatial statistical techniques in the management of surface water quality. The full paper described in this extended outline discusses the relevance of the findings of each of these works to the HYDROFOR assessment effort. Each of these works concludes with a recommendation to apply either GWR or a more traditional OLS-based spatial statistical technique to address its limitations due to regressor spatial homogeneity.

Finally, also reviewed is literature on applications of peripherally relevant spatial statistical techniques emerging out of the fields of hydrology, aquatic ecology and forestry. Again, each concludes with statements on the importance of avoiding globally weighted regression analysis when relevant spatial data are available.

To adequately estimate the effectiveness of measures intended to mitigate or prevent forestry operation impacts on Ireland's aquatic ecology, more precise, quantitative information on the location-specific performance of these measures must be generated. And as a prerequisite to ascertaining these measures' respective performances, adequate knowledge of the pathways of forestry diffuse pollutants and causal factors for hydro-modifications must already be on hand. Information on the spatial relationships between the various attributes of Ireland's forests and forestry operations and the effectiveness of the mitigation measures they employ to protect aquatic resources (represented via geo-referenced indicator parameters) is currently a critical missing link.

Cost-effective sets of forestry measures cannot be determined and implemented without these critical inputs. And in the absence of implementation of truly cost-effective sets of mitigation measures, realisation of the full public benefits of Ireland's aquatic ecology and water uses will be protracted, and the optimal economic employment of Ireland's forest resources will be inhibited. The HYDROFOR effort is currently leading Ireland's collective forestry and water resources management community in its cooperative effort to address this challenge. It is doing so, in part, by pursuing the assessment described in this research paper outline.

References

Brunsdon, C, Fotheringham, S., Charlton, M. (1998) Geographically weighted regression – modelling spatial non-stationarity. The Statistician, 47(3), 431-443.