Evaluation of a surface hydrological connectivity index in agricultural catchments

Key messages

- Accurate characterisation of hydrological connectivity (the propensity for connection of surface flows to the river channel,) is important for identifying critical source areas of phosphorus loss (i.e. where high-P sources have a high propensity for connection to receiving water-bodies via effective transport pathways).
- However, there is a lack of suitable metrics for characterising hydrological connectivity at scales where P losses can be managed.
- This study shows the potential of the 'Network Index' model to characterise hydrological connectivity at land-management scales in two contrasting agricultural catchments (*ca.* 12 km^2) using a 5 m digital elevation model.
- At the subcatchment scale (*ca.* 130 ha), modelled connectivity matched observations well (R^2 = 0.52) despite soil type variability. Ditch information was not required to model subcatchment connectivity; however it was required to model subcatchment boundaries and thus the extent of critical source areas.
- At the field scale, the NI has potential for broadly discerning the most connected from the least connected fields which is valuable for identifying where critical source areas-based management should be targeted.

Network Index application

The Network Index (NI) was proposed by Lane et al. (2004) as a modification of the Topographic wetness Index (TWI) (defined as ln (α/tanβ) where α is the local upslope area and tanβ is the local slope), to include an element of connectivity. The NI approach is based on the concept that the lowest (driest) value of TWI along a flowpath to the stream is likely to have the greatest potential for infiltration of surface water and therefore limits the degree of connectivity to the stream. The NI identifies the lowest value of TWI along a flowpath to the stream and assigns this value to each new cell encountered upstream along the flow path until a lower TWI value is encountered (Fig. 1b). Connectivity is represented by the probability that lower NI values are likely to be connected less frequently and for shorter periods of time than higher NI values.

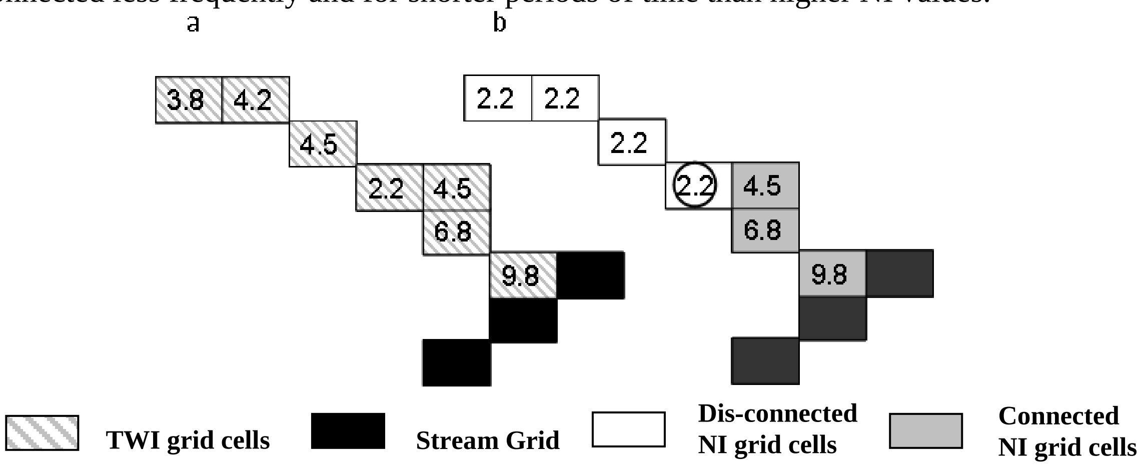

Figure 1. Comparison of a) the propensity for saturation predicted using the Topographic Wetness Index, and b) the propensity for connection of saturated areas using the NI, for a hypothetical flowpath to a stream. Higher values indicate higher propensity in both cases. The circled cell illustrates the lowest value of TWI along the flowpath to the stream. The white cells show where the TWI and NI values differ

Hypothesis 1
The accuracy of the NI would be poor in landscapes with variable soil types.

Background
As the NI is typically applied using digital elevation models (DEMs), the potential for the NI Index to accurately predict surface connectivity depends on the degree to which topography controls connectivity. Soil internal drainage capacity is a non-topographic control, thus is not accounted for in the model.

Results & Discussion
Hypothesis 1 rejected. At the subcatchment scale, modelled surface connectivity matched observations well (R^2 = 0.52) despite soil type variability (Fig. 2). However this was attributed to the correlation between soil type and topographically-controlled connectivity in these catchments. Poorly drained soils generally coincided with areas of topographically-controlled high NI values (i.e. low slopes in the low-lands and with short flow paths to the stream) and well drained soils coincided with areas of topographically-controlled low NI values (high slopes in the uplands with longer flow paths to the stream). At the field scale, the NI was reliable for distinguishing the most connected from the least connected fields. Of the most connected fields 83% were poorly drained and of the least connected fields 92% were well drained, demonstrating a strong association between connectivity and soil type also at this scale.

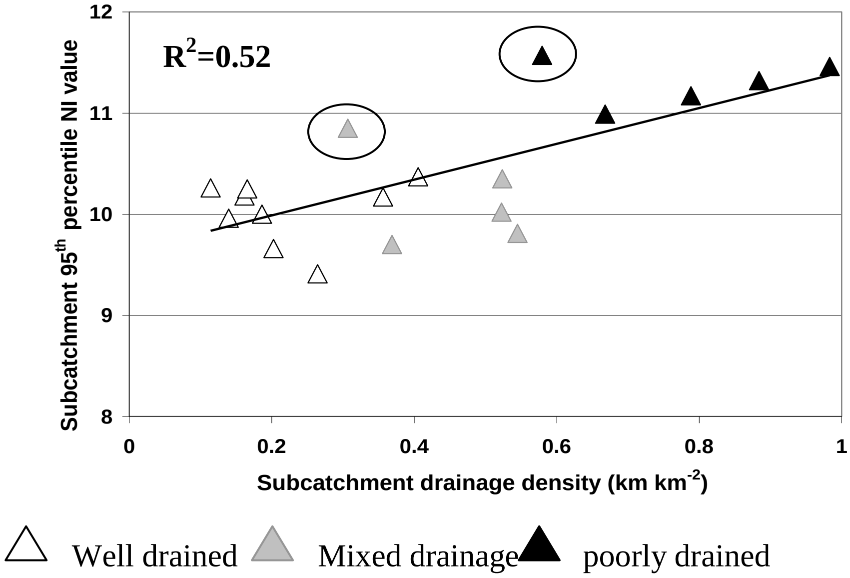

Figure 2. Predicted connectivity (95th percentile NI values) vs. observed connectivity (channel density) for subcatchments across both catchments. Subcatchments where NI values were particularly over-estimated are circled

Hypothesis 2

Application of the NI to a DEM which does not capture ditch features will be constrained by inaccurate prediction of flow location.

Background

Network Index accuracy also depends on the degree to which surface features that control the connectivity are captured by the underlying DEM. Micro-topographic features such as surface ditches influence the *location* of surface connectivity by capturing and re-routing surface flow along the channel (ditch and stream) network and away from its natural flowpath. As the resolution of the DEM in this study (5m) was coarser than the resolution of surface ditch features, it likely did not capture surface ditch features.

Result & Discussion:

Hypothesis 2 accepted. The locations of channel networks were within 39 m of observed channel networks for Arable A and within 60 m for Grassland B (at the 95% confidence level). The total area assigned to incorrect subcatchments was 31 ha in Arable A (2.8% of the total catchment area) and 133 ha in Grassland B (11% of the total catchment area) (Fig. 2). 133 ha is equivalent to the total area encompassed by the sum of four average-sized farms in Ireland. Thus, if the NI was used to identify subcatchments at high risk of P loss, four farmers in this catchment area could be advised to introduce mitigation measures needlessly, and/or four higher risk farms may remain un-detected.

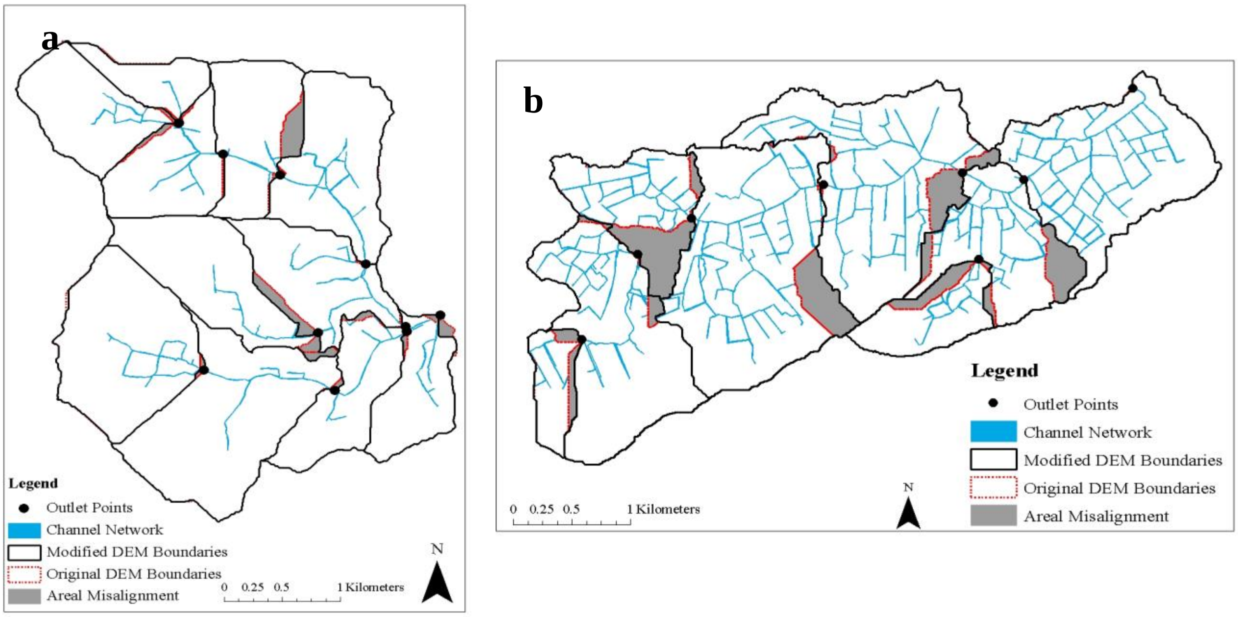

Figure 3. Alignment of subcatchment boundaries derived from the original DEM (red) and a modified DEM (hydrologically corrected - see note page 4) (black) with the channel network, for a) Arable A and b) Grassland B.

Hypothesis 3
Application of the NI to a DEM which does not capture ditch features will over-estimate the magnitude of surface connectivity in landscapes where surface flows are prevalent.

Background
In surface-flow driven landscapes, ditches may re-route a large proportion of total flows along the channel network instead of downslope. This may result in a reduction in surface saturation and connectivity in downslope fields.

Results & Discussion:
Hypothesis 3 rejected. Large over-estimations of surface connectivity were only observed in two out of ten subcatchments (circled in Fig. 2). Rejection of hypothesis 3 indicates that ditches had a low over-all influence on the magnitude of observed surface connectivity in these subcatchments, even where surface flows were prevalent. This suggests that less topographic detail may be better for predicting surface saturation (and thus connectivity) at the subcatchment scale.

Note on hydrological correction:

The accuracy of the NI, applied to a 'hydrologically corrected' 5m DEM, for predicting connectivity location and magnitude was also tested. The DEM was hydrologically corrected by overlaying and 'burning' a channel raster layer into the DEM. The location of connectivity was accurately predicted using the hydrologically corrected DEM; channel networks were within 7 m of observed channels (at the 95% confidence interval) and subcatchment boundaries were accurately delineated in both catchments. However, the magnitude of connectivity was not accurately predicted using the hydrologically corrected DEM due artefacts of the hydrological correction process; Hydrological correction causes high slopes at channel edges which reduce the local TWI. If these channel edge grid cells become the lowest value of TWI along the pathway to the stream low connectivity will also be propagated upslope whereas in reality the low TWI only has a local effect on connectivity.

This work is published in Shore et al. (2013)

References:

Shore, M., Murphy, P.N.C., Jordan, P., Mellander, P-E., Kelly-Quinn, M., Cushen, M., Mechan, S., Shine, O., Melland, A.R., 2013. Evaluation of a surface hydrological connectivity index in agricultural catchments. J. Environ. Model. Softw. 47, 7-15.

Lane, S.N., Brookes, C.J., Kirkby, M.J., Holden, J., 2004. A network-index-based version of TOPMODEL for use with high-resolution digital topographic data. Hydrol. Process. 18, 191-201.