Ecosystem services: landscape risk contribution and mitigation of soil loss and water pollution

Purpose

To apportion a ***relative*** value across the landscape corresponding to the risk of diffuse pollution sources reaching the water network. The spatial mapping of pollution risk, in turn informs estimates of the mitigation of this risk by existing habitats and the potential for mitigation through habitat creation. The primary focus is on agricultural derived pollution from soil erosion or surface water run-off.

Background

Only 33 of the total of 134 river catchments in Cornwall assessed under the water framework directive are currently rated as possessing a “good“ overall quality (see figure 1).

For 72 (54%) of those catchments failing to attain “good” status, the underlying cause of pollution was attributed to a diffuse source. In every one of these catchments, mining (including quarrying) is identified as a current or historic cause of diffuse pollution. However, agriculture and rural land management is also identified as a cause in 52 of these same catchments.

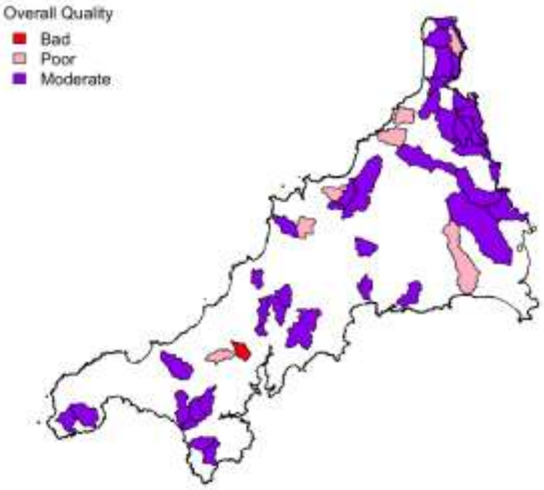

Figure 1: River catchments of "not good" overall quality for which a diffuse pollution source and agriculture or rural land management are identified among underlying causes. Note: areas draining directly to the coast or directly into major estuaries are not included in the water framework catchments. (Data from Environment Agency API accessed 2019)

The mechanisms for pollution generation, transport and delivery can vary according to the type of pollutant, its source and/or mode and timing of application. Landscape and watershed scale processes also influence the risk from diffuse pollution to aquatic ecosystems. Land cover and use will affect the generation, interception and/or transportation of fine sediment, solutes and organic matter (Reaney *et al.* 2011). Many types of agricultural pollutants (*eg* organic matter, nitrates, phosphates, pesticides) 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 in general these are not considered major pathways of agricultural water pollution in Cornwall.

Changes to habitat and land cover affect the transportation of pollution to the water network. Targeted planting of woodland on pollutant sources and delivery pathways has been shown to reduce diffuse nutrient, pesticide and sediment delivery to watercourses (Nesbet et al 2011 in FR 2014). The ecosystem 'services' of such pollution mitigation can be particularly valuable to catchments used for drinking water supply, aquaculture businesses and bathing water.

Mapping methodology

The method adopts the approach of *SCIMAP* (Reaney *et al.* 2011) to model 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 estimate the risk contribution of different locations across the landscape to the downstream water environment.

The methodology involves the following key steps that are subsequently discussed in further detail.

(i) Creating a hydrological elevation model ensuring that the whole landscape is joined up in a hydrological flow model that corresponds closely to observed water courses.
(ii) Estimate the risk of pollution generation associated with water runoff and soil erosion.
(iii) Estimate the risk of surface waterborne pollutants reaching the water network.
(iv) Model the flow and accumulation of risk to, and across, the watercourse network.
(v) Mapping of mitigation values.

i. Hydrological digital elevation model

Flow paths derived from 'uncorrected' digital elevation models (DEM), particularly at lower resolutions, often do not join-up or correspond to known watercourses. Artefacts such narrow streams, drainage channels and covered flow under road and rail bridges can all impede accurate flow modelling. The original 100 metre DEM is therefore corrected by using a breach-fill technique (Lindsay 2016, 2018) that ensures flow connectivity across the landscape. Permanent watercourses were defined as all areas with a upslope contributing area greater than 1km2 , and these closely matched known stream networks (from OS Open Rivers data).

The resulting hydrological DEM is used for the calculation of flow directions and upstream contributing area (flow accumulation). Some discrepancy is observed between flow derived from the hydrological DEM and actual watercourses, particularly in urban catchments where flow is often below surface, catchments with limited elevation variation and/or where there has been recent modification to original watercourses.

ii. Estimate the risk of pollution generation

Factors derived from the *RUSLE* model[1], widely used to estimate rates of soil erosion by rainfall, were used as parameters for estimating the risk of pollution generation.

The risk of pollution generation (*Rgen*) is defined as:

$$Rgen = Rhydro \times Rland$$

Rhydro is the 'hydrological' risk of erosion relating to topology, rainfall and soil type:

$$Rhydro = (LS\text{-}factor * R\text{-}factor * S\text{-}factor)$$

- **LS-factor** is the effect of topology and equal to the local slope factor[2];
- **R-factor** is the rainfall erosivity, which we equated to total precipitation;
- **K factor:** was derived from the classification of UK soil associations by their susceptibility to erosion (Evans 1990). However, this classification takes little account of risks associated with the compaction of clay-rich soils, such as the Culm measures in North-East Cornwall. Compaction increases surface water run-off and enhances the risk of soil erosion and the risk of slurry, manures and sprays that are washed

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[1] See Panagos et al (2015) for application to mapping soil loss across Europe. The soil and landcover data used in the mapping was found not to be reliable for southwest England.

[2] Alternatively the streampower index can be used and the two factors are closely correlated.

from the surface of compacted land (Henshaw 2005, CaBA report). The K-factor was therefore 'corrected' using the standard percentage runoff of the soil type (REF) and values scaled to an appropriate range for the soil types observed.

Rland a risk associated with land cover and management that is defined using RUSLE parameters as:

$$Rland = (C\text{-}factor * P\text{-}factor)$$

- **C-factor:** values from various soil erosion and sediment models (Panagos et al 2017, Perks et al 2017) were adapted and re-scaled (0:1) to reflect a combined pollution risk for different land cover classes (see table 1).
- **P-factor:** No reliable land management data was available for the whole of Cornwall, instead an additional factor derived from the length of hedgerows present in each grid cell was used to capture an effect of field size (table 2).

iii. Estimate risk of surface waterborne pollutants reaching the water network

The generational risk does not consider the likelihood of pollution reaching the river/water network or the potential of land cover and topography to affect this transportation. The **locational risk** (*Rloc*) is defined as the likelihood of pollution reaching the water network and is calculated as:

$$Rloc = Rgen \times Delivery\ Index.$$

A potential risk of pollution entering the watercourse network, without consideration of existing landcover can be estimated as:

$$Rpotloc = Rhydro \times Delivery\ Index$$

In both cases the **'Delivery Index'** is derived from the topographic wetness index (Beven and Kirkby, 1979) as a measure of the propensity to generate saturation excess overland flow. The probability of surface water borne pollutants reaching the watercourse network is determined from a linear scaling of the lowest topographic wetness index (calculated from multi-directional flow accumulation) encountered along the downstream flow path[3].

iv. Model the flow and accumulation of risk across the landscape and watercourse network.

The accumulation of pollution risk through the water network can be simulated by modelling flow across the landscape. The locational risk is used as the loading in a mass-flux model that routes and accumulates the risk under the assumption that the risk at any point is the sum of all locational risks upstream of that point. Flow paths are calculated from a single direction indicator ('D8 method'). The effect of dilution is subsequently incorporated by scaling risk accumulation by the upslope contributing area.

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[3] This does not account for any 'interception' of flow due to downstream landcover.

v. Estimating water pollution mitigation services

Application of the risk modelling to ecosystem service estimates involves firstly, identifying potentially vulnerable areas and their upstream catchments (reflecting service 'demand'), and, secondly, assigning a mitigation value across these landscapes.

a) Identifying vulnerable activities and waterbodies

A reduction in water quality will impact on biodiversity and ecosystem function and bring direct economic and social costs. Key economic activities dependent on suitable water quality include:

- Drinking water abstraction
- Aquaculture
- Recreational use of bathing waters

The catchments draining into each type of vulnerable area were calculated from the hydrological-corrected DEM. The catchment areas could then be used to 'mask' estimates of mitigation value so they correspond to specific types of vulnerable activities.

b) Estimating mitigation values of existing habitats

To map the ecosystem service value of land cover to mitigate water pollution we used two measures:

- Firstly, the difference between the *Rloc* and *Rpotloc* represents the existing mitigation of the risk of pollution reaching the water network, without consideration of any interception or absorption mechanism.
- Secondly, to capture the potential of habitat intercepting pollution along its flow path the accumulation of locational risk (*Rloc*) was multiplied by a habitat interception factor (see table 3) and scaled by 1 minus the log of the upslope contributing area, to reflect how habitat sediment or water interception will have a reduced effect along larger watercourses.

The 'water pollution mitigation value' of existing habitat was taken as the sum of the two values.

Types of map

Landscape risk contribution maps:

- **Soil erosion by water (excluding land cover effects)** – from *Rhydro* provides an indication of the inherent 'topographical' risk of soil erosion.
- **Soil erosion by water (including land cover effects)** – from *Rgen* provides an indication of the risk of soil erosion given existing land cover.
- **Soil / sediment risk to all watercourses** – from *locational risk* provides an indication of the relative contribution of the landscape to the risk of water pollution.
- **Soil / sediment risk to drinking water** – from the *locational risk* for drinking water.
- **Soil / sediment risk to aquaculture -** from the *locational risk* for aquaculture vulnerable area.

- **Soil / sediment risk to bathing water -** from the *locational risk* for bathing waters vulnerable area.

Ecosystem service maps:

- **Soil erosion mitigation** – from the difference between *Rhydro* and *Rgen*.
- **Drinking water quality -** from the water pollution mitigation value for drinking water vulnerable area.
- **Aquaculture quality -** from the water pollution mitigation value for aquaculture vulnerable area.
- **Bathing water quality -** from the water pollution mitigation value for bathing waters vulnerable area.

For mapping purposes all risk contribution and mitigation map values were normalised to a range between 0 and 100.

Use and Application

Ecosystem service maps were used in the existing nature network mapping, reflecting the relative service value of the landscape in terms of mitigating soil erosion and the risk of sediment reaching potentially vulnerable areas of the water network.

For woodland and wetland opportunity maps, the soil / sediment risk contribution maps, derived from *Rloc*, are used as indicative of the potential mitigation benefits of habitat creation.

The uncertainties associated with mapping the relative contribution of the landscape to the risk of water pollution, and the mitigation service of habitats, are significant and wide-ranging.

- ✓ The risk contribution maps provide an indication of areas where a change in land cover is most likely to affect soil erosion and/or sediment pollution reaching the watercourse network.
- ✓ The mitigation maps identify existing habitats most likely to contribute to the mitigation of soil erosion and sediment reaching watercourses.
- ❗ The risk contributions associated with different land cover types can only reflect broad relative values without consideration of land management practices which play a key role in determining risk generation and mitigation of soil erosion and water pollution. For example, bad woodland management practices might in some circumstances contribute greater pollution risk than well-managed arable land.
- ❗ The method does not account for any loss of risk due to deposition along the water network, although deposition is generally considered to be relatively small in most networks. Furthermore, it does not include any interception of overland flow by landcover, although the mitigation values do reflect potential interception in their values.
- ℹ A major source of water pollution in Cornwall is associated with the overflow of combined sewers during heavy rainfall events. The spatial distribution of this risk is highly determined by sewage outflow locations. In principal this risk could be

integrated into the mapping approach using the location of overflows as sources of high risk generation.

- Significant improvements to the methodology would be attained by spatial information on crop types grown on arable land and/or estimates of agricultural inputs such as nitrogen, phosphorous and pesticides.
- The method does not consider the characteristics of water courses and how these affect pollution concentrations, deposition or transformation. There are many factors by which the physical characteristics of watercourses and riverine habitats can reduce bank erosion along watercourses, affect water flow and therefore the accumulation and deposition of pollutants.
- The relative importance of different mechanisms involved in the transportation of pollutants will vary between different types of pollutants.

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Data sources – use and copyright

Data used in the creation of this and the other ecosystem service maps on Lagas are listed here.

Annex Method Tables

Table 1: Land cover factor used to weight percentage land cover found in each 100x100 metre grid cell to calculate generational risk.

Land cover	**Land cover factor**
Coniferous woodland	0.05
Broadleaf woodland	0.05
Scrub	0.1
Felled woodland	0.05
Semi-natural grassland	0.25
Wet grassland	0.25
Acid grassland	0.25
Wetland	0.05
Heathland	0.1
Inland Rock	0.75
Maritime rock	0.2
Maritime sediment	0
Coastal sand dunes	0.25
Intertidal mudflat	0
Saltmarsh	0
Water	0
Arable	1
Improved grassland	0.5
Built-up	0.3

Table 2: 'Management' factor derived from the sum of hedgerow lengths (in metres) per 100m2 cell, used to calculate generational risk.

From	**To**	**Factor value**
0	25	1
25	150	0.95
150	300	0.9
300	600	0.75
300+	(max = 2742)	0.5

Table 3: Interception of pollution values (INThab) by landcover type used to map water pollution mitigation values.

Landcover	**INThab**
Coniferous woodland	1
Broadleaf woodland	1
Scrub	0.25
Semi-natural grassland	0.1
Wetland	0.5
Heath / Moor	0.2
Inland Rock	0
Open Mosaic	0
Maritime cliff	0.1
Littoral Rock	0
Maritime sediment	0.1
Water	0
Arable	0
Improved grassland	0.05
Urban	0.2*NDVI
Hedges	Cover * 0.2