**Water quality benefits**

**Introduction**

Landscape and watershed scale processes can influence pollution risk to aquatic ecosystems in terms of the impacts of delivery of fine sediment, solutes and organic matter (Reaney *et al.* 2011). For example, targeted planting of woodland on pollutant sources and delivery pathways have been shown to reduce diffuse nutrient, pesticide and sediment delivery to watercourses (Nesbet et al 2011 in FR 2014).

The mechanism for pollution transport and delivery vary according to the type of pollutant and its source. Many types of agricultural (eg organic matter, nitrates, phosphates, pesticides) and other pollutants can be transported through surface water runoff either by the erosion and transport of particulate matter or direct transport of water-soluble pollutants. More complex pathways can include the pollution of ground water sources but these are not addressed by this methodology and in general are not considered major pathways of agricultural water pollution in Cornwall (REF?).

Soil loss is cited as a direct reason for failure of river waterbodies to reach a ‘good’ status in over 10% of cases in England and as a detrimental factor in many drinking water sensitive zones (ref?). It is also likely to play an important role in other causes for watercourses failing to achieve a ‘good’ status. GET A TABLE FOR CORNWALL CATCHMENTS REASONS FOR FAILURE?

The aim of the methodology is to apportion a relative value across the landscape corresponding to the risk of diffuse, soil-based pollution sources reaching the water network.

The method does not consider the characteristics of water courses themselves and how these might affect pollution concentrations, deposition or transformation. There are many factors by which landcover and use along river courses can reduce bank erosion and soil loss along watercourses and/or slow water flow. Riverine landcover type and use will also influence the quality of watercourse habitats and ecosystem functioning that in turn can bring water quality benefits.

**Estimating pollution risk across the landscape**

The method chosen to estimate risks to water quality and mitigation services involve the following key steps that are subsequently discussed in further detail.

1. Calculating a high-resolution hydrological elevation model where modelled water flows correspond closely to observed water courses.
2. Estimate risk of soil loss from water erosion.
3. Estimate the risk of waterborne pollutants reaching the water network.
4. Model the accumulation of risk throughout the watercourse network.

***i. Hydrological digital elevation model***

Without correction, flow paths derived from digital elevation models (DEM) will not always correspond to known watercourses due to artefacts of the DEM, particularly at lower resolutions. Typical artefacts include narrow streams and drainage channels, as well as river flow under other terrain features such as road and rail bridges. Two measures were taken to ensure that modelled flowed closely resembled observed flows:

1. Hydrological modelling was carried out at a higher resolution using a cell size of 25m2 before outputs were resampled to 100m2. A resolution of 5m2 was also considered but comparison of the extracted stream network from each resolution found minimal differences.
2. The original DEM was corrected by using a breach-fill technique (REFS) that ensured a high level of flow connectivity across the landscape. Permanent watercourse were defined as all areas with a upslope contributing area greater than 1km2 , and these were found to closely match known stream networks (OS Open Riversdata). Some remaining no-flow cells in the corrected DEM were found to be primarily restricted to coastal edges.

The hydrological DEM was used for the calculation of flow directions, upstream contributing area (flow accumulation) and derived measures such as topographical wetness index. The original DEM was used for all other calculations including slope used for the derivation of the wetness index.

***ii. Risk of soil loss from water erosion (RUSLE\_calcs.R)***

Estimates of factors affecting soil erosion across Europe produced using the RUSLE2015 model (Panagos et al 2015 [The new assessment of soil loss by water erosion in Europe](http://www.sciencedirect.com/science/article/pii/S1462901115300654)) have been adapted to provide an estimate of soil loss mitigation due to landcover.

The factors used in the estimation, namely K-Factor (Soil Erodibility), R-factor (Rainfall erosivity) and the LS-factor (Slope Length and Steepness), provide an estimate of potential soil loss (RUSLE.base) independent of landcover.

**RUSLE.base = K-factor + R-factor + LS-factor**

**IS THIS MEANT TO BE SUM ??**

To estimate soil loss under existing (or hypothesized landcover types) requires the addition of factors representing landcover type, management (C-factor) or support practices (P-factor).

Instead of using the ESDAC C-factor, which was derived from Corine landcover data, tailored landcover values were used based on CEH 2015 landcover classification. Values were derived from previous studies as reviewed by Panaglos et al (2015) although the difference in the C value for improved grassland and arable land was explicitly reduced to reflect the potential of these uses to vary between years (see table 1 for the values assigned to land classes). The P-factor is most often used to capture the effect of tillage and use of cover crop to reduce erosion. With a lack of reliable information on cultivation practices, we have instead added a P-factor based on the total hedgerow length (ERCCIS data ref) within each cell (see Table 2).

The custom C and P layers were used to derive a modified RUSLE estimation of current soil loss due to water erosion under current landcover.

**RUSLE.lc = K-factor + R-factor + LS-factor + C-factor + P-factor**

The soil loss mitigation value was calculated as the normalised difference between RUSLE.lc and RUSLE.base.

|  |  |
| --- | --- |
| **Landcover** | **RUSLE C-factor** |
| Coniferous woodland | 0.001 |
| Broadleaf woodland | 0.001 |
| Semi-natural grassland | 0.04 |
| Wetland | 0.01 |
| Heath / Moor | 0.05 |
| Inland Rock | 0.0 |
| Maritime cliff | 0.08 |
| Littoral Rock | 0.0 |
| Supralittoral sediment | 0.0 |
| Littoral sediment | 0.0 |
| Water | 0.0 |
| Arable | 0.2 |
| Improved grassland | 0.1 |
| Urban | 0.0 |

**Table** 1: landcover C factor used in RUSLE calculations

|  |  |  |
| --- | --- | --- |
| **From** | **To** | **RUSLE P-factor** |
| 0 | 25 | 1 |
| 25 | 150 | 0.95 |
| 150 | 300 | 0.9 |
| 300 | 600 | 0.75 |
| 300+ | (max = 2742) | 0.5 |

**Table 2:** P-factor based on sum of hedgerows length (in metres) within 100m2 cell

***iii. Risk of soil loss and water-born pollutants reaching watercourses***

The RUSLE-derived soil loss mitigation value provides an estimation of the service provided by existing landcover to mitigate potential soil loss. It provides a static map of potential soil loss but does not offer any modelling of soil transportation to the river/water network or the potential of landcover to intercept or otherwise influence this transportation. Furthermore, it takes no account of pollution associated with surface water runoff, independent of soil erosion. The water quality mitigation benefits of landcover can not only function by reducing soil erosion but also by reducing the likelihood of soil or water-based pollutants reaching the water network.

A simple dynamic model can capture the transportation flux of sediment / pollutants by overland flow to the watercourse network *ie* a simple mass-flux model. Such a model can include a loading parameter, but also a transportation or interception factor that reflects the probability or amount of the pollutant transported by the flow to the river network.

Without spatial data on pollution loadings or river flow parameters, we have adapted the approach of *SCIMAP* (Reaney *et al.* 2011) to modfel the flow of ‘risk’ through the hydrological network. The premise of the approach is that flow paths accumulate distributed sources of pollutants from across the landscape into the river corridor. The approach is relative and aims to judge the riskiness of one location in the landscape for locations in the downstream water environment as compared with all other locations in the landscape.

The approach involves the estimation of:

1. **Generational risk** is derived from the calculation of hydrological risk (energy available for erosion) weighted by resistance to erosion due to soil type, landcover and use. We have adopted the factors used in the RUSLE method (described above) to estimate the generational risk. The hydrological risk corresponds to the sum of local slope factor[[1]](#footnote-1) (LS-factor) and the rainfall erosivity (R-factor). The resistance to erosion corresponds to the sum of RUSLE estimates of soil (K-factor), landcover (C-factor) and management (P-factor) effects on erosion risk, so that: Rgen = Rhydro \* Rerod
2. **Delivery Index** of eroded material is derived from the topographic wetness index[[2]](#footnote-2) (Beven and Kirkby, 1979) as a measure of the propensity to generate saturation excess overland flow. Any temporal variability in connectivity is assumed to correspond to spatial variability. The probability of surface water borne pollutants reaching the watercourse network is determined from a linear scaling of the lowest topographic wetness index encountered along the downstream flow path[[3]](#footnote-3). The wetness index is calculated from a multi-directional flow accumulation method (REF) as studies suggest (Kopecky et al 2010) the superiority of the method to a single direction flow indicator particularly for soil wetness applications.
3. **Locational risk** is defined as the likelihood of pollution reaching the water network and is calculated from the sum of the Generational risk and the Delivery Index.
4. **Accumulation of locational risk** uses the locational risk as the loading in a mass-flux model that routes and accumulates the risk under the assumption that the risk at a point is the sum of all locational risks upstream of that point. Flow paths are calculated from a single direction flow indicators (D8 method). The effect of dilution can be incorporated by scaling by the upslope contributing area (weighted by rainfall if this has been included in the generational risk). The method does not account for any loss of risk due to deposition along the water network although such deposition is generally considered to be relatively small in most networks.

FIGURES for an example catchment

The method does not account for any interception of overland flow by landcover. One method for incorporating the effect of landcover on connectivity and its potential to intercept overland flow is to weight TWI by an estimate of overland flow velocity calculated using a modified Manning’s equation which incorporates a landcover effect on velocity. However, several studies suggest that overland flow is often concentrated along rills and narrow channels and therefore the effect of landcover on overland flow can be highly variable.

SPR or K-factor?

**Identifying dependencies on water quality – existing and potential pollution mitigation services**

1. ***Vulnerable waterbodies and catchment areas***

Additional designations and information, concerning the quality of watercourses, can be used to identify catchment areas vulnerable to a range of threats. River waterbodies that have been rated as possessing ‘not good’ quality status (Water Framework Directive classification REF) are identified as priority areas for improvements to water quality. Existing land designations associated with threats to watercourses such as nitrate and phosphate sensitive areas can also indicate priority areas for the mitigation of pollution affecting water quality.

Vulnerable ‘not good’ catchments where the reason for failure is identified as a ‘diffuse pollution’ source are considered areas where mitigation of pollutants affecting water quality is particularly valuable. This amounted to 74 of the 116 waterbodies that did not achieve “Good” overall quality. For opportunity mapping these areas are considered priorities where an increase in pollution mitigation value from a change in land cover would be particularly welcome.

Separate weightings for each type of vulnerable areas (drinking water abstraction, aquaculture, bathing water, ‘not good’ waterbody) can be applied in prioritisation and opportunity mapping.

1. ***Vulnerable Activities***

In addition to a potential impact on biodiversity and ecosystem function, a reduction in water quality can bring significant economic and social costs. We identified key industries and activities highly dependent on suitable water quality as:

* Drinking water abstraction
* Aquaculture
* Tourism via bathing water quality

The main location of these areas and the catchments draining into them were located using a variety of geographical data sources (see Table \*).

1. ***Uses in mapping***

**Comparison of results with other sources of risk**

Compare max(?) accumulated risk in watercourses with quality of catchment – any link?

**Mining pollution sources and connectivity**

* Of the xx river catchments across Cornwall assessed under the Water Framework ??, ?? were classified as of ‘not good’ quality and mining was identified as a reasons in ?? cases.
* Methodological limitations and alternatives
* Could use soil estimates of heavy metals as loading instead of RUSLE.
* Compare with sediment estimates.

**Notes on alternatives**

* Role of deposition – advocates of RUSLE suggest low deposition outside of watercourses
* The relative importance of the different mechanisms involved in the transportation of pollutants will vary between different types of pollutants. FOR EXAMPLE
* Good land management / farming practices are not captured in this methodology
* Hedgerows
* Sediment loss has been shown to be strongly related to overland flow levels (Henshaw 2005)

**R code**

Vulnerable Activity Data

Extract EA waterbody data functions

RUSLE calculations = RUSLE\_calcs.R

SCIMAP type approach – scimap\_functions.R

**References**

[Beven, K.J.](https://en.wikipedia.org/wiki/Keith_Beven); Kirkby, M. J. (1979). "A physically based, variable contributing area model of basin hydrology". *Hydrolological Science Bulletin*. **24** (1): 43–69. [doi](https://en.wikipedia.org/wiki/Digital_object_identifier):[10.1080/02626667909491834](https://doi.org/10.1080%2F02626667909491834).

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1. Alternatively the streampower index ( REF) can be used and the two factors are closely correlated. [↑](#footnote-ref-1)
2. An unfortunate implication of using TWI as the sole indicator of connectivity can be that any factor increasing soil wetness, such as vegetation cover, should increase connectivity and thereby risk of pollution from upstream areas. In reality, vegetation cover is as likely to reduce pollution risk, by reducing flow velocity and improving soil infiltration, particularly during heavy rainfall events when soil wetness if unlikely to be the limiting factor determining pollution connectivity. For the effect of vegetation parameters on soil wetness see Timimi et al (2010). [↑](#footnote-ref-2)
3. This does not account for any ‘interception’ of flow due to downstream landcover. [↑](#footnote-ref-3)